Part D—Introduction and Applications Guidance

D.1. PURPOSE OF PART D

Part D presents information regarding the effects of various safety treatments (i.e., countermeasures). This information is used to estimate how effective a countermeasure or set of countermeasures will be in reducing crashes at a specific location. The effects of treatments, geometric characteristics, and operational characteristics of a location can be quantified as a crash modification factor (CMF) or described by trends (e.g., appears to cause a decrease in total crashes). The level of information (e.g., a CMF, a known trend, unknown effect) depends on the quality and quantity of research completed regarding the treatment's effect on crash frequency. The research that developed the HSM established a screening process and convened a series of expert panels to determine which safety evaluation results are considered sufficiently reliable for inclusion in the HSM (see Section D.5 for more information). Part D presents the information that passed the screening test or met expert panel approval, or both; this information is organized in the following chapters:

- Chapter 13, Roadway Segments;
- Chapter 14, Intersections;
- Chapter 15, Interchanges;
- Chapter 16, Special Facilities and Geometric Situations; and
- Chapter 17, Road Networks.

CMFs presented in Part D can also be used in the methods and calculations shown in Chapter 6, "Select Countermeasures" and Chapter 7, "Economic Appraisal." These methods are used to calculate the potential crash reduction due to a treatment, convert the crash reduction to a monetary value and, compare the monetary benefits of reduced crashes to the monetary cost of implementing the countermeasure(s), as well as to the cost of other associated impacts (e.g., delay, right-of-way). Some CMFs may also be used in the predictive method presented in Part C.

D.2. RELATIONSHIP TO THE PROJECT DEVELOPMENT PROCESS

The CMFs in Part D are used to estimate the change in crashes as a result of implementing a countermeasure(s). Applying the Part D material to estimate change in crashes often occurs within operations and maintenance activities. It can also occur in projects in which the existing roadway network is assessed and modifications are identified, designed, and implemented with the intent of improving the performance of the facility from a capacity, safety, or multimodal perspective.

Figure D-1 illustrates the relationship between Part D and the project development process. As discussed in Chapter 1, the project development process is the framework being used in the HSM to relate safety analysis to activities within planning, design, construction, operations, and maintenance.

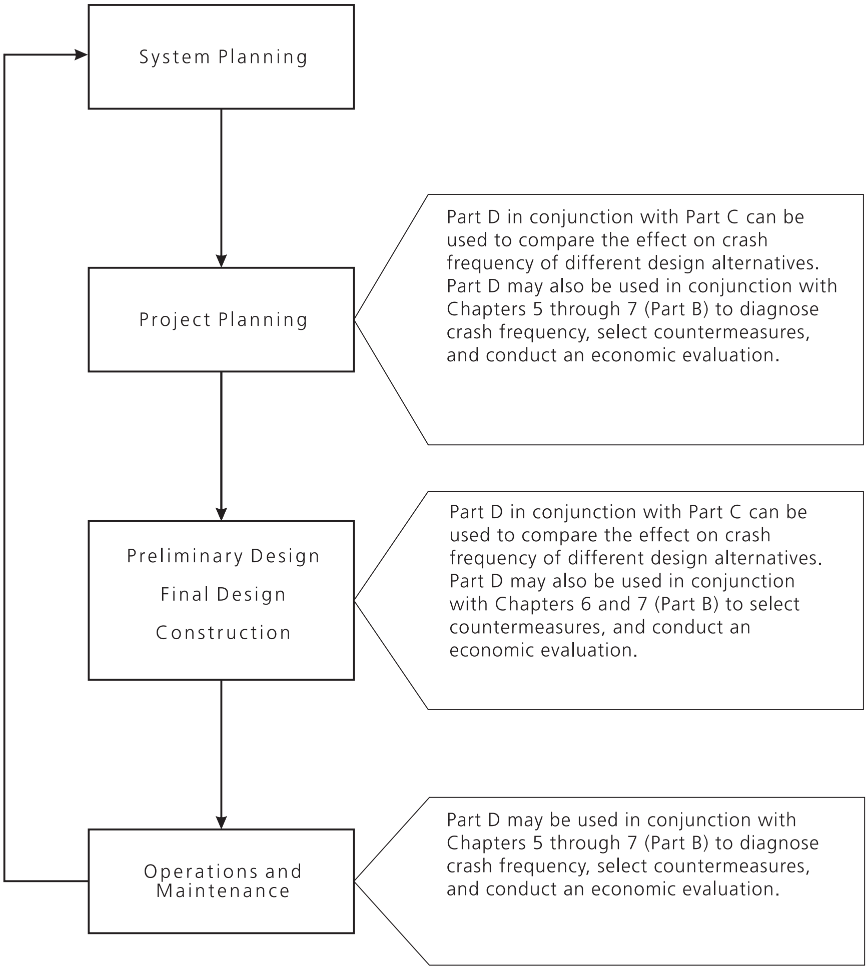


Figure D-1. Part D Relation to the Project Development Process

D.3. RELATIONSHIP TO PARTS A, B, AND C OF THE HIGHWAY SAFETY MANUAL

Part A of the HSM provides introductory and fundamental knowledge needed for applying the HSM. It introduces concepts such as human factors, how to count crashes, data needs, regression-to–the-mean, countermeasures, and crash modification factors. The material in Part A provides valuable context regarding how to apply different parts of the HSM and how to use the HSM effectively in typical project activities or within established processes. Prior to using the information in Part D, an understanding of the material regarding CMFs presented in Part A—Chapter 3, "Fundamentals" is recommended, as well as an understanding of the information presented in Section D.4.

Part B presents the six basic components of a roadway safety management process as related to transportation engineering and planning. The material is useful for monitoring, improving and maintaining safety on an existing roadway network. Applying the methods and information presented in Part B creates an awareness of sites most likely to experience crash reductions with the implementation of improvements, the type of improvement most likely to yield benefits, an estimate of the benefit and cost of improvement(s), and an assessment of an improvement's effectiveness. The information presented in Part D should be used in conjunction with the information presented in Chapter 6, "Select Countermeasures" and Chapter 7, "Economic Appraisal."

Part C introduces techniques for predicting crashes on two-lane rural highways, multilane rural highways, and urban and suburban arterials. This material is particularly useful for estimating expected average crash frequency of new facilities under design and of existing facilities under extensive re-design. It facilitates a proactive approach to considering safety before crashes occur. Some Part D CMFs are included in Part C and for use with specific Safety Performance Functions (SPFs). Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Section C.7.

D.4. GUIDE TO APPLYING PART D

The notations and terms cited and defined in the subsections below are used to indicate the level of knowledge regarding the effects on crash frequency of the various geometric and operational elements presented throughout Part D.

The following subsections explain useful information about:

- How the CMFs are categorized and organized in each chapter;
- The notation used to convey the reliability of each CMF;
- Terminology used in each chapter;
- Application of CMFs; and
- Considerations when applying CMFs.

To effectively use the crash modification factors in Part D, it is important to understand the notations and terminology, as well as the situation in which the countermeasure associated with the CMF is going to be applied. Understanding these items will increase the likelihood of success when implementing countermeasures.

D.4.1. Categories of Information

At the beginning of each section of Part D, treatments are summarized in tables according to the category of information available (i.e., crash modification factors or evidence of trends). These tables serve as a quick reference of the information available related to a specific treatment. Table D-1 summarizes how the information is categorized.

Table D-1. Categories of Information in Part D

Symbol Used in Part D Summary Tables	Available Information
✓	CMFs are available (i.e., sufficient quantitative information is available to determine a reliable CMF). The CMFs and standard errors passed the screening test to be included in the HSM.
T	There is some evidence of the effects on crash frequency, although insufficient quantitative information is available to determine a reliable CMF. In some instances, the quantitative information is sufficient to identify a known trend or apparent trend in crash frequency and/or user behavior, but not sufficient to apply in estimating changes in crash frequency. Published documentation regarding the treatment was not sufficiently reliable to present a CMF in this edition of the HSM.
—	Quantitative information about the effects on crash frequency is not available for this edition of the HSM. Published documentation did not include quantitative information regarding the effects on crash frequency of the treatment. A list of these treatments is presented in the appendices to each chapter.

For those treatments with CMFs, the CMFs and standard errors are provided in tables. When available, each table supplies the specific treatment, road type or intersection type, setting (i.e., rural, urban, or suburban), traffic volumes, and crash type and severity to which the CMF can be applied.

The appendix to each chapter presents those treatments with known trends and unknown effects. For those treatments without CMFs, but which present a trend in crashes or user behavior, it is reasonable to apply them in situations where there are indications that they may be effective in reducing crash frequency. A treatment without a CMF indicates that there is an opportunity to apply and study the effects of the treatments, thereby adding to the current understanding of the treatment's effect on crashes. See Chapter 9, "Safety Effectiveness Evaluation" for more information regarding methods to assess the effectiveness of a treatment.

D.4.2. Standard Error and Notation Accompanying CMFs

In general, the standard deviation indicates the precision of a set of repeated measurements, in other words, precision is the degree to which repeated measurements are close to each other. When calculating, for example, the mean of a set of measurements, then the mean itself has a standard deviation; the standard deviation of the mean is called the *standard error*. In Part D, the standard error indicates the precision of an estimated CMF. *Accuracy* is a measure of the proximity of an estimate to its actual or true value. The difference between the average of repeated measurements and its true value is an estimate of its bias. The true value of a CMF is seldom known but steps can be taken to minimize the bias associated with its estimate (e.g., by using an appropriate statistical approach, applying an EB adjustment for regression-to-the-mean bias). Accuracy and precision estimates are generally difficult to separate mathematically because precision is to some degree built into accuracy. Standard error in Part D is important because more accurate and precise CMFs lead to more cost effective decisions.

Figure D-2 illustrates the concepts of precision and accuracy. If the estimates (the + signs) form a tight cluster, they are precise. However, if the center of that cluster is not the bull's-eye, then the estimates are precise but not accurate. If the estimates are scattered and do not form a tight cluster, they are neither precise nor accurate.

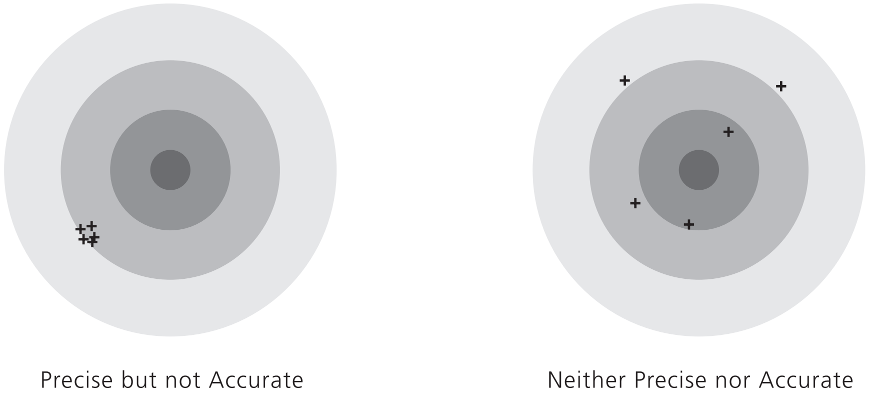


Figure D-2. Precision and Accuracy

Some CMFs in Part D have a standard error associated with them. Standard errors in Part D with values less than 0.1 are presented to two decimal places, standard errors greater than 0.1 have been rounded to the nearest 0.1 and are presented to one decimal place. The most reliable (i.e., valid) CMFs have a standard error of 0.1 or less, and are indicated with **bold** font. Reliability indicates that the CMF is unlikely to change substantially with new research. Less reliable CMFs have standard errors of 0.2 or 0.3 and are indicated with *italic* font. All quantitative standard errors presented with CMFs in Part D are less than or equal to 0.3.

To emphasize the meaning and awareness of each standard error, some CMFs in Part D are accompanied by a superscript. These superscripts have specific meanings:

- *: The asterisk indicates that the CMF value itself is within the range 0.90 to 1.10, but that the confidence interval (defined by the CMF ± two times the standard error) may contain the value 1.0. This is important to note since a treatment with such a CMF could potentially result in (a) a reduction in crashes (safety benefit), (b) no change, or (c) an increase in crashes (safety disbenefit). These CMFs should be used with caution.

- ^: The carat indicates that the CMF value itself is within the range 0.90 to 1.10 but that the lower or upper end of the confidence interval (defined by the CMF ± two times the standard error) may be exactly at 1.0. This is important to note since a treatment with such a CMF may result in no change in safety. These CMFs should be used with caution.
- º: The degree symbol indicates that the standard error has not been quantified for the CMF; therefore, the potential error inherent in the value is not known. This usually occurs when the factor is included as an equation.
- +: The plus sign indicates that the CMF is the result of combining CMFs from multiple studies.
- ?: The question mark indicates CMFs that have the opposite effects on different crash types or crash severities. For example, a treatment may increase rear-end crashes but decrease angle crashes. Or a treatment may reduce fatal crashes but increase property damage only (PDO) crashes.

Understanding the meanings of the superscripts and the standard error of a CMF will build familiarity with the reliability and stability that can be expected from each treatment. A CMF with a relatively high standard error does not mean that it should not be used; it means that the CMF should be used with the awareness of the range of results that could be obtained. Applying these treatments is also an opportunity to study the effectiveness of the treatment after implementation and add to the current information available regarding the treatment's effectiveness (see Chapter 9, "Safety Effectiveness Evaluation" for more information).

D.4.3. Terminology

Described below are some of the key words used in Part D to describe the CMF values or information provided. Key words to understand are:

- Unspecified: In some cases, CMF tables include some characteristics that are "unspecified." This indicates that the research did not clearly state the road type or intersection type, setting, or traffic volumes of the study.
- Injury: In Part D of the HSM, injury crashes include fatal crashes unless otherwise noted.
- All Settings: In some instances, research presented aggregated results for multiple settings (e.g., urban and suburban signalized intersections); the same level of information is reflected in the HSM.
- Insufficient or No Quantitative Information Available: Indicates that the documentation reviewed for the HSM did not contain quantitative information that passed the screening test for inclusion in the HSM. It doesn't mean that such documentation does not exist.

D.4.4. Application of CMFs to Estimate Crash Frequency

As discussed above, CMFs are used to estimate crash frequency or the change in crashes due to a treatment. There are multiple approaches to calculate an estimated number of crashes using a CMF. These include:

1. Applying the CMF to an expected number of crashes calculated using a calibrated safety performance function and EB to account for regression-to-the-mean bias;

2. Applying the CMF to an expected number of crashes calculated using a calibrated safety performance function; and

3. Applying the CMF to historic crash count data.

Of the three ways to apply CMFs, listed above, the first approach produces the most reliable results. The second approach is the second most reliable and the third approach is the approach used if a safety performance function is not available to calculate the expected number of crashes. Additional details regarding safety performance functions, expected number of crashes, regression-to-the-mean, and EB methodology are discussed in Chapter 3, "Fundamentals." The specific step-by-step process for calculating an estimated change in crashes using approach 1 or 2 listed above is presented in Chapter 7, "Economic Appraisal."

CMFs may be presented in Part D chapters as numerical values, equations, graphs, or a combination of these. CMFs may be applied under any of the following scenarios:

1. Direct application of a numerical CMF value and standard error obtained from a table: The CMF is multiplied directly with the base crash frequency to estimate the crash frequency and standard error with the treatment in place.

2. Direct application of a CMF value obtained from a graph: The CMF value is obtained from a graph (which presents a range for a given treatment) and is subsequently multiplied directly with the base crash frequency to estimate the crash frequency with the treatment in place. No standard error is provided for graphical CMFs.

3. Direct application of a CMF value obtained from an equation: The CMF value is calculated from an equation (which is a function of a treatment range) and is subsequently multiplied with the base crash frequency to estimate the crash frequency with the treatment in place. No standard error is provided for CMFs calculated using equations.

4. Multiplication of multiple CMF values from a table, graph, or equation: Multiple CMFs are obtained or calculated from a table, graph, or equation and are subsequently multiplied. This procedure is followed when more than one treatment is being considered for implementation at the same time at a given location. See Chapter 3 for guidance about the independence assumption when applying multiple CMFs.

5. Division of two CMF values from a table, graph, or equation: Two CMFs are obtained or calculated from a table, graph, or equation and are subsequently divided. This procedure is followed when one of the CMFs (denominator) represents an initial condition (not equal to the CMF base condition, and therefore not equal to a CMF value of 1.0) and the other CMF (numerator) represents the treatment condition.

6. Interpolation between two numerical CMF values from a table: An unknown CMF value is calculated as the interpolation of two known CMF values.

The examples presented throughout Part D chapters illustrate the application of CMFs under these scenarios.

D.4.5. Considerations when Applying CMFs to Estimate Crash Frequency

Standard errors have been provided for many CMFs in Part D. Where standard errors are available, these should be used to calculate the confidence interval of the projected change in crash frequency. Section 3.5.3 provides additional information regarding the application of standard errors.

CMFs are multiplicative when a treatment can be applied in multiple increments, or when multiple CMFs are applied simultaneously. When applying multiple CMFs, engineering judgment should be used to assess the interrelationship and/or independence of individual treatments being considered for implementation. Section 3.5.3 provides additional information regarding the application of multiplicative CMFs.

CMFs may be divided when the existing condition corresponds to a CMF value (other than the base value of 1.00) and the treatment condition corresponds to another CMF value. In this case, a ratio of the CMFs may be calculated to account for the variation between the existing condition and the treatment condition. Section 3.5.3 provides additional information regarding the application of CMF ratios.

D.5. DEVELOPMENT OF CMFS IN PART D

The following sections provide an overview of the Literature Review Procedure, Inclusion Process, and Expert Panel that were developed and applied while creating Part D of the HSM. This information provides background to the knowledge included in the HSM, and may also be useful to others in the field of transportation safety by:

- Providing a framework to review safety literature to determine the reliability of published results;

- Outlining the characteristics of safety studies that lead to more reliable results;
- Promoting higher quality evaluation of treatments to advance the knowledge of safety effects; and
- Encouraging improvements to the methods applied for the first edition by expanding and enhancing the knowledge for future editions of the HSM.

D.5.1. Literature Review Procedure

The information presented in Part D is based on an extensive literature review of published transportation safety research, mostly dated from the 1960s to June 2008.

A literature review procedure was developed to document available knowledge using a consistent approach. The procedure includes methods to calculate CMFs based on published data, estimate the standard error of published or calculated CMFs, and adjust the CMFs and standard errors to account for study quality and method. The steps followed in the literature review procedure are:

1. Determine the estimate of the effect on crash frequency, user behavior, or CMF of a treatment based on one published study
2. Adjust the estimate to account for potential bias from regression-to-the-mean or changes in traffic volume, or both
3. Determine the ideal standard error of the CMF
4. Apply a Method Correction Factor to ideal standard error, based on the study characteristics
5. Adjust the corrected standard error to account for bias from regression-to-the-mean and/or changes in traffic volume

In a limited number of cases, multiple studies provided results for the same treatment in similar conditions.

D.5.2. Inclusion Process

The CMFs from the literature review process were evaluated during the Inclusion Process, based on their standard errors, to determine whether or not they are sufficiently reliable and stable to be presented in the HSM. A standard error of 0.10 or less indicates a CMF value that is sufficiently accurate, precise, and stable. For treatments that have a CMF with a standard error of 0.1 or less, other related CMFs with standard errors of 0.2 to 0.3 may also be included to account for the effects of the same treatment on other facilities, or other crash types or severities.

Not all potentially relevant CMFs could be evaluated in the inclusion process. For example, CMFs that are expressed as functions, rather than as single values, typically do not have an explicitly defined standard error that can be considered in the inclusion process.

The basis for the inclusion process is providing sound support for selecting the most cost-effective road safety treatments. For any decision-making process, it is generally accepted that a more accurate and precise estimate is preferable to a less accurate or less precise one. The greater the accuracy of the information used to make a decision, the greater the chance that the decision is correct. A higher degree of precision is preferable to improve the chance that the decision is correct.

D.5.3. Expert Panel Review

In addition, several expert panels were formed and convened as part of the research projects that developed the predictive method presented in Part C. These expert panels reviewed and assessed the relevant research literature related to the effects on crash frequency of particular geometric design and traffic control features. The expert panels subsequently recommended which research results were appropriate for use as CMFs in the Part C predictive method. These CMFs are presented in both Parts C and D. Many, but not all, of the CMFs recommended by the expert panels meet the criteria for the literature review and inclusion processes presented in Sections D.5.1 and D.5.2. For example, CMFs that are expressed as functions, rather than as single values, often did not have explicitly defined standard errors and, therefore, did not lend themselves to formal assessment in the literature review process.

D.6. CONCLUSION

Part D presents the effects on crash frequency of various treatments, geometric design characteristics, and operational characteristics. The information in Part D was developed using a literature review process, an inclusion process, and a series of expert panels. These processes led to identification of CMFs, trends, or unknown effects for each treatment in Part D. The level of information presented in the HSM is dependent on the quality and quantity of previous research.

Part D includes all CMFs assessed with the literature review and inclusion process, including measures of their reliability and stability. These CMFs are applicable to a broad range of roadway segment and intersection facility types, not just those facility types addressed in the Part C predictive methods.

Some Part D CMFs are included in Part C and for use with specific SPFs. Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Part C.

The information presented in Part D is used to estimate the effect on crash frequency of various treatments. It can be used in conjunction with the methodologies in Chapter 6, “Select Countermeasures” and Chapter 7, “Economic Appraisal.” When applying the CMFs in Part D, understanding the standard error and the corresponding potential range of results increases opportunities to make cost-effective choices. Implementing treatments with limited quantitative information presented in the HSM presents the opportunity to study the treatment’s effectiveness and add to the current base of information.

Chapter 13—Roadway Segments

13.1. INTRODUCTION

Chapter 13 presents the CMFs 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.

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

Chapter 13 is organized into the following sections:

- Definition, Application, and Organization of CMFs (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 13.13);
- Crash Effects of Roadway Access Management (Section 13.14);
- Crash Effects of Weather Issues (Section 13.15); and
- Conclusion (Section 13.16).

Appendix 13A presents the crash trends for treatments for which CMFs are not currently known, and a listing of treatments for which neither CMFs nor trends are unknown.

13.2. DEFINITION, APPLICATION, AND ORGANIZATION OF CMFS

CMFs 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. CMFs are used to estimate the potential change in expected crash frequency or crash severity plus or minus a standard error due to implementing a particular action. The application of CMFs 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 CMFs presented in this chapter can be used in conjunction with activities in Chapter 6, "Select Countermeasures" and Chapter 7, "Economic Appraisal." Some Part D CMFs are included in Part C for use in the predictive method. Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Section C.7. Chapter 3, "Fundamentals," Section 3.5.3, "Crash Modification Factors" provides a comprehensive discussion of CMFs including: an introduction to CMFs, how to interpret and apply CMFs, and applying the standard error associated with CMFs.

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

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

Treatments with CMFs (Category 1 above) are typically estimated for three crash severities: fatal, injury, and non-injury. In the HSM, fatal and injury are generally combined and noted as injury. Where distinct CMFs 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 CMFs 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 a CMF 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 CMFs are not presented are discussed in Appendix 13A.

13.3. DEFINITION OF A ROADWAY SEGMENT

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 CMFs

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

Table 13-1. Summary of Treatments Related to Roadway Elements

HSM Section	Treatment	Rural Two-Lane Road	Rural Multilane 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 13A.2.2.1	Increase median width	-	T	N/A	T	T	-	-

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
- = Indicates that a CMF 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 CMFs

13.4.2.1. Modify Lane Width

Rural two-lane roads

Widening lanes on rural two-lane roads reduces a specific set of related crash types, namely single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The CMF for lane width is determined with the equations presented in Table 13-2, which are illustrated by the graphs in Figure 13-1 (10,16,33). The crash effect of lane width varies with traffic volume, as shown in the exhibits.

Relative to a 12-ft-wide lanes base condition, 9-ft-wide lanes increase the frequency of related crash 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-wide lanes, 9-ft-wide lanes increase the frequency of related crash types identified above more than either 10-ft-wide or 11-ft-wide lanes (16,33).

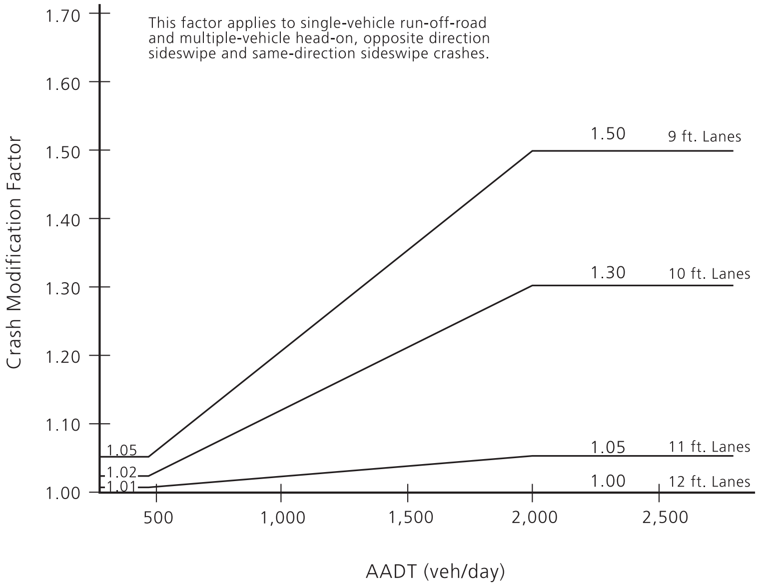
For lane widths other than 9, 10, 11, and 12 ft, the crash effect can be interpolated between the lines shown in Figure 13-1.

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

Table 13-2. CMF for Lane Width on Rural Two-Lane Roadway Segments (16)

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

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



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

Figure 13-1. Potential Crash Effects of Lane Width on Rural Two-Lane Roads Relative to 12-ft Lanes (3)

Figure 13-7 and Equation 13-3 in Section 13.4.3 may be used to express the lane width CMFs in terms of the crash effect on total crashes, rather than just the crash types identified in Table 13-2 and Figure 13-1 (10,16,33).

The box 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 5-mile segment (assumed values):

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

Answer:
1) Identify the Applicable CMFs

a) Figure 13-1 for *opposite-direction sideswipe* crashes

b) Equation 13-3 or Figure 13-7 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 Figure 13-7, may be applied.

2) Calculate the CMF for the existing 10-ft-wide lanes

a) For opposite-direction sideswipe crashes

CMF_{ra} = 1.30 (Figure 13-1)

b) For total crashes

$CMF_{total} = (1.30 - 1.00) \times 0.30 + 1.00 = 1.09$ (Equation 13-3 or Figure 13-7)

3) Calculate the CMF for the proposed 11-ft-wide lanes

a) For opposite-direction sideswipe crashes

CMF_{ra} = 1.05 (Figure 13-1)

b) For total crashes

$CMF_{total} = (1.05 - 1.00) \times 0.30 + 1.00 = 1.01$ (Equation 13-3 or Figure 13-7)

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

a) For opposite-direction sideswipe crashes

$CMF_{ra\ treatment} = 1.05/1.30 = 0.81$

b) For total crashes

$CMF_{total\ treatment} = 1.01/1.09 = 0.93$

5) Apply the treatment CMF ($CMF_{treatment}$) 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 CMF, therefore a confidence interval cannot be calculated.

Rural Multilane Highways

Widening lanes on rural multilane highways reduces the same specific set of related crash types as rural two-lane highways, namely single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The CMF for lane width is determined with the equations presented in Table 13-3 for undivided multilane highways and in Table 13-4 for divided multilane highways. These equations are illustrated by the graphs shown in Figures 13-2 and 13-3, 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-wide lanes base condition, 9-ft-wide lanes increase the frequency of related crash 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-wide lanes, 9-ft-wide lanes increase the frequency of related crash types identified above more than either 10-ft-wide or 11-ft-wide lanes.

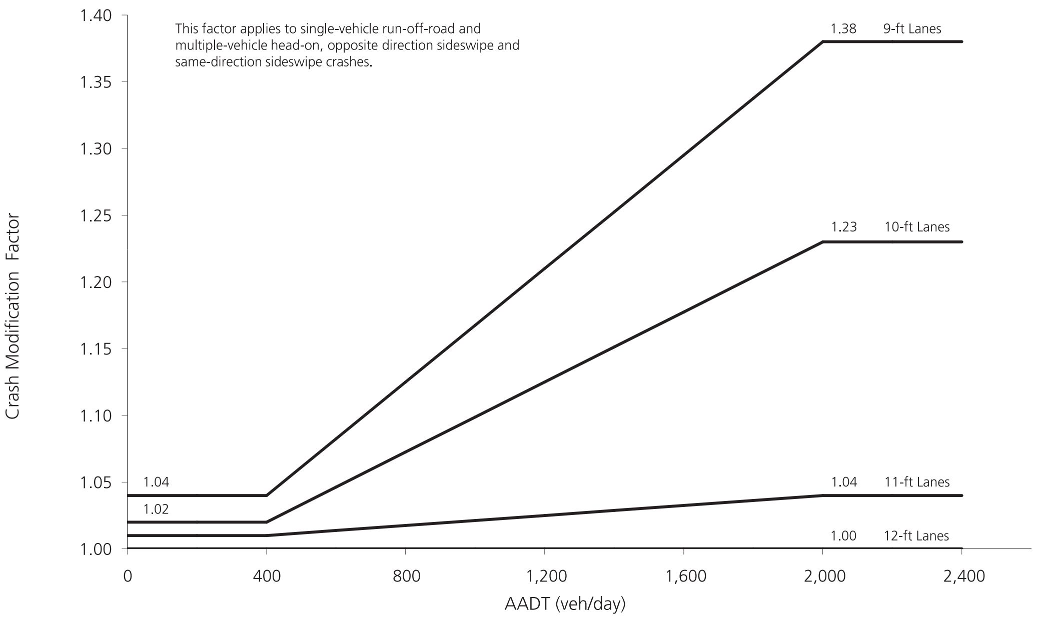
For lane widths other than 9, 10, 11, and 12 ft, the crash effect can be interpolated between the lines shown in Figures 13-2 and 13-3. Lanes less than 9-ft wide can be assigned a CMF equal to 9-ft lanes. Lanes greater than 12-ft wide can be assigned a crash effect equal to 12-ft lanes.

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 CMF is determined separately for the lane width in each direction of travel and the resulting CMFs are then averaged. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is 12-ft lanes.

Table 13-3. CMF for Lane Width on Undivided Rural Multilane Roadway Segments (34)

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

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



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

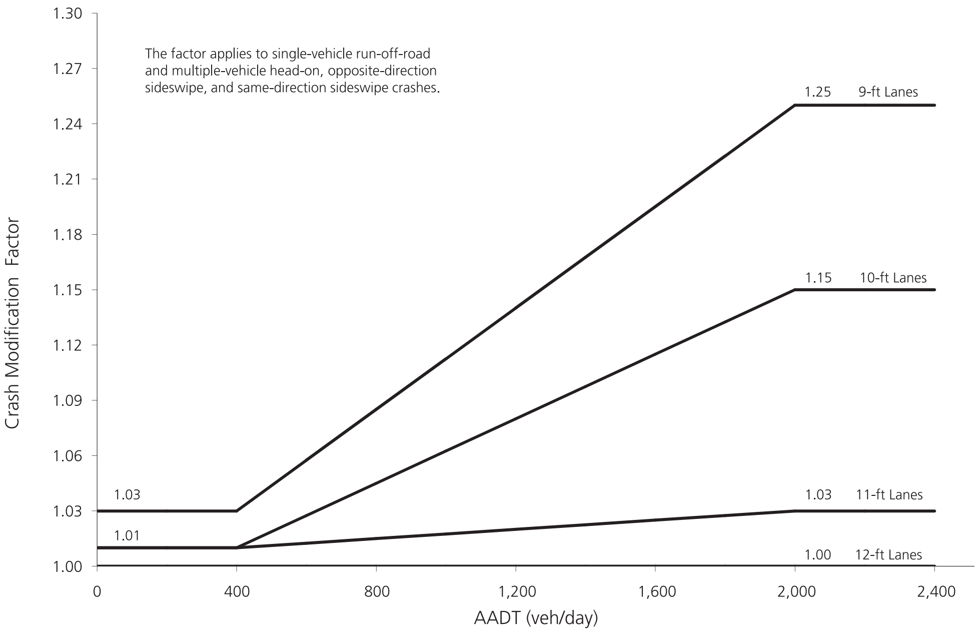
Figure 13-2. Potential Crash Effects of Lane Width on Undivided Rural Multilane Roads Relative to 12-ft Lanes (34)

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 CMF should be determined separately for the lane width in each direction of travel and the resulting CMFs is then averaged. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is 12-ft lanes.

Table 13-4. CMF 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	$1.03 + 1.38 \times 10^{-4}(AADT-400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5}(AADT-400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT-400)$	1.03
12 ft or more	1.00	1.00	1.00

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



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

Figure 13-3. Potential Crash Effects of Lane Width on Divided Rural Multilane Roads Relative to 12-ft Lanes (34)

Equation 13-3 in Section 13.4.3 may be used to express the lane width CMFs 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

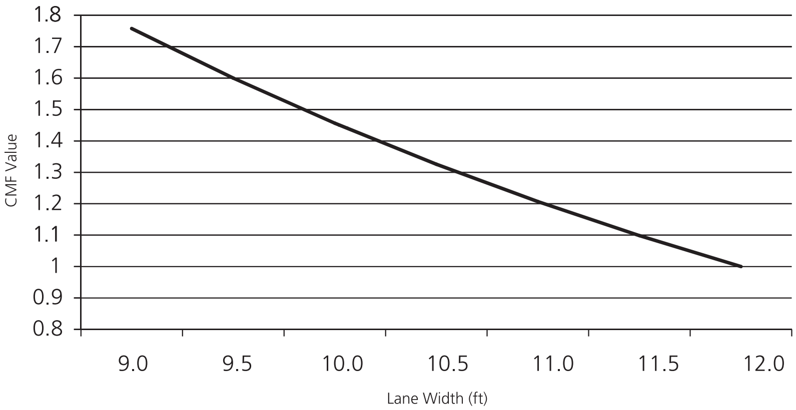
Rural frontage roads differ from rural two-lane roads because they have restricted access along at least one side of the road, a higher percentage of turning traffic, and periodic ramp-frontage-road terminals with yield control (22). CMFs for rural frontage roads are provided separately from CMFs for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

Equation 13-1 presents the CMF for lane width on rural frontage roads between successive interchanges (22). Figure 13-4 is based on Equation 13-1. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is 12-ft-wide lanes.

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

Where:

LW = average lane width (ft)



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

Figure 13-4. Potential Crash Effects of Lane Width on Rural Frontage Roads (22)

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 crashes more than either 10-ft or 11-ft lanes.

Both one-way and two-way frontage roads were considered in the development of this CMF. Development of this CMF was limited to lane widths ranging from 9 to 12 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 Table 13-5 (4). The crash effects of adding a sixth lane to a base condition five-lane urban freeway by crash severity are also shown in Table 13-5 (4).

These CMFs apply to urban freeways with median barriers with a base condition (i.e., the condition in which the CMF = 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.

Table 13-5. Potential Crash Effects of Adding Lanes by Narrowing Existing Lanes and Shoulders (4)

Treatment	Setting (Road Type)	Traffic Volume AADT	Crash Type (Severity)	CMF	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 CMFs. These CMFs 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.

Crash 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 converting 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 Table 13-6 (15). The base condition for this CMF (i.e., the condition in which the CMF = 1.00) is a four-lane roadway cross section. Original lane width is unknown.

Table 13-6. Potential Crash Effects of Four to Three Lane Conversion, or "Road Diet" (15)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.
Original lane width is unknown.

13.4.2.4. Add or Widen Paved Shoulder

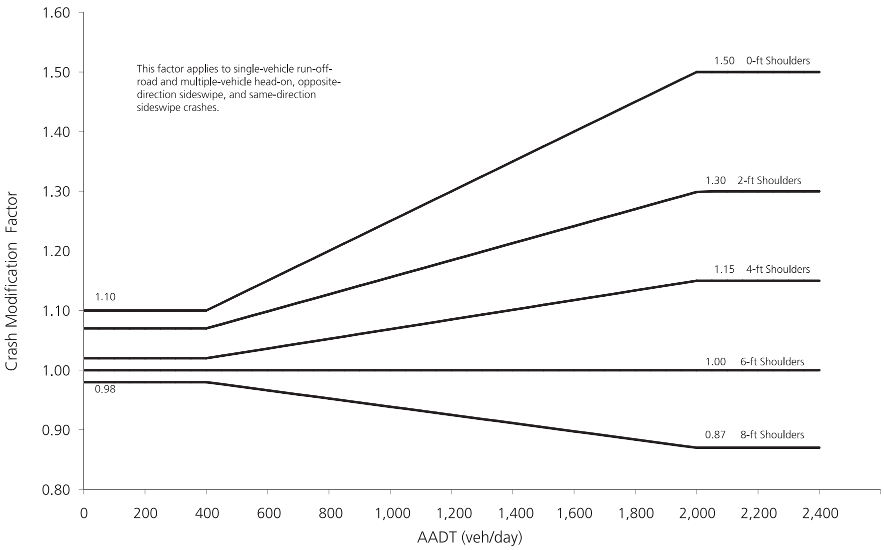
Rural two-lane roads

Widening paved shoulders on rural two-lane roads reduces the same related crashes types as widening lanes; single-vehicle run-off-the-road crashes, multi-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions. The CMF for shoulder width is determined with the equations presented in Table 13-7, which are illustrated by the graph in Figure 13-5 (16,33,36). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is a 6-ft-wide shoulder.

Table 13-7. CMF for Shoulder Width on Rural Two-Lane Roadway Segments

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



NOTE: Standard error of CMF is unknown.

Figure 13-5. Potential Crash Effects of Paved Shoulder Width on Rural Two-Lane Roads Relative to 6-ft Paved Shoulders (16)

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

For roads with an 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 crash 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 Figure 13-5. Shoulders greater than 8 ft wide can be assigned a CMF equal to 8-ft wide shoulders (16).

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

Figure 13-7 and Equation 13-3 in Section 13.4.3 may be used to express the crash effect of paved shoulder width on rural two-lane roads as an effect on total crashes, rather than just the crash types identified in Figure 13-5 (16).

Rural multilane highways

Research by Harkey et al. (15) concluded that the shoulder width CMF presented in Table 13-7 and Figure 13-5 may be applied to undivided segments of rural multilane highways as well as to rural two-lane highways.

The CMF for changing shoulder width on multilane divided highways in

Table 13-8 applies to the shoulder on the right side of a divided roadway. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is an 8-ft-wide shoulder.

Table 13-8. Potential Crash Effects of Paved Right Shoulder Width on Divided Segments (15)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
8-ft to 6-ft conversion	Rural (Multilane Highways)	Unspecified	All types (Unspecified)	1.04	N/A
8-ft to 4-ft conversion				1.09	N/A
8-ft to 2-ft conversion				1.13	N/A
8-ft to 0-ft conversion				1.18	N/A
Base Condition: 8-ft-wide shoulder.					

NOTE: N/A = Standard error of CMF is unknown.

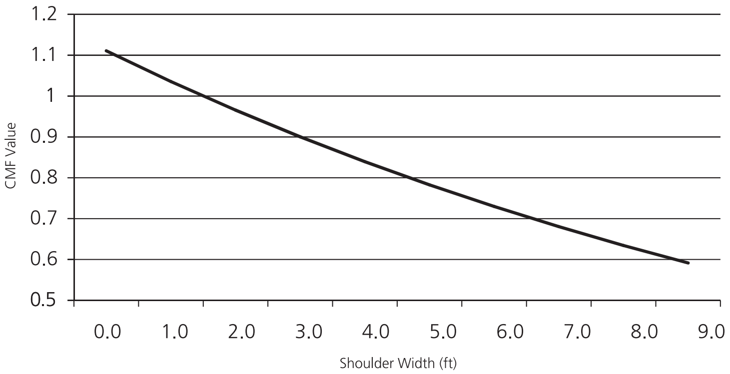
Rural frontage roads

Rural frontage roads typically consist of an environment that is slightly more complex than a traditional rural two-lane highway. Equation 13-2 presents a CMF for shoulder width on rural frontage roads (22), Figure 13-6 is based on Equation 13-2. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is a shoulder width (SW) of 1.5-ft.

$$CMF_{SW} = e^{-0.070(SW - 1.5)} \tag{13-2}$$

Where:

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



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

Figure 13-6. Potential Crash Effects of Paved Shoulder Width on Rural Frontage Roads

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 CMF. Development of this CMF 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 Table 13-9 (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 CMF = 1.00) and that some type of shoulder is currently in place. Note that this CMF cannot be applied for a single shoulder type (horizontally across the table), the CMF in Table 13-9 is exclusively for application to a situation that consists of modification from one shoulder type to another shoulder type (vertically in the table for one given shoulder width).

Table 13-9. Potential Crash Effects of Modifying the Shoulder Type on Rural Two-Lane Roads for Related Crash Types (16,33,36)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF							
				Shoulder type	Shoulder width (ft)						
					1	2	3	4	6	8	10
Modify Shoulder Type	Rural (Two-lane Roads)	Unspecified	Single-vehicle run-off-the-road crashes 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 crash types to which this CMF applies include single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions.
To determine the CMF for changing the shoulder type, divide the "new" condition CMF by the "existing" condition CMF.
This CMF cannot be applied for a single shoulder type to identify a change in shoulder width (horizontally in the table). This CMF is to be applied exclusively to a situation that consists of modifying 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 CMF is determined separately for the shoulder type in each direction of travel and then averaged (16).

Figure 13-7 and Equation 13-3 in Section 13.4.3 may be used to determine the crash effect of shoulder type on total crashes, rather than just the crash types identified in Table 13-9.

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 Table 13-10 (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 CMF (i.e., the condition in which the CMF = 1.00) is the absence of a raised median.

Table 13-10. Potential Crash Effects of Providing a Median on Urban Two-Lane Roads (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.

Rural multilane highways and urban arterials

The crash effects of providing a median on urban arterial multilane roads are shown in Table 13-11 (8). Providing a median on rural multi-lane roads reduces both injury and non-injury crashes, as shown in Table 13-11 (8). The base condition of the CMF (i.e., the condition in which the CMF = 1.00) is the absence of a raised median.

Table 13-11. Potential Crash Effects of Providing a Median on Multi-Lane Roads (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide a median	Urban (Arterial Multilane[(a)])	Unspecified	All types (Injury)	**0.78?**	**0.02**
			All types (Non-injury)	**1.09?**	**0.02**
	Rural (Multilane[(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 U.S. 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 CMFs. These CMFs 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

Table 13-12 through Table 13-16 present CMFs for changing the median width on divided roads with traversable medians. These CMFs are based on the work by Harkey et al. (15). Separate CMFs are provided for roads with TWLTLs, full access control and with partial or no access control. For urban arterials, the CMFs are also dependent upon whether the arterial has four lanes or more. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the presence of a 10-ft-wide traversable median. The type of traversable median (grass, depressed) was not identified.

Table 13-12. 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	Crash Type (Severity)	CMF	Std. Error
10-ft 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-ft to 30-ft conversion				**0.74**	**0.04**
10-ft to 40-ft conversion				**0.63**	**0.05**
10-ft to 50-ft conversion				**0.54**	**0.06**
10-ft to 60-ft conversion				**0.46**	**0.07**
10-ft to 70-ft conversion				**0.40**	**0.07**
10-ft to 80-ft conversion				**0.34**	**0.07**
10-ft to 90-ft conversion				**0.29**	**0.07**
10-ft to 100-ft conversion				**0.25**	**0.06**
Base condition: 10-ft-wide traversable median.					

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

Table 13-13. 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	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Rural (4 lanes with partial or no access control)	1,000 to 90,000	Cross-median crashes (Unspecified)	**0.84**	**0.03**
10-ft to 30-ft conversion				**0.71**	**0.06**
10-ft to 40-ft conversion				**0.60**	**0.07**
10-ft to 50-ft conversion				**0.51**	**0.08**
10-ft to 60-ft conversion				**0.43**	**0.09**
10-ft to 70-ft conversion				**0.36**	**0.09**
10-ft to 80-ft conversion				**0.31**	**0.09**
10-ft to 90-ft conversion				**0.26**	**0.08**
10-ft to 100-ft conversion				**0.22**	**0.08**
Base condition: 10-ft-wide traversable median.					

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

Table 13-14. 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	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Urban (4 lanes with full access control)	4,400 to 131,000	Cross-median crashes (Unspecified)	**0.89**	**0.04**
10-ft to 30-ft conversion				**0.80**	**0.07**
10-ft to 40-ft conversion				**0.71**	**0.09**
10-ft to 50-ft conversion				**0.64**	**0.1**
10-ft to 60-ft conversion				**0.57**	**0.1**
10-ft to 70-ft conversion				**0.51**	**0.1**
10-ft to 80-ft conversion				**0.46**	**0.1**
10-ft to 90-ft conversion				**0.41**	**0.1**
10-ft to 100-ft conversion				**0.36**	**0.1**
Base condition: 10-ft-wide traversable median.					

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

Table 13-15. 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	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Urban (5 or more lanes with full access control)	2,600 to 282,000	Cross-median crashes (Unspecified)	**0.89**	**0.04**
10-ft to 30-ft conversion				**0.79**	**0.07**
10-ft to 40-ft conversion				**0.71**	**0.1**
10-ft to 50-ft conversion				**0.63**	**0.1**
10-ft to 60-ft conversion				**0.56**	**0.1**
10-ft to 70-ft conversion				**0.50**	**0.1**
10-ft to 80-ft conversion				**0.45**	**0.1**
10-ft to 90-ft conversion				*0.40*	*0.2*
10-ft to 100-ft conversion				*0.35*	*0.2*
Base condition: 10-ft-wide traversable median.					

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

Table 13-16. 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	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Urban (4 lanes with partial or no access control)	1,900 to 150,000	Cross-median crashes (Unspecified)	**0.87**	**0.04**
10-ft to 30-ft conversion				**0.76**	**0.06**
10-ft to 40-ft conversion				**0.67**	**0.08**
10-ft to 50-ft conversion				**0.59**	**0.1**
10-ft to 60-ft conversion				**0.51**	**0.1**
10-ft to 70-ft conversion				**0.45**	**0.1**
10-ft to 80-ft conversion				**0.39**	**0.1**
10-ft to 90-ft conversion				**0.34**	**0.1**
10-ft to 100-ft conversion				**0.30**	**0.1**
Base condition: 10-ft-wide traversable median.					

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs 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 CMFs for crashes related to specific crash types into CMFs for total crashes.

Figure 13-7 and Equation 13-3 may be used to express the lane width CMF (Section 13.4.2.1), add or widen paved shoulder CMF (Section 13.4.2.4), and modify shoulder type CMF (Section 13.4.2.5) in terms of the crash effect on total crashes, rather than just the related crash types identified in the respective sections (10,16,33).

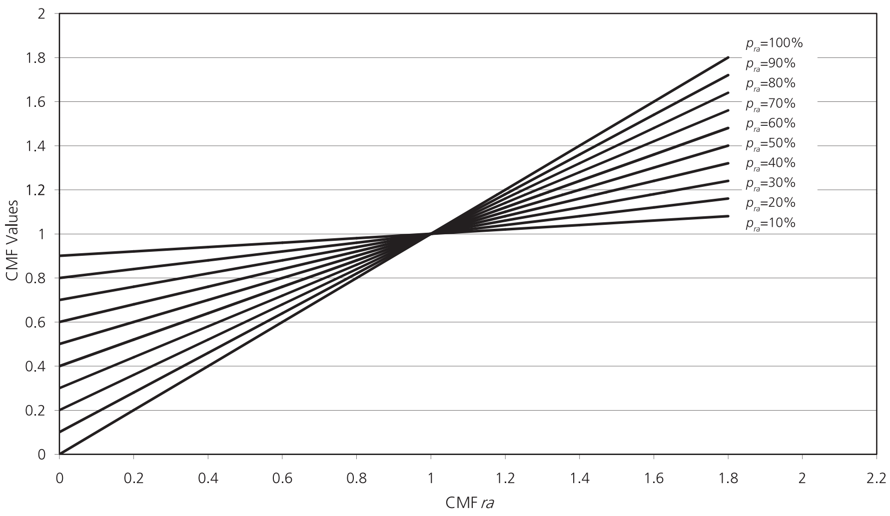


Figure 13-7. Potential Crash Effects of Lane Width on Rural Two-Lane Roads on Total Crashes (16)

$$CMF = (CMF_{ra} - 1.0) \times p_{ra} + 1.0 \tag{13-3}$$

Where:

CMF = crash modification factor for total crashes;

CMF_{ra} = crash modification factor for related crashes, i.e., single-vehicle run-off-the-road crashes and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions; and

p_{ra} = related crashes expressed as a proportion of total crashes.

13.5. Crash Effects of Roadside Elements

13.5.1. Background and Availability of CMFs

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 (1).

The knowledge presented here may be applied to roadside elements as well as to the median of divided highways. Table 13-17 summarizes common treatments related to roadside elements and the corresponding CMF availability.

Table 13-17. 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 13A.3.2.2	Increase clear roadside recovery distance	T	—	—	—	—	—
Appendix 13A.3.2.3	Install curbs	—	—	—	—	T	T
Appendix 13A.3.2.4	Increase the distance to utility poles and decrease utility pole density	T	T	T	T	T	T
Appendix 13A.3.2.5	Install roadside barrier along embankments	T	T	T	T	T	T

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

13.5.2.1. Flatten Sideslopes

Rural two-lane roads

The effect on total crashes of flattening the roadside slope of a rural two-lane road is shown in Table 13-18 (15). The effect on single-vehicle crashes of flattening side slopes is shown in Table 13-19 (15). The base conditions of the CMFs (i.e., the condition in which the CMF = 1.00) is the sideslope in the *before* condition.

Table 13-18. Potential Crash Effects on Total Crashes of Flattening Sideslopes (15)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF				
				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 CMF is unknown.

Table 13-19. Potential Crash Effects on Single Vehicle Crashes of Flattening Sideslopes (15)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF				
				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 CMF is unknown.

The box presents an example of how to apply the preceding CMFs 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 (assumed values):

  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 CMFs corresponding to the change in sideslope from 1V:3H to 1V:7H

   a) For total crashes

   CMF_{total} = 0.85 (Table 13-18)

   b) For single, vehicle crashes

   $CMF_{single\ vehicle}$ = 0.74 (Table 13-19)

2) Apply the treatment CMF ($CMF_{treatment}$) 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 CMFs.

Rural multilane highways

Table 13-20 presents CMFs for the effect of sideslopes on multilane undivided roadway segments. These CMFs were developed by Harkey et al. (10) from the work of Zegeer et al. (6). The base condition for this CMF (i.e., the condition in which the CMF = 1.00) is a sideslope of 1V:7H or flatter.

Table 13-20. Potential Crash Effects of Sideslopes on Undivided Segments (15,34)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
1V:7H or Flatter	Rural (Multilane 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 or flatter 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 Table 13-21 (8). CMF values for other increments may be interpolated from the values presented in Table 13-21.

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

Table 13-21. Potential Crash Effects of Increasing the Distance to Roadside Features (8)

Treatment	Setting (Road type)	Traffic Volume	Crash Type (Severity)	CMF	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 U.S. studies: Cirillo (1967), Zegeer et al. (1988).
Bold text is used for the most reliable CMFs. These CMFs 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 multilane highways, freeways, expressways, and 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-the-road crashes, as shown in Table 13-22 (8). The CMF for fatal run-off-the-road crashes is shown in Table 13-22 (8). A less rigid barrier type may not be suitable in certain circumstances.

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

Table 13-22. Potential Crash Effects of Changing Barrier to Less Rigid Type (8)

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

NOTE: Based on U.S. 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 CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.
Distance to roadside barrier 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 multilane highways

Installing any type of median barrier on rural multilane highways reduces fatal-and-injury crashes of all types, as shown in Table 13-23 (8).

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

Table 13-23. Potential Crash Effects of Installing a Median Barrier (8)

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

NOTE: Based on U.S. 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 CMFs. These CMFs 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 multilane highways, freeways, expressways, and urban and suburban arterials

The crash effects of installing crash cushions at fixed roadside features are shown in Table 13-24 (8). The crash effects for fatal and non-injury crashes with fixed objects are also shown in Table 13-24 (12). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of crash cushions.

Table 13-24. Potential Crash Effects of Installing Crash Cushions at Fixed Roadside Features (8)

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

NOTE: Based on U.S. studies: Viner and Tamanini 1973; Griffin 1984; Kurucz 1984; and international studies: Schoon 1990; Proctor 1994.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs 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 Table 13-25. Photographs that illustrate the roadside design for each RHR level are presented in Appendix 13A.3.

Table 13-25. 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.

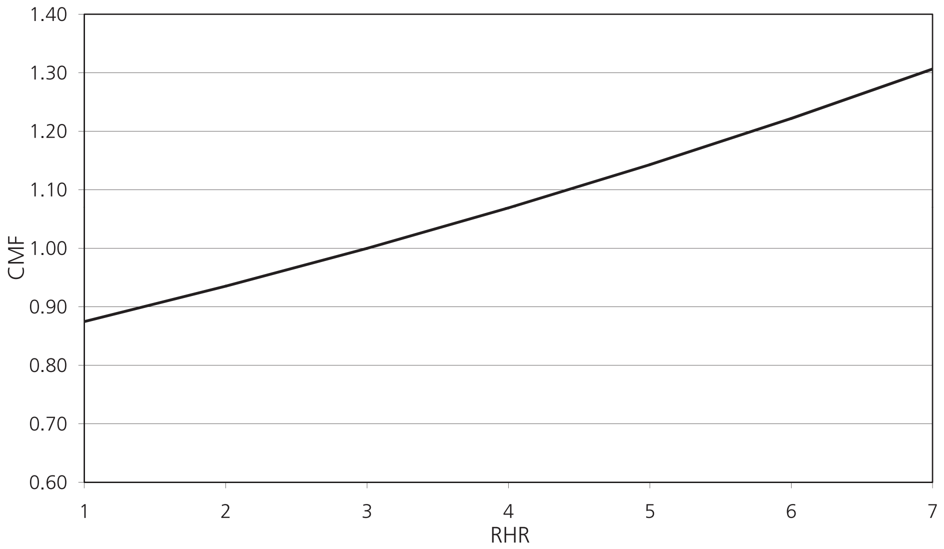
Rural two-lane roads

The CMFs for roadside design are presented in Equation 13-4 and Figure 13-8, using RHR equal to 3 as the base condition (i.e., the condition in which the CMF = 1.00).

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

Where:

RHR = Roadside hazard rating for the roadway segment.



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

Figure 13-8. Potential Crash Effects of Roadside Hazard Rating for Total Crashes on Rural Two-Lane Highways (16)

13.6. CRASH EFFECTS OF ALIGNMENT ELEMENTS

13.6.1. Background and Availability of CMFs

Table 13-26 summarizes common treatments related to alignment elements and the corresponding CMF availability.

Table 13-26. 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 13A.4.2.1	Modify Tangent Length Prior to Curve	T	T	T	T	T	T	T
Appendix 13A.4.2.2	Modify Horizontal Curve Radius	—	—	—	—	—	T	T

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF is not available and a trend is not known.

13.6.2. Alignment Treatments with CMFs

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

Rural two-lane roads

The probability of a crash 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 a CMF, as shown in Equation 13-5. The standard error of this CMF is unknown. This equation applies to all types of roadway segment crashes (16,35). Figure 13-9 illustrates a graphical representation of Equation 13-5. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of curvature.

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

Where:

L_c = Length of horizontal curve including length of spiral transitions, if present (mi);

R = Radius of curvature (ft); and

S = 1 if spiral transition curve is present; 0 if spiral transition curve is not present.

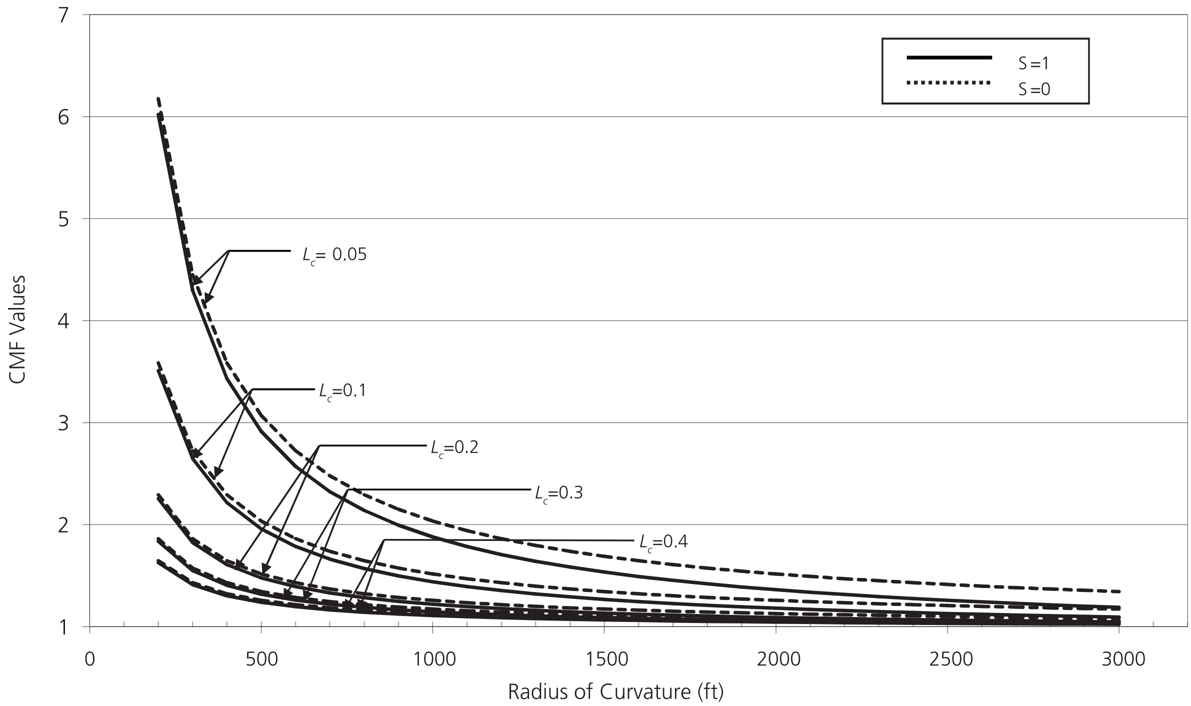


Figure 13-9. Potential Crash Effect of the Radius, Length, and Presence of Spiral Transition Curves in a Horizontal Curve

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 Table 13-27 (16,35). The base condition of the CMFs summarized in Table 13-27 (i.e., the condition in which the CMF = 1.00) is an SV value that is less than 0.01.

Table 13-27. Potential Crash Effects of Improving Superelevation Variance (SV) of Horizontal Curves on Rural Two-Lane Roads (16,35)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF
Improve SV < 0.01	Rural (Two-lane)	Unspecified	All types (All severities)	1.00
Improve 0.01 ≤ SV < 0.02				= 1.00 + 6 (SV – 0.01)
Improve SV > 0.02				= 1.06 + 3 (SV – 0.02)
Base Condition: Superelevation variance < 0.01.				

NOTE: Standard error of CMF 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 CMF for changing superelevation, divide the "new" condition CMF by the "existing" condition CMF.

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 Table 13-28 (35). The crash effect of increasing the vertical grade for crashes of all types and severities relative to a flat roadway (i.e., 0% grade) is also shown in Table 13-28 (16).

These CMFs 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 CMFs may be applied to the entire grade from one point of vertical intersection (PVI) to the next (16).

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

Table 13-28. Potential Crash Effects of Changing Vertical Grade on Rural Two-Lane Roads (16,24)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Increase vertical grade by 1%	Rural (Two-lane)	Unspecified	SVROR (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 CMFs. These CMFs have a standard error of 0.1 or less.
SVROR = single-vehicle run-off-the-road crashes.
CMFs 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—Introduction and Applications Guidance.
N/A = Standard error of CMF is unknown.

13.7. CRASH EFFECTS OF ROADWAY SIGNS

13.7.1. Background and Availability of CMFs

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) (9), 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.

Table 13-29 summarizes common treatments related to signs and the corresponding CMF availability.

Table 13-29. Summary of Treatments Related to Roadway Signs

HSM Section	Treatment	Rural Two-Lane Road	Rural Multilane 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 crash ahead warning signs	—	—	✓	—	—	—
13.7.2.3	Install changeable "Queue Ahead" warning signs	—	—	✓	—	—	—
13.7.2.4	Install changeable speed warning signs	✓	✓	✓	✓	✓	✓
Appendix 13A.5.1.1	Install signs to conform to MUTCD	—	—	—	—	T	—

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF is not available and a trend is not known.

13.7.2. Roadway Sign Treatments with CMFs

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 multilane highways, expressways, freeways, and urban and suburban arterials

Compared to no signage, providing combination horizontal alignment/advisory speed signs reduces the number of all types of injury crashes, as shown in Table 13-30 (8). The crash effect on all types of non-injury crashes is also shown in Table 13-30.

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

Table 13-30. Potential Crash Effects of Installing Combination Horizontal Alignment/ Advisory Speed Signs (W1-1a, W1-2a) (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 U.S. studies: McCamment 1959; Hammer 1969; and international study: Rutley 1972.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.

13.7.2.2. Install Changeable Crash Ahead Warning Signs

Freeways

Changeable crash warning signs on freeways inform drivers of a crash on the roadway ahead. The crash effect of installing changeable crash ahead warning signs on urban freeways is shown in Table 13-31 (8). The base condition of the CMF (i.e., the condition in which the CMF = 1.00) is the absence of crash ahead warning signs.

Table 13-31. Potential Crash Effects of Installing Changeable Crash Ahead Warning Signs (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Install changeable crash ahead warning signs	Urban (Freeways)	Unspecified	All types (Injury)	*0.56*	*0.2*
Base Condition: Absence of changeable crash ahead warning signs.					

NOTE: Based on international study: Duff 1971.
Italic text is used for less reliable CMFs. These CMFs 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 Table 13-32 (8). The crash effect on rear-end, non-injury crashes is also shown in Table 13-32 (8). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of changeable “Queue Ahead” warning signs.

Table 13-32. Potential Crash Effects of Installing Changeable "Queue Ahead" Warning Signs (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs 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 Guidance.

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 multilane highways, expressways, freeways, and urban and suburban arterials

The crash effect of installing individual changeable speed warning signs is shown in Table 13-33. The base condition of the CMF (i.e., the condition in which the CMF = 1.00) is the absence of changeable speed warning signs.

Table 13-33. Potential Crash Effects of Installing Changeable Speed Warning Signs for Individual Drivers (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have standard errors between 0.2 to 0.3.

13.8. CRASH EFFECTS OF ROADWAY DELINEATION

13.8.1. Background and Availability of CMFs

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 (9).

Table 13-34 summarizes common treatments related to delineation and the corresponding CMF availability.

Table 13-34. 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 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 PMDs	✓	✓	N/A	N/A	—	—
13.8.2.7	Install snowplowable, permanent RPMs	✓	—	✓	—	—	—
Appendix 13A.6.1.1	Install chevron signs on horizontal curves	—	—	—	—	T	T
Appendix 13A.6.1.2	Provide distance markers	—	—	T	—	—	—
Appendix 13A.6.1.3	Place converging chevron pattern markings	—	—	—	—	T	T
Appendix 13A.6.1.4	Place edgeline and directional pavement markings on horizontal curves	T	—	—	—	—	—

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

13.8.2.1. Install Post-Mounted Delineators (PMDs)

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, are shown in Table 13-35. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of PMDs.

Table 13-35. Potential Crash Effects of Installing PMDs (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Install PMDs	Rural (Two-lane undivided)	Unspecified	All types (Injury)	**1.04***	**0.1**
			All types (Non-injury)	**1.05***	**0.07**
Base Condition: Absence of PMDs.					

Bold text is used for the most reliable CMFs. These CMFs 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 MarkingsPlace Standard Edgeline Markings (4 to 6 inches wide)

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 are shown in Table 13-36. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of standard edgeline markings.

Table 13-36. Potential Crash Effects of Placing Standard Edgeline Markings (4 to 6 inches wide) (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 U.S. 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 CMFs. These CMFs 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 inches) Edgeline Markings

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

Rural two-lane roads

The crash effects of placing 8-inch-wide edgeline markings on rural two-lane roads that currently have standard edgeline markings are shown in Table 13-37 (8). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the use of standard edgeline markings (4 to 6 inches wide).

Table 13-37. Potential Crash Effects of Placing Wide (8 inch) Edgeline Markings (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Place wide (8 inches) 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 CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs 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 Guidance.

13.8.2.4. Place Centerline Markings

The MUTCD provides guidelines and warrants for installing centerline markings (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 Table 13-38 (8). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of centerline markings.

Table 13-38. Potential Crash Effects of Placing Centerline Markings (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs 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 Guidance.
Study does not report if the roadway segments meet MUTCD guidelines for applying centerline markings.

13.8.2.5. Place Edgeline and Centerline Markings

The MUTCD provides guidelines and warrants for applying edgeline and centerline markings (9).

Rural two-lane roads and rural multilane highways

Placing edgeline and centerline markings where no markings exist decreases injury crashes of all types, as shown in Table 13-39. The base condition of the CMF (i.e., the condition in which the CMF = 1.00) is the absence of markings.

Table 13-39. Potential Crash Effects of Placing Edgeline and Centerline Markings (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 U.S. study: Tamburri, Hammer, Glennon and Lew, 1968. Study does not report if the roadway segments meet MUTCD guidelines for applying edgeline and centerline markings.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.

13.8.2.6. Install Edgelines, Centerlines, and PMDs

Edgeline markings, centerline markings, and PMDs are often combined on roadway segments.

Rural two-lane roads, and rural multilane highways

The crash effects of installing edgelines, centerlines, and PMDs where no markings exist are shown in Table 13-40. The base condition of the CMF (i.e., the condition in which the CMF = 1.00) is the absence of markings.

Table 13-40. Potential Crash Effects of Installing Edgelines, Centerlines, and PMDs (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Install edgelines, centerlines, and PMDs	Urban/Rural (Two-lane/multilane undivided)	Unspecified	All types (Injury)	**0.55**	**0.1**
Base Condition: Absence of markings.					

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

13.8.2.7. Install Snowplowable, Permanent RPMs

Installing snowplowable, permanent RPMs requires consideration of traffic volumes and horizontal curvature (2).

Rural two-lane roads

The crash effects of installing snowplowable, permanent 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 Table 13-41 (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 CMFs (i.e., the condition in which the CMF = 1.00) is the absence of RPMs.

Table 13-41. Potential Crash Effects of Installing Snowplowable, Permanent RPMs (2)

Treatment	Setting (Road Type)	Traffic Volume AADT	Crash Type (Severity)	CMF	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 RPMs.					

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs 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, permanent RPMs on rural four-lane freeways for nighttime crashes by traffic volume are shown in Table 13-42 (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 CMFs (i.e., the condition in which the CMF = 1.00) is the absence of RPMs.

Table 13-42. Potential Crash Effects of Installing Snowplowable, Permanent RPMs (2)

Treatment	Setting (Road Type)	Traffic Volume AADT	Crash Type (Severity)	CMF	Std. Error
Install snowplowable, permanent RPMs	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 RPMs.					

NOTE: *Italic* text is used for less reliable CMFs. These CMFs 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 CMFs

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 non-residential areas where the noise generated is unlikely to disturb adjacent residents. 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).

Table 13-43 summarizes common treatments related to rumble strips and the corresponding CMF availability.

Table 13-43. Summary of Treatments Related to Rumble Strips

HSM Section	Treatment	Rural Two-Lane Road	Urban Two-Lane Road	Rural Multilane 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 13A.7.1.1	Install continuous shoulder rumble strips and wider shoulders	—	—	—	T	—	—	—
Appendix 13A.7.1.2	Install transverse rumble strips	T	—	—	—	—	—	—

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

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 multilane highways

The crash effects of installing continuous milled-in shoulder rumble strips on rural multi-lane divided highways with posted speeds of 55 to 70 mph are shown in Table 13-44 (6). The crash effects on all types of injury severity and single-vehicle run-off-the-road crashes are also shown in Table 13-44. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of shoulder rumble strips.

Table 13-44. Potential Crash Effects of Installing Continuous Shoulder Rumble Strips on Multilane Highways (6)

Treatment	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	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*
			SVROR (All severities)	*0.90**	*0.3*
			SVROR (Injury)	*0.78**	*0.3*
Base Condition: Absence of shoulder rumble strips.					

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.
SVROR = Single-vehicle run-off-the-road crashes
* 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 SVROR crashes. The specific circumstances are SVROR crashes with contributing factors including alcohol, drugs, inattention, inexperience, fatigue, illness, distraction, and glare. The CMFs are presented in Table 13-45 (25).

The crash effects on all SVROR crashes of all severities and injury severity are also shown in Table 13-45. There is no evidence that shoulder rumble strips have an effect on multi-vehicle crashes within the boundaries of the treatment area (13). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of shoulder rumble strips.

Table 13-45. Potential Crash Effects of Installing Continuous Shoulder Rumble Strips on Freeways (25,13)

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

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.
SVROR = Single vehicle run-off-the-road crashes.
Specific SVROR 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 box presents an example of how to apply the preceding CMFs to assess the crash effects of implementing rumble strips on an urban freeway.

Effectiveness of Implementing Rumble Strips

Question:
The installation of rumble strips is being considered along an urban freeway segment to reduce SVROR 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 CMF

CMF = 0.82 (Table 13-45)

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 CMF in Table 13-45 as 0.10. The multiplication of the standard error by 2 yields a 95 percent probability that the true value is between 13.6 and 22.4 crashes/year. See Section 3.5.3 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 installing 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-the-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.

Establised national guidelines do not currently exist for the application of centerline rumble strips, however guidelines are expected to be included in NCHRP 17-32 Guidance for the Application of Shoulder and Centerline Rumble Strips. NCHRP Synthesis 339 Synthesis of Highway Practice Regarding Ceterline Rumble Strips, published in 2005, contains some guidelines. Appendix 13A 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 Table 13-46 (8). The crash effects for head-on and opposing-direction sideswipe crashes are also shown in Table 13-46.

The CMFs 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 CMFs are also applicable to horizontal curves and tangent sections, and passing and no-passing zones (26). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of centerline rumble strips.

Table 13-46. Potential Crash Effects of Installing Centerline Rumble Strips (14)

Treatment	Setting (Road Type)	Traffic Volume AADT	Crash Type (Severity)	CMF	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**
			Head-on and opposing-direction sideswipe (All severities)	**0.79**	**0.1**
			Head-on 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 CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.

13.10. CRASH EFFECTS OF TRAFFIC CALMING

13.10.1. Background and Availability of CMFs

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 objective.

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 among vehicular, pedestrian, and bicycle traffic.

Table 13-47 summarizes common treatments related to traffic calming and the corresponding CMF availability.

Table 13-47. Summary of Treatments Related to Traffic Calming

HSM Section	Treatment	Rural Two-Lane Road	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.10.2.1	Install speed humps	N/A	N/A	N/A	N/A	✓	✓
Appendix 13A.8.2.1	Install transverse rumble strips on intersection approaches	—	—	N/A	N/A	T	T
Appendix 13A.8.2.2	Apply several traffic calming measures to a road segment	N/A	N/A	N/A	N/A	✓	—

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

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 Table 13-48 (8). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of speed humps.

Table 13-48. Potential Crash Effects Of Installing Speed Humps (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs 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 CMFs

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 crashes 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.

Table 13-49 summarizes common treatments related to on-street parking and the corresponding CMF availability.

Table 13-49. 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 a CMF is available for this treatment.
— = Indicates that a CMF 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 CMFs

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 Table 13-50. The base condition of the CMFs summarized in Table 13-50 (i.e., the condition in which the CMF = 1.00) is the provision of on-street parking.

Table 13-50. Potential Crash Effects of Prohibiting On-Street Parking (22,19)

Treatment	Setting (Road Type)	Traffic Volume AADT	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.
+ Combined CMF, see Part D—Introduction and Applications Guidance.

Crash 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 Table 13-51 (8). The crash effect on injury crashes of all types is also shown in Table 13-51. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the provision of free parking.

Table 13-51. Potential Crash Effects of Converting from Free to Regulated On-Street Parking (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 study: Dijkstra 1990
Bold text is used for the most reliable CMFs. These CMFs 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 Guidance.

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 Table 13-52 (8). The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the provision of unrestricted parking.

Table 13-52. Potential Crash Effects of Implementing Time-Limited On-Street Parking (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Implement time-limited parking restrictions	Urban (Arterial and Collector)	Unspecified	All types (All severities)	**0.89**	**0.06**
			Parking-related crashes (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 CMFs. These CMFs 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 a CMF for on-street parking that includes the crash effects not only of angle versus 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 CMF (i.e., the condition in which the CMF = 1.00) is the absence of on-street parking. A CMF for changing from angle parking to parallel parking can be determined by dividing the CMF determined for parallel parking by the CMF determined for angle parking. This CMF applies to total roadway segment crashes. The standard error for this CMF is unknown.

The CMF is determined as:

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

Where:

CMF_{1r} = crash modification factor for the effect of on-street parking on total crashes;

f_{pk} = factor from Table 13-53;

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.

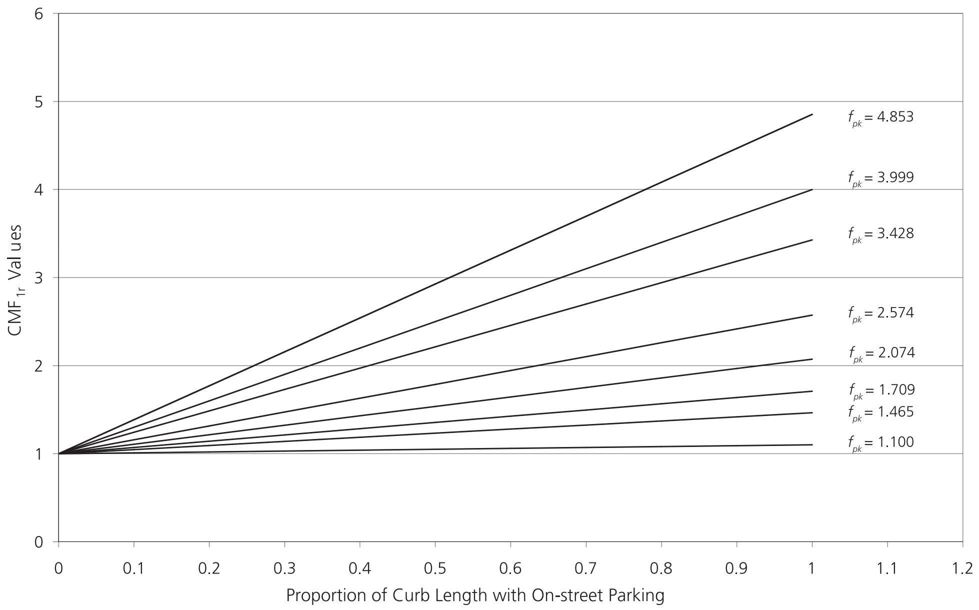


Figure 13-10. Potential Crash Effects of Implementing On-Street Parking (5)

Table 13-53. Type of Parking and Land Use Factor (f_{pk} in Equation 13-6)

	Type of Parking and Land Use			
	Parallel Parking		Angle Parking	
Road Type	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 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.

Crash 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 because of fewer parking spaces as a result of converting angle parking to parallel parking. However, the crash effect is not certain at this time.

The box presents an example of how to apply the preceding equation and graph to assess the crash effects of converting angle to parallel parking on a residential two-lane arterial road.

Effectiveness of Converting Angle Parking into 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 percent of its total length. The local jurisdiction is investigating the impacts of converting 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 Table 13-53)
- 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 (assumed value) = 8 crashes/year

Find:
- Expected average crash frequency after converting from angle to parallel parking
- Change in expected average crash frequency

Answer:
1) Identify the parking and land use factor for existing condition angle parking

f_{pk} = 3.428 (Table 13-53)

2) Identify the parking and land use factor for proposed condition parallel parking

f_{pk} = 1.465 (Table 13-53)

3) Calculate the CMF for the existing condition

CMF = 2.94 (Equation 13-6 or Figure 13-10)

4) Calculate the CMF for the proposed condition

CMF= 1.37 (Equation 13-6 or Figure 13-10)

5) Calculate the treatment CMF ($CMF_{treatment}$) corresponding to the change in parking scheme

$CMF_{treatment}$ = 1.37/2.94 = 0.47

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

6) Apply the treatment CMF ($CMF_{treatment}$) to the expected number of crashes along the roadway segment without the treatment.

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

7) 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

8) Discussion: changing the parking scheme may potentially result in a reduction of 4.2 crashes/year. A standard error was not available for this CMF.

13.12. CRASH EFFECTS OF ROADWAY TREATMENTS FOR PEDESTRIANS AND BICYCLISTS

13.12.1. Background and Availability of CMFs

Pedestrians and bicyclists are considered vulnerable road users because 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 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 13A 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.

Table 13-54 summarizes common roadway treatments for pedestrians and bicyclists, there are currently no CMFs available for these treatments. Appendix 13A presents general information and potential trends in crashes and user behavior for applicable roadway types.

Table 13-54. Summary of Roadway Treatments for Pedestrians and Bicyclists

HSM Section	Treatment	Rural Two-Lane Road	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
Appendix 13A.9.1.1	Provide a sidewalk or shoulder	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.2	Install raised pedestrian crosswalks	N/A	N/A	N/A	N/A	T	T
Appendix 13A.9.1.3	Install pedestrian-activated flashing yellow beacons with overhead signs	N/A	N/A	N/A	N/A	T	T
Appendix 13A.9.1.4	Install pedestrian-activated flashing yellow beacons with overhead signs and advance pavement markings	N/A	N/A	N/A	N/A	T	T
Appendix 13A.9.1.5	Install overhead electronic signs with pedestrian-activated crosswalk flashing beacons	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.6	Reduce posted speed limit through school zones during school times	T	T	N/A	N/A	T	T
Appendix 13A.9.1.7	Provide pedestrian overpasses and underpasses	—	—	N/A	N/A	T	T
Appendix 13A.9.1.8	Mark crosswalks at uncontrolled locations, intersection or mid-block	—	N/A	N/A	N/A	T	T
Appendix 13A.9.1.9	Use alternative crosswalk markings at mid-block locations	—	N/A	N/A	N/A	T	T
Appendix 13A.9.1.10	Use alternative crosswalk devices at mid-block locations	—	N/A	N/A	N/A	T	T
Appendix 13A.9.1.11	Provide a raised median or refuge island at marked and unmarked crosswalks	N/A	N/A	N/A	N/A	T	T
Appendix 13A.9.1.12	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 13A.9.1.13	Install pedestrian refuge islands or split pedestrian crossovers	N/A	N/A	N/A	N/A	T	T
Appendix 13A.9.1.14	Widen median	N/A	—	N/A	N/A	T	T
Appendix 13A.9.1.15	Provide dedicated bicycle lanes (BLs)	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.16	Provide wide curb lanes (WCLs)	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.17	Provide shared bus/bicycle lanes	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.18	Re-stripe roadway to provide bicycle lane	N/A	N/A	N/A	N/A	T	—
Appendix 13A.9.1.19	Pave highway shoulders for bicycles	T	T	N/A	N/A	N/A	—
Appendix 13A.9.1.20	Provide separate bicycle facilities	N/A	N/A	N/A	N/A	T	—

NOTE: T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
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 CMFs

Artificial 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.

Table 13-55 summarizes common treatments related to highway lighting and the corresponding CMF availability.

Table 13-55. 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 lighting	✓	✓	✓	✓	✓	✓

NOTE: ✓ = Indicates that a CMF is available for this treatment.

13.13.2. Highway Lighting Treatments with CMFs

13.13.2.1. Provide Highway Lighting

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

The crash effects of providing highway lighting on roadway segments that previously had no lighting are shown in Table 13-56. The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the absence of lighting.

Table 13-56. Potential Crash Effects of Providing Highway Lighting (7,8,12,27)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 et al., 2008; and international studies: Elvik and Vaa 2004.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
N/A Standard error of the CMF is unknown.

The CMFs for nighttime injury crashes and nighttime crashes 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 crashes by injury severity and time of day from Minnesota and Michigan.

13.14. CRASH EFFECTS OF ROADWAY ACCESS MANAGEMENT

13.14.1. Background and Availability of CMFs

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 crashes 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 for public-road intersections. However, where intersection characteristics or side-road traffic volume data is lacking, some minor, very-low-volume intersections may be treated as driveways for analysis purposes.

Table 13-57 summarizes common treatments related to access points and the corresponding CMF availability.

Table 13-57. Summary of Treatments Related to Access Management

HSM Section	Treatment	Rural Two-Lane Road	Urban Two-Lane Road	Suburban Two-Lane Roads	Rural Multilane Highway	Freeway	Expressway	Urban Arterial	Suburban Arterial
13.14.2.1	Modify access point density	✓	N/A	N/A	—	N/A	—	✓	✓
Appendix 13A.10.1.1	Reduce number of median crossings and intersections	—	N/A	N/A	—	N/A	—	T	T

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

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 13-7 (16) and Figure 13-11. The base condition (i.e., the condition in which the CMF = 1.00) for access point density is five access points per mile. The standard error of the CMF is unknown.

$$CMF = \frac{0.322 + DD \times [0.05 - 0.005 \times In(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times In(AADT)]} \tag{13-7}$$

Where:

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

DD = access point density measured in driveways per mile.

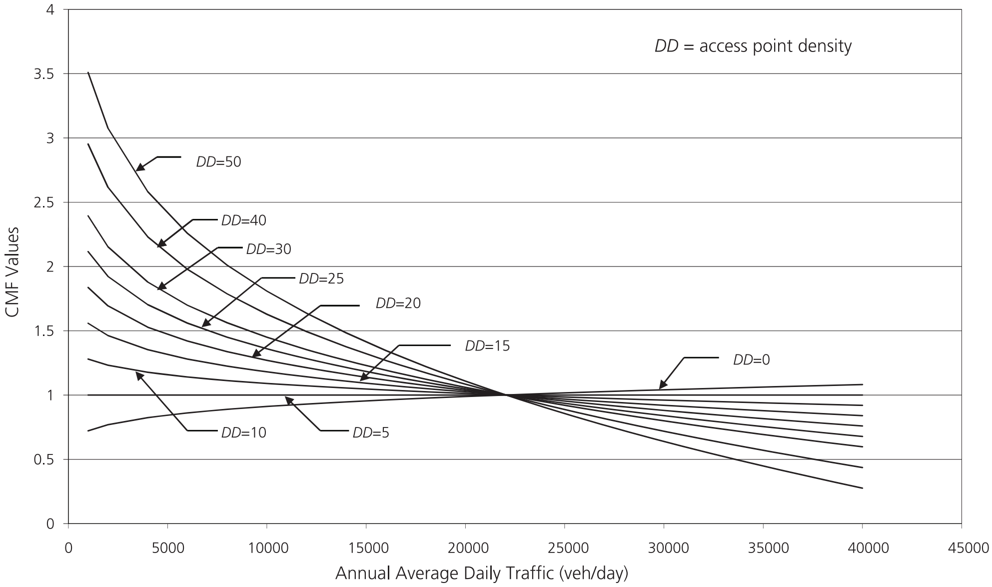


Figure 13-11. Potential Crash Effects of Access Point Density on Rural Two-Lane Roads

Urban and Suburban Arterials

The crash effects of decreasing access point density on urban and suburban arterials are shown in Table 13-58 (8).

The base condition of the CMFs (i.e., the condition in which the CMF = 1.00) is the initial driveway density prior to the implementation of the treatment as presented in Table 13-58.

Table 13-58. Potential Crash Effects of Reducing Access Point Density (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	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 CMFs. These CMFs have a standard error of 0.1 or less.

13.15. CRASH EFFECTS OF WEATHER ISSUES

13.15.1. Background and Availability of CMFs

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

Table 13-59 summarizes common treatments related to weather issues and the corresponding CMF availability.

Table 13-59. 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 13A.11.2.1	Install changeable fog warnings signs	—	—	T	—	—	—
Appendix 13A.11.2.2	Install snow fences for the whole winter season	T	T	—	—	N/A	N/A
Appendix 13A.11.2.3	Raise the state of preparedness for winter maintenance	—	—	—	—	—	—
Appendix 13A.11.2.4	Apply preventive chemical anti-icing during the whole winter season	T	T	T	T	T	T

NOTE: ✓ = Indicates that a CMF is available for this treatment.
T = Indicates that a CMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix 13A.
— = Indicates that a CMF 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 CMFs

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 crash 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 crash 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 crash 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 crashes 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.

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

Rural two-lane roads, rural multilane highways, freeways, expressways, and 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 raising a road's standards for winter maintenance by one class are shown in Table 13-60 (8). The base conditions of the CMFs (i.e., the condition in which the CMF = 1.00) consist of the original maintenance hierarchy assigned to a roadway prior to implementing the treatment.

Table 13-60. Potential Crash Effects of Raising Standards by One Class for Winter Maintenance for the Whole Winter Season (8)[2]

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Raise standard by one class 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 CMFs. These CMFs 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 CMFs 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 13A.

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 CMFs are included in Part C for use in the predictive method. Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Section C.7.

2. Nearly all studies were conducted in Scandinavian countries. The length and severity of the winter season varies substantially between regions of these countries. In southern 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.

13.17. REFERENCES

(1) AASHTO. *Roadside Design Guide*. American Association of State Highway and Transportation Officials, Washington, DC, 2002.

(2) Bahar, G., C. Mollett, B. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. *National Cooperative Highway Research Report 518: Safety Evaluation of Permanent Raised Pavement Markers*. NCHRP, Transportation Research Board, Washington, DC, 2004.

(3) Bahar, G. and M. L. Parkhill. *Synthesis of Practices for the Implementation of Centreline Rumble Strips—Final Draft*. 2004.

(4) Bauer, K. M., D. W. Harwood, W. E., Hughes, and K. R Richard. *Safety Effects of Using Narrow Lanes and Shoulder-Use Lanes to Increase the Capacity of Urban Freeways*. 83rd Transportation Research Board Annual Meeting, Washington, DC, 2004.

(5) Bonneson, J. A., K. Zimmerman, and K. Fitzpatrick. *Roadway Safety Design Synthesis*. Report No. FHWA/TX-05/0-4703--1, Texas Department of Transportation, November, 2005.

(6) Carrasco, O., J. McFadden, and P. Chandhok, *Evaluation of the Effectiveness of Shoulder Rumble Strips on Rural Multi-lane Divided Highways In Minnesota*. 83rd Transportation Research Board Annual Meeting, Washington, DC, 2004.

(7) Elvik, R. Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure. In *Transportation Research Record 1485*. TRB, National Research Council, Washington, DC, 1995. pp. 112–123.

(8) Elvik, R. and T. Vaa. *Handbook of Road Safety Measures*. Elsevier, Oxford, United Kingdom, 2004.

(9) FHWA. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2003.

(10) Griffin, L. I., and K. K. Mak. *The Benefits to Be Achieved from Widening Rural, Two-Lane Farm-to-Market Roads in Texas*, Report No. IAC (86-87)—1039. Texas Transportation Institute, College Station, TX, April, 1987.

(11) Griffin, L. I. and R. N. Reinhardt. *A Review of Two Innovative Pavement Patterns that Have Been Developed to Reduce Traffic Speeds and Crashes*. AAA Foundation for Traffic Safety, Washington, DC, 1996.

(12) Griffith, M. S. Comparison of the Safety of Lighting Options on Urban Freeways. *Public Roads,* Vol. 58, No. 2, 1994. pp. 8–15.

(13) Griffith, M. S., *Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways*. 78th Transportation Research Board Annual Meeting, Washington, DC, 1999.

(14) Hanley, K. E., A. R. Gibby, and T. C. Ferrara. Analysis of Accident Reduction Factors on California State Highways. In *Transportation Research Record 1717*. TRB, National Research Council Washington, DC, 2000, pp. 37–45.

(15) Harkey, D.L., S. Raghavan, B. Jongdea, F.M. Council, K. Eccles, N. Lefler, F. Gross, B. Persaud, C. Lyon, E. Hauer, and J. Bonneson. *National Cooperative Highway Research Report 617: Crash Reduction Factors for Traffic Engineering and ITS Improvements*. NCHRP, Transportation Research Board, Washington, DC, 2008.

(16) Harwood, D. W., F. M. Council, E. Hauer, W. E. Hughes, and A. Vogt. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. FHWA-RD-99-207, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2000.

(17) Hauer, E. *Lane Width and Safety*. 2000.

(18) Hauer, E. *The Median and Safety*. 2000.

(19) Hauer, E., F. M. Council, and Y. Mohammedshah. *Safety Models for Urban Four-Lane Undivided Road Segments*. 2004.

(20) Huang, H. F., J. R. Stewart, and C. V. Zegeer. Evaluation of Lane Reduction "Road Diet" Measures on Crashes and Injuries. In *Transportation Research Record 1784*. TRB, National Research Council, Washington, DC, 2002. pp. 80–90.

(21) ITE. *Traffic Engineering Handbook Fifth Edition*. Institute of Transportation Engineers, Washington, DC, 1999.

(22) Lord, D., and J. A. Bonneson. *Development of Accident Modification Factors for Rural Frontage Road Segments in Texas*. Presented at the 86th annual meeting of the Transoportation Research Board, Washington, DC, 2007.

(23) Miaou, S. *Measuring the Goodness of Fit of Accident Prediction Models*. FHWA-RD-96-040, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 1996.

(24) Miaou, S. *Vertical Grade Analysis Summary.* Unpublished, May 1998.

(25) Perrillo, K. *The Effectiveness and Use of Continuous Shoulder Rumble Strips*. Federal Highway Administration, U.S. Department of Transporation, Albany, NY, 1998.

(26) Persaud, B. N., R. A. Retting, and C. Lyon, *Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads*. Insurance Institute for Highway Safety, Arlington,VA, 2003.

(27) Preston, H. and T. Schoenecker. *Safety Impacts of Street Lighting at Rural Intersections*. Minnesota Department of Transportation, St. Paul, MN, 1999.

(28) *Technical Advisory: Shoulder Rumble Strips.* Available from http://safety.fhwa.dot.gov/roadway_dept/policy_guide/t504035.cfm Vol. T 5040.35, (2001).

(29) Torbic, D. J., L. Elefteriadou, and M. El-Gindy. *Development of More Bicycle-Friendly Rumble Strip Configurations*. 80th Transportation Research Board Annual Meeting, Washington, DC, 2001.

(30) TRB. *Highway Capacity Manual 2000*. Transportation Research Board, National Research Council, Washington, DC, 2000.

(31) TRB. *NCHRP Synthesis of Highway Practice Report 332: Access Management on Crossroads in the Vicinity of Interchanges*. Transportation Research Board, National Research Council, Washington, DC, 2004. pp. 1–82.

(32) Various. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements* Volume 1. FHWA-TS-82-232, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1982.

(33) Zegeer, C. V., D. W. Reinfurt, J. Hummer, L. Herf, and W. Hunter. Safety Effects of Cross-Section Design for Two-Lane Roads. In *Transportation Research Record 1195*. TRB, National Research Council, Washington, DC, 1988.

(34) Zegeer, C. V., D. W. Reinfurt, W. W. Hunter, J. Hummer, R. Stewart, and L. Herf. Accident Effects of Sideslope and Other Roadside Features on Two-Lane Roads. In *Transportation Research Record 1195*. TRB, National Research Council, Washington, DC, 1988, pp. 33–47.

(35) Zegeer, C. V., J. R. Stewart, F. M. Council, D. W. Reinfurt, and E. Hamilton, Safety Effects of Geometric Improvements on Horizontal Curves. In *Transportation Research Record 1356*. TRB, National Research Council, Washington, DC, 1992.

(36) Zegeer, C. V., R. C. Deen, and J. G. Mayes. Effect of Lane and Shoulder Width on Accident Reduction on Rural, Two-Lane Roads. In *Transportation Research Record 806*, TRB, National Research Council, Washington, DC, 1981.

APPENDIX 13A

13A.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 CMFs are available, a more detailed discussion can be found within the chapter body. The absence of a CMF indicates that at the time this edition of the HSM was developed, completed research had not developed statistically reliable and/or stable CMFs 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 13A.2);
- Roadside Elements (Section 13A.3);
- Alignment Elements (Section 13A.4);
- Roadway Signs (Section 13A.5);
- Roadway Delineation (Section 13A.6);
- Rumble Strips (Section 13A.7);
- Traffic Calming (Section 13A.8);
- Roadway Treatments for Pedestrians and Bicyclists (Section 13A.9);
- Roadway Access Management (Section 13A.10);
- Weather Issues (Section 13A.11); and
- Treatments with Unknown Crash Effects (Section 13A.12).

13A.2. ROADWAY ELEMENTS

13A.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-crash 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, for example, 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, thereby increasing the exposure of pedestrians to vehicles.

Shoulders

Shoulders are intended to perform several functions, including: to provide a recovery area for out-of-control vehicles, to provide an emergency stopping area, and to 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 crashes 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 crash 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 crash 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.

13A.2.2. Roadway Element Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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.

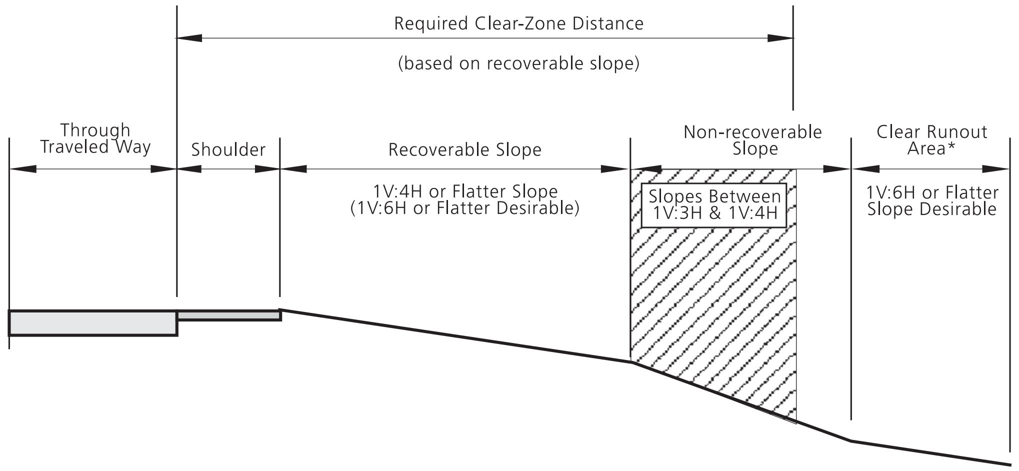
13A.3. ROADSIDE ELEMENTS

13A.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 Figure 13A-1.



NOTE: *The Clear Run-Out 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 Run-Out Area is equal to that portion of the Clear Zone Distance located on the non-recoverable slope.

Figure 13A-1. Clear Zone Distance with Example of a Parallel Foreslope Design (3)

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).

Although there are positive safety benefits to the clear zone, there is no single clear zone width that defines maximum safety because 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.

Figures 13A-2 through 13A-8 show the seven RHR levels. In the safety prediction procedure for two-lane rural roads (Chapter 10), roadside design is described by the RHR.

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

Figure 13A-2. Typical Roadway with RHR of 1

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

Figure 13A-3. Typical Roadway with RHR of 2

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

Figure 13A-4. Typical Roadway with RHR of 3

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

Figure 13A-5. Typical Roadway with RHR of 4

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

Figure 13A-6. Typical Roadway with RHR of 5

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

Figure 13A-7. Typical Roadway with RHR of 6

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.

Figure 13A-8. Typical Roadway with RHR of 7

13A.3.2. Roadside Element Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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.

13A.3.2.2. Increase Clear Roadside Recovery Distance

Rural two-lane roads

Increasing the clear roadside recovery distance appears to reduce related crash types (i.e., run-off-the-road, head-on, and sideswipe crashes) (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).

13A.3.2.3. Install Curbs

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.

Although cement concrete and bituminous (asphalt) concrete curbs are used extensively, 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 crashes of all severities (25). Installing curbs instead of narrow flush shoulders on suburban multi-lane highways appears to increase crashes of all types and severities (25). However, the magnitude of the crash effect is not certain at this time.

13A.3.2.4. Increase Distance to Utility Poles and Decrease Utility Pole Density

Rural two-lane roads, rural multilane highways, freeways, expressways, and 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 crashes 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 crashes (53). However, the magnitude of the crash effect is not certain at this time.

13A.3.2.5. Install Roadside Barrier along Embankments

Rural two-lane roads, rural multilane highways, freeways, expressways, and urban and suburban arterials
Installing roadside barriers along embankments appears to reduce the number of fatal and injury run-off-the-road crashes and the number of run-off-the-road crashes 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).

13A.4. ALIGNMENT ELEMENTS

13A.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 crash severity. As more severe crashes are more likely than minor crashes to be reported to the police and to be entered into crash databases, the number of reported crashes likely depends on speed and grade.

- Speed differential: It is generally believed that crash frequency increases when speed differential increases. Because road grade affects speed differential, vertical alignment may also affect crash 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).

13A.4.2. Alignment Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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 crashes 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.

13A.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 run-off-the-road crashes on urban and suburban arterials (25).

13A.5. ROADWAY SIGNS

13A.5.1. Roadway Sign Treatments with no CMFs—Trends in Crashes or User Behavior

13A.5.1.1. Install Signs to Conform to MUTCD

The MUTCD defines the standards 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 crashes (7). The crash effect on non-injury crashes may consist of an increase, decrease, or no change in non-injury crashes (7).

13A.6. ROADWAY DELINEATION

13A.6.1. Roadway Delineation Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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 crashes of all types. However, the magnitude of the crash effect is not certain at this time.

13A.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 crashes (13). However, the magnitude of the crash effect is not certain at this time.

13A.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 crashes of all severities (16). However, the magnitude of the crash effect is not certain at this time.

13A.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 crashes of the SVROR type (13). However, the magnitude of the crash effect is not certain at this time.

13A.7. RUMBLE STRIPS

13A.7.1. Rumble Strip Treatments with no CMFs—Trends in Crashes or User Behavior

13A.7.1.1. Install Continuous Shoulder Rumble Strips and Wider Shoulders

Freeways

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

13A.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, highway-rail grade crossings, bridges, and tunnels.

There are currently no national guidelines for applying 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 crash types combined, as well as wet and nighttime crashes of all severities. However, the magnitude of the crash effect is not certain at this time (4).

13A.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, or 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.

13A.8. TRAFFIC CALMING

13A.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.

13A.8.2. Traffic Calming Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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 crashes of all severities (13). However, the magnitude of the crash effect is not certain at this time.

13A.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 crashes of all severities and of injury severity (13). Non-injury crashes may also experience a reduction with the implementation of traffic calming.

Crash migration is a possible result of traffic calming. Drivers who are forced to slow down by traffic calming measures 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.

13A.9. ROADWAY TREATMENTS FOR PEDESTRIANS AND BICYCLISTS

13A.9.1. Pedestrian and Bicycle Treatments with no CMFs—Trends in Crashes or User Behavior

13A.9.1.1. Provide a Sidewalk or Shoulder

"Walking along roadway" pedestrian crashes tend to occur at night on roadways without sidewalks or paved shoulders. 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 with roadways without a sidewalk or wide shoulder, urban roads with a sidwewalk or wide shoulder at least 4 ft wide appear 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, for example, 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 with roads with sidewalks on one side, roads with sidewalks on both sides appear to reduce the risk of pedestrian crashes (48).

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

13A.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 crashes (13). It is reasonable to conclude that raised pedestrian crosswalks have an overall positive effect on crash occurrence because 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).

13A.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.

13A.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 with 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.

13A.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 effectively reduce 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).

13A.9.1.6. Reduce Posted Speed Limit through School Zones during School Times

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

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).

13A.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 percent 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 percent 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 crashes may increase slightly near the overpass (9). However, the magnitude of the crash effect is not certain at this time.

13A.9.1.8. Mark Crosswalks at Uncontrolled Locations, Intersections, or Mid-Block

Urban and suburban arterials

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).

13A.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 among those alternative crosswalk markings.

13A.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 crashes 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.

Figures 13A-9 and 13A-10 present examples of Zebra and Pelican crossings.

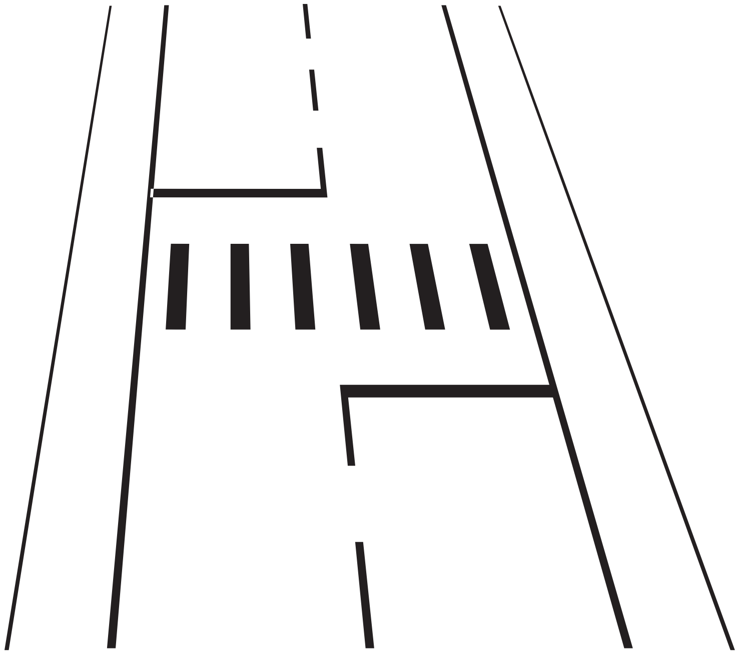


Figure 13A-9. Zebra Crossing

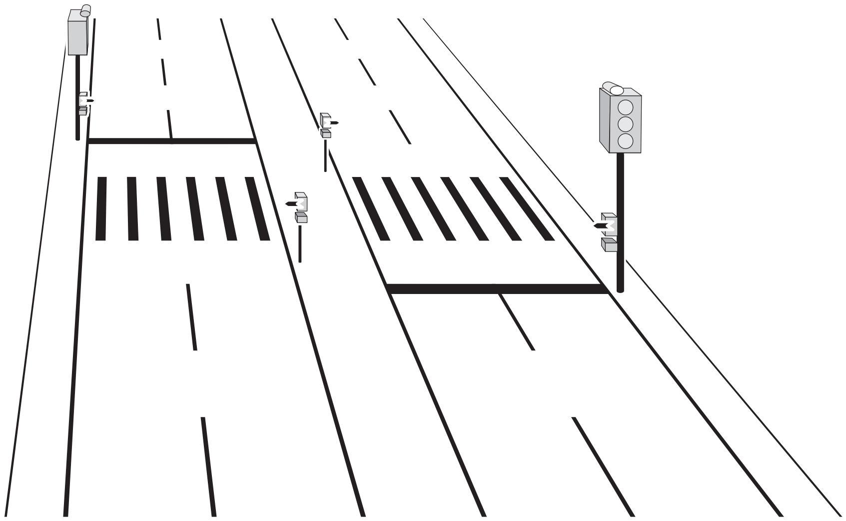


Figure 13A-10. Pelican Crossing

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). Figure 13A-11 presents an example of a Puffin crossing.

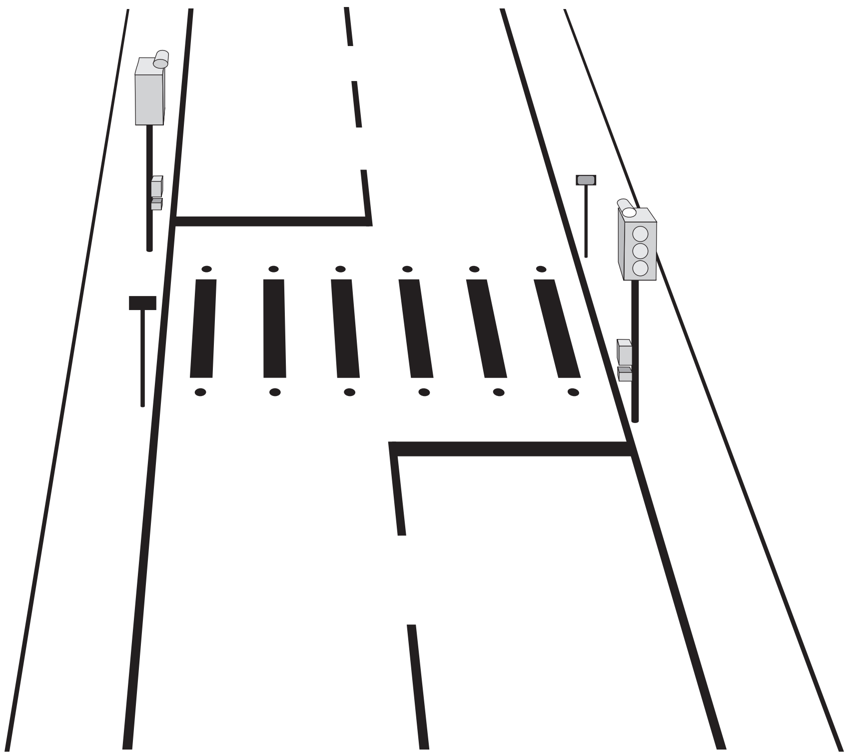


Figure 13A-11. Puffin Crossing

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) Figure 13A-12 presents an example of a Toucan crossing.

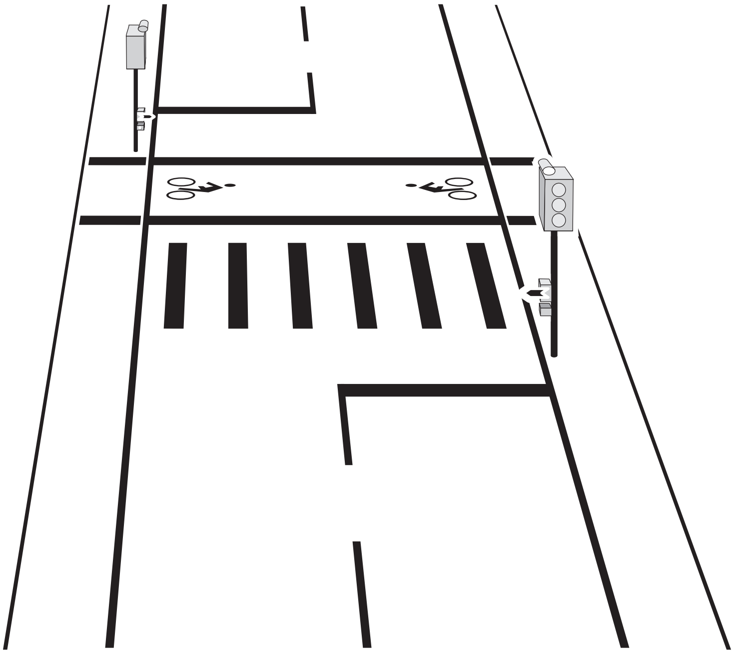


Figure 13A-12. Toucan Crossing

13A.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 mid-block 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 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.

13A.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 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).

Suburban arterial streets with raised curb medians appear to have lower pedestrian crash rates as compared with 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.

13A.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 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 crashes (5).

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

13A.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.

13A.9.1.15. Provide Dedicated Bicycle Lanes

Urban arterials

Providing dedicated bicycle lanes in urban areas appears to reduce bicycle- 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 with a WCL, the dedicated bicycle lane may also lead to higher levels of comfort for both bicyclists and motorists (18).

Three types of bicycle-vehicle crashes 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).

13A.9.1.16. Provide WCLs

Urban arterials

One alternative to providing a dedicated bicycle lane is to design a wider curb lane to accommodate both bicycles and vehicles. A curb lane 12 ft wide or more appears to improve the interaction between bicycles and 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 often than on roadway segments with bicycle lanes (18,29).

Compared with WCLs with the same motor vehicle traffic volume, bicyclists appear to ride farther from the curb in bicycle lanes 5.2 ft wide or greater (29).

13A.9.1.17. Provide Shared Bus/Bicycle Lanes

Urban arterials

Compared with streets with general use lanes, streets with shared bus/bicycle lanes appear to reduce total crashes, although bicycle traffic may increase after installing the shared bus/bicycle lanes (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).

13A.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).

13A.9.1.19. Pave Highway Shoulders for Bicycle Use

Rural two-lane roads and rural multilane 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-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).

13A.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 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.

13A.10. ROADWAY ACCESS MANAGEMENT

13A.10.1. Roadway Access Management Treatments with no CMFs—Trends in Crashes or User Behavior

13A.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.

13A.11. WEATHER ISSUES

13A.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"or "heavy fog area"), or in-vehicle information systems, or a 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 crashes. By improving winter maintenance standards, it may be possible to mitigate the expected increase in crashes. A number of treatments can be applied to control snow, slush, and ice.

13A.11.2. Weather Issue Treatments with No CMFs—Trends in Crashes or User Behavior

13A.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 crashes that occur during foggy conditions (26,31). However, the magnitude of the crash effect is not certain at this time.

13A.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.

13A.11.2.3. Raise the State of Preparedness for Winter Maintenance

Limited research suggests that 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—may reduce the number of crashes or, in some cases, have no impact at all. The research suggests that the measure may be more effective in the early morning hours (13).

13A.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 because 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, and urban and suburban arterials

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

13A.12. TREATMENTS WITH UNKNOWN CRASH EFFECTS

13A.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 or turf)

13A.12.2. Treatments Related to Roadside Elements

- Remove roadside features, 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, and fire hydrants
- Modify barrier end treatments, including breakaway cable terminal (BCT) and modified eccentric loader terminal (MELT).

13A.12.3. Treatments Related to Alignment Elements

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

13A.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)
- Modify sign support material

13A.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 temporary pavement markers

13A.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

13A.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

13A.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

13A.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

13A.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, and curb ramp design
- Change the location of trees, poles, posts, news racks, and other roadside features
- Illuminate sidewalks
- Consider presence of driveways in relation to pedestrian and bicycle facilities
- Provide signage for pedestrian and bicyclist information
- Consider pedestrian and bicyclists in 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, and warning devices)
- Widen bicycle lanes
- Install rumble strips adjacent to bicycle lane
- Provide bicycle boulevards

13A.12.11. Treatments Related to Access Management

- Modify signalized intersection spacing

13A.12.12. Treatments Related to Weather Issues

- Install changeable weather warnings signs (e.g., high winds, snow, freezing rain, and low visibility)
- Install static warning signs for weather or road surface (e.g., "bridge road surface freezes before road," and "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

13A.13. APPENDIX REFERENCES

(1) AASHTO. *A Policy on Geometric Design of Highways and Streets, 4th ed*. Second Printing. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

(2) AASHTO. *A Policy on Geometric Design of Highways and Streets 5th ed*. American Association of State Highway and Transportation Officials, Washington, DC, 2004.

(3) AASHTO. *Roadside Design Guide*. American Association of State Highway and Transportation Officials, Washington, DC, 2002.

(4) Agent, K. R. and F. T. Creasey. *Delineation of Horizontal Curves*. UKTRP-86-4. Kentucky Transportation Cabinet, Frankfort, KY, 1986.

(5) Bacquie, R., C. Mollett, V. Musacchio, J. Wales, and R. Moraes. *Review of Refuge Islands and Split Pedestrian Crossovers—Phase 2*. City of Toronto, Toronto, Ontario, Canada, 2001.

(6) Bahar, G., C. Mollett, B. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. *National Cooperative Highway Research Report 518: Safety Evaluation of Permanent Raised Pavement Markers*. NCHRP, Transportation Research Board, Washington, DC, 2004.

(7) Box, P. Angle Parking Issues Revisited 2001. *ITE Journal,* Vol. 72, No. 3, 2002. pp. 36–47.

(8) Bowman, B. L. and R. L. Vecellio. Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety. In *Transportation Research Record 1445*, TRB, National Research Council, Washington, DC, 1994. pp. 169–179.

(9) Campbell, B. J., C. V. Zegeer, H. H. Huang, and M. J. Cynecki. *A Review of Pedestrian Safety Research in the United States and Abroad*. FHWA-RD-03-042, Federal Highway Administration, McLean, VA, 2004.

(10) City of Eugene. *18th Avenue Bike Lanes—One Year Report, Memorandum to City Council*. City of Eugene, Eugene, Oregon, 1980.

(11) Claessen, J. G. and D. R. Jones. *The Road Safety Effectiveness of Raised Wide Medians*. Proceedings of the 17th Australian Road Research Board Conference, 1994. pp. 269–287.

(12) Davies, D. G. *Research, Development and Implementation of Pedestrian Safety Facilities in the United Kingdom*. FHWA-RD-99-089, Federal Highway Administration, McLean, VA, 1999.

(13) Elvik, R. and T.Vaa, *Handbook of Road Safety Measures*. Elsevier, Oxford, United Kingdom, 2004.

(14) Garder, P. Rumble Strips or Not Along Wide Shoulders Designated for Bicycle Traffic. In *Transportation Research Record 1502*, TRB, National Research Council, Washington, DC, 1995. pp. 1–7.

(15) Gattis, J. L. *Comparison of Delay and Crashes on Three Roadway Access Designs in a Small City*. Transportation Research Board 2nd National Conference, Vail, CO, 1996. pp. 269–275.

(16) Griffin, L. I. and R. N. Reinhardt. *A Review of Two Innovative Pavement Patterns that Have Been Developed to Reduce Traffic Speeds and Crashes*. AAA Foundation for Traffic Safety, Washington, DC, 1996.

(17) Hanley, K. E., A. R. Gibby, and T. C. Ferrara. Analysis of Crash Reduction Factors on California State Highways. In *Transportation Research Record 1717*. TRB, National Research Council, Washington, DC, 2000. pp. 37–45.

(18) Harkey, D. L. and J. R., Stewart. Evaluation of Shared-Use Facilities for Bicycles and Motor Vehicles. In *Transportation Research Record 1578*. TRB, National Research Council, Washington, DC, 1997. pp. 111–118.

(19) Harwood, D. W., F. M. Council, E. Hauer, W. E. Hughes, and A. Vogt. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways. FHWA-RD-99-207*, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2000.

(20) Hauer, E. *Lane Width and Safety*. 2000.

(21) Hauer, E. *Road Grade and Safety*. 2001.

(22) Hauer, E. *Safety of Horizontal Curves*. 2000.

(23) Hauer, E. *Shoulder Width, Shoulder Paving and Safety*. 2000.

(24) Hauer, E. *The Median and Safety*. 2000.

(25) Hauer, E., F. M. Council, and Y. Mohammedshah. Saf*ety Models for Urban Four-Lane Undivided Road Segments*. 2004.

(26) Hogema, J. H., R. van der Horst, and W. van Nifterick. Evaluation of an automatic fog-warning system. *Traffic Engineering and Control*, Vol. 37, No. 11, 1996. pp. 629–632.

(27) Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. FHWA-RD-00-104, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2001.

(28) Huang, H. F., C. V. Zegeer, R. Nassi, and B. Fairfax. *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*. FHWA-RD-00-098, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2000.

(29) Hunter, W. W. and J. R. Stewart. *An Evaluation Of Bike Lanes Adjacent To Motor Vehicle Parking*. Highway Safety Research Center, University of North Carolina, Chapel Hill, NC, 1999.

(30) Hunter, W. W., J. S. Stutts, W. E. Pein, and C. L. Cox. *Pedestrian and Bicycle Crash Types of the Early 1990's*. FHWA-RD-95-163, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 1995.

(31) Janoff, M. S., P. S. Davit, and M. J. Rosenbaum. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements Volume 11*. FHWA-TS-82-232, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1982.

(32) Jensen, S. U. *Junctions and Cyclists*. Proc. Velo City '97—10th International Bicycle Planning Conference, Barcelona, Spain, 1997.

(33) Knoblauch, R. L., B. H. Tustin, S. A. Smith, and M. T. Pietrucha. *Investigation of Exposure Based Pedestrian Crash Areas: Crosswalks, Sidewalks, Local Streets and Major Arterials*. FHWA/RD/88/038, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1988.

(34) Knoblauch, R. L., M. Nitzburg, and R. F. Seifert. *Pedestrian Crosswalk Case Studies: Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota*. FHWA-RD-00-103, Federal Highway Administration, McLean, VA, 2001.

(35) Lacy, K., R. Srinivasan, C. V. Zegeer, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. *National Cooperative Highway Research Report 500 Volume 8: A Guide for Addressing Collisions Involving Utility Poles*. NCHRP, Transportation Research Board, Washington, DC, 2004.

(36) Laursen, J. G. *Nordic Experience with the Safety of Bicycling*. Denmark, Bicycle Federation of America, 1993.

(37) Lott, D. F. and D. Y. Lott. Differential Effect of Bicycle Lanes on Ten Classes of Bicycle-Automobile Crashes. In *Transportation Research Record 605*. TRB, National Research Council, Washington, DC, 1976. pp. 20–24.

(38) McHenry, S. R. and M. J. Wallace. *Evaluation of Wide Curb Lanes as Shared Lane Bicycle Facilities*. Maryland State Highway Administration, Baltimore, MD, 1985.

(39) McMahon, P. J., C. V. Zegeer, C. Duncan, R. L. Knoblauch, J. R. Stewart, and A. J. Khattak. *An Analysis of Factors Contributing to "Walking Along Roadway" Crashes: Research Study and Guidelines for Sidewalks and Walkways*. FHWA-RD-01-101, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2002.

(40) Miaou, S. P. *Measuring the Goodness-of-Fit of Accident Prediction Models*. FHWA-RD-96-040, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 1996.

(41) Nee, J. and M. E. Hallenbeck. *A Motorist and Pedestrian Behavioral Analysis Relating to Pedestrian Safety Improvements—Final Report*. Washington State Transportation Commission, Seattle, WA, 2003.

(42) Neuman, T. R., R. Pfefer, K. L. Slack, K. K. Hardy, F. M. Council, H. McGee, L. Prothe, and K. A. Eccles. *National Cooperative Highway Research Report 500 Volume 6: A Guide for Addressing Run-off-Road Collisions*. Transportation Research Board, Washington, DC, 2003.

(43) Nitzburg, M. and R. L. Knoblauch. *An Evaluation of High-Visibility Crosswalk Treatment—Clearwater Florida*. FHWA-RD-00-105, Federal Highway Administration, McLean, VA, 2001.

(44) Perrillo, K. *The Effectiveness and Use of Continuous Shoulder Rumble Strips*. Federal Highway Administration, U.S. Department of Transportation, Albany, NY, 1998.

(45) Ronkin, M. P. Bike Lane or Shared Roadway? *Pro Bike News*, Vol. 13, No. 3, 1993. pp. 4-5.

(46) Scriven, R. W. *Raised Median Strips—A Highly Effective Road Safety Measure*. Proceedings of the 13th Australian Road Research Board Conference, 1986. pp. 46–53.

(47) Smith, R. L. and T. Walsh. Safety Impacts of Bicycle Lanes. In *Transportation Research Record 1168*. TRB, National Research Council, Washington, DC, 1988. pp. 49–59.

(48) Tobey, H. N., E. M. Shunamen, and R. L. Knoblauch. *Pedestrian Trip Making Characteristics and Exposure Measures*. DTFH61-81-00020, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1983.

(49) Torbic, D. J., L. Elefteriadou, and M. El-Gindy. *Development of More Bicycle-Friendly Rumble Strip Configurations*. 80th Transportation Research Board Annual Meeting, Washington, DC, 2001.

(50) TRB. *Highway Capacity Manual 2000*. Transportation Research Board, National Research Council, Washington, DC, 2000.

(51) Van Houten, R., R. A. Retting, J. Van Houten, C. M. Farmer, and J. E. L. Malenfant. Use of Animation in LED Pedestrian Signals to Improve Pedestrian Safety. *ITE Journal,* Vol. 69, No. 2, 1999. pp. 30–38.

(52) Various. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements Volume 1*. FHWA-TS-82-232, Federal Highway Administration, Washington, DC, 1982.

(53) Zegeer, C. V. and M. J. Cynecki. Determination of Cost-Effective Roadway Treatments for Utility Pole Crashes. In *Transportation Research Record 970*. TRB, National Research Council, Washington, DC, 1984. pp. 52–64.

(54) Zegeer, C. V., R. Stewart, H. Huang, and P. Lagerwey. *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines*. FHWA-RD-01-075, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, 2002.