# Chapter 15—Interchanges

## 15.1. INTRODUCTION

Chapter 15 presents Crash Modification Factors (CMFs) for design, traffic control, and operational elements at interchanges and interchange ramp terminals. Roadway, roadside, and human factors elements related to pedestrian and bicycle crashes are also discussed. The information is used to identify effects on expected average crash frequency resulting from treatments applied at interchanges and interchange ramp terminals.

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

Chapter 15 is organized into the following sections:

- Definition, Application, and Organization of CMFs (Section 15.2);
- Definition of an Interchange and Ramp Terminal (Section 15.3);
- Crash Effects of Interchange Design Elements (Section 15.4); and
- Conclusion (Section 15.5).

Appendix 15A presents the crash effects of treatments for which CMFs are not currently known.

## 15.2. 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 CMFs of researched 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 pass the CMF screening test established for inclusion in the HSM. 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 15A.

## 15.3. DEFINITION OF AN INTERCHANGE AND RAMP TERMINAL

An interchange is defined as "a system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways or highways on different levels." Interchanges vary from single ramps connecting local streets to complex and comprehensive layouts involving two or more highways (1).

An interchange ramp terminal is defined as an at-grade intersection where a freeway interchange ramp intersects with a non-freeway cross-street.

Figure 15-1 illustrates typical interchange configurations (1).

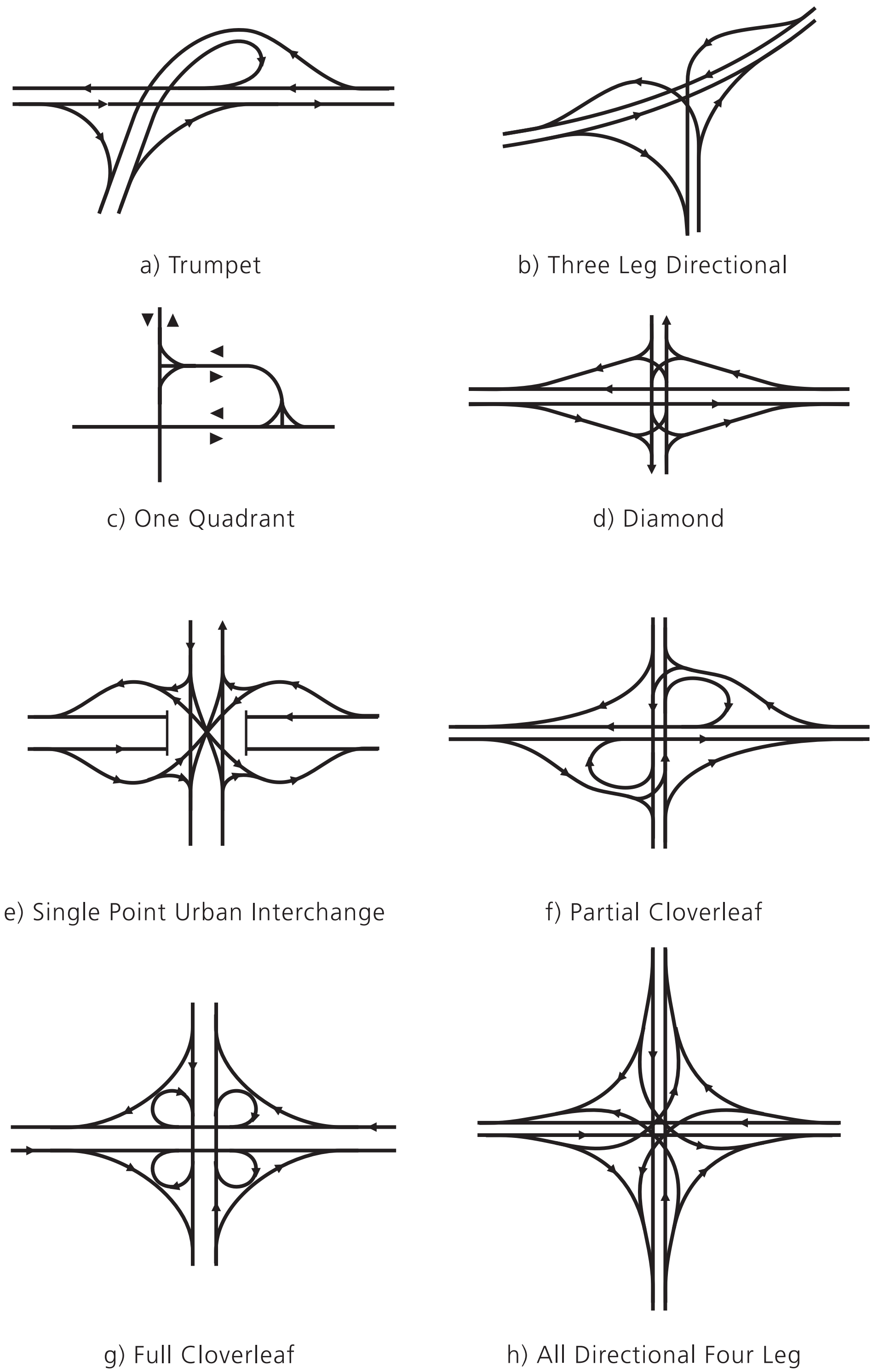


**Figure 15-1.** Interchange Configurations (1)

## 15.4. CRASH EFFECTS OF INTERCHANGE DESIGN ELEMENTS

### 15.4.1. Background and Availability of CMFs

Table 15-1 lists common treatments related to interchange design and the CMFs available in this edition of the HSM. Table 15-1 also contains the section number where each CMF can be found.

**Table 15-1.** Treatments Related to Interchange Design

| HSM Section | Treatment | Trumpet | One Quadrant | Diamond | Single Point Urban | Partial Cloverleaf | Full Cloverleaf | Directional |
|---|---|---|---|---|---|---|---|---|
| 15.4.2.1 | Convert intersection to grade-separated interchange | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 15.4.2.2 | Design interchange with crossroad above freeway | ✓ | — | ✓ | — | ✓ | ✓ | — |
| 15.4.2.3 | Modify speed change lane design | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 15.4.2.4 | Modify two-lane-change merge/diverge area to one-lane-change | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Appendix 15A.2.2.1 | Redesign interchange to modify interchange configuration | T | T | T | T | T | T | T |
| Appendix 15A.2.2.2 | Modify interchange spacing | T | T | T | T | T | T | T |
| Appendix 15A.2.2.3 | Provide right-hand exit and entrance ramps | T | T | T | T | T | T | T |
| Appendix 15A.2.2.4 | Increase horizontal curve radius of ramp roadway | T | T | T | T | T | T | T |
| Appendix 15A.2.2.5 | Increase lane width of ramp roadway | T | T | T | T | T | T | T |
| Appendix 15A.2.2.6 | Increase length of weaving areas between adjacent entrance and exit ramps | T | T | T | T | T | T | T |
| Appendix 15A.2.2.7 | Redesign interchange to provide collector-distributor roads | T | T | T | T | T | T | T |
| Appendix 15A.2.2.8 | Provide bicycle facilities at interchange ramp terminals | T | 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 15A.
— = Indicates that a CMF is not available and a crash trend is not known.

## 15.4.2. Interchange Design Element Treatments with CMFs

### 15.4.2.1. Convert Intersection to Grade-Separated Interchange

The potential crash effects of converting a three-leg or four-leg at-grade intersection into a grade-separated interchange is shown in Table 15-2 (3). The base condition for the CMFs summarized in Table 15-2 (i.e., the condition in which the CMF = 1.00) is maintaining the subject intersection at-grade.

**Table 15-2.** Potential Crash Effects of Converting an At-Grade Intersection into a Grade-Separated Interchange (3)

| Treatment | Setting (Intersection Type) | Traffic Volume | Crash Type (Severity) | CMF | Std. Error |
|---|---|---|---|---|---|
| Convert at-grade intersection into grade-separated interchange | Setting unspecified (Four-leg intersection, traffic control unspecified) | Unspecified | All crashes in the area of the intersection (All severities) | **0.58** | **0.1** |
| | | | All crashes in the area of the intersection (Injury) | **0.43** | **0.05** |
| | | | All crashes in the area of the intersection (Non-injury) | **0.64** | **0.1** |
| | Setting unspecified (Three-leg intersection, traffic control unspecified) | | All crashes in the area of the intersection (All severities) | *0.84* | *0.2* |
| | Setting unspecified (Three-leg or four-leg, signalized intersection) | | All crashes in the area of the intersection (All severities) | **0.73** | **0.08** |
| | | | All crashes in the area of the intersection (Injury) | **0.72** | **0.1** |
| Base Condition: At-grade intersection. | | | | | |

NOTE: **Bold** text is used for the more statistically 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.

### 15.4.2.2. Design Interchange with Crossroad Above Freeway

The potential crash effects of designing a diamond, trumpet, or cloverleaf interchange with the crossroad above the freeway is shown in Table 15-3 (4).

The base condition of the CMFs summarized in Table 15-3 (i.e., the condition in which the CMF = 1.00) consists of designing a diamond, trumpet, or cloverleaf interchange with the crossroad below the freeway.

**Table 15-3.** Potential Crash Effects of Designing an Interchange with Crossroad Above Freeway (4)

| Treatment | Setting (Interchange Type) | Traffic Volume | Crash Type (Severity) | CMF | Std. Error |
|---|---|---|---|---|---|
| Design diamond, trumpet, or cloverleaf interchange with crossroad above freeway | Unspecified (Unspecified) | Unspecified | All crashes in the area of the interchange (All severities) | **0.96*** | **0.1** |
| Base Condition: Design diamond, trumpet, or cloverleaf interchange with crossroad below freeway. | | | | | |

NOTE: **Bold** text is used for the more statistically 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.

### 15.4.2.3. Modify Speed Change Lane Design

A speed change lane typically connects two facilities with differing speed limits. Speed change lanes include acceleration and deceleration lanes at on-ramps and off-ramps respectively. Speed change lanes include several design elements, such as lane width, shoulder width, length, and taper design.

CMF functions for acceleration lane length are incorporated in the FHWA Interchange Safety Analysis Tool (ISAT) software as follows (2,6):

For total crashes (all severity levels combined):

$$CMF = 1.296 \times e^{(-2.59 \times L_{accel})} \quad (15\text{-}1)$$

For fatal-and-injury crashes:

$$CMF = 1.576 \times e^{(-4.55 \times L_{accel})} \quad (15\text{-}2)$$

Where:

$L_{accel}$ = length of acceleration lane (mi).

$L_{accel}$ is measured from the nose of the gore area to the end of the lane drop taper. The base condition for the CMFs in Equations 15-1 and 15-2 is a 0.1-mi- (528-ft-) long acceleration lane. The variability of these CMFs is unknown.

If an acceleration lane with an existing length other than 0.1 mi (528 ft) is lengthened, a CMF for that change in length can be computed as a ratio of two values computed with Equations 15-1 and 15-2. For example, if an acceleration lane with a length of 0.12 mi (634 ft) were lengthened to 0.20 mi (1,056 ft), the applicable CMF for total crashes would be the ratio of the CMF determined with Equation 15-1 for the existing length of 0.20 mi (1,056 ft) to the CMF determined with Equation 15-1 for the proposed length of 0.12 mi (634 ft), this calculation is illustrated in Equation 15-3.

$$CMF = \frac{1.576 \times e^{(-4.55 \times 0.12)}}{1.576 \times e^{(-4.55 \times 0.20)}} = 0.69 \quad (15\text{-}3)$$

The crash effects and standard error associated with increasing the length of a deceleration lane that is currently 690 ft or less in length by about 100 ft is shown in Table 15-4 (4).

The base condition of the CMFs in Table 15-4 (i.e., the condition in which the CMF = 1.00) is maintaining the existing deceleration lane length of less than 690 ft. The CMF in Table 15-4 may be extrapolated in proportion to the change in lane length for increases in length of less than or more than 100 ft as long as the resulting deceleration lane length does not exceed 790 ft.

**Table 15-4.** Potential Crash Effects of Extending Deceleration Lanes (4)

| Treatment | Setting (Interchange Type) | Traffic Volume | Crash Type (Severity) | CMF | Std. Error |
|---|---|---|---|---|---|
| Extend deceleration lane by approx. 100 ft | Unspecified (Unspecified) | Unspecified | All types (All severities) | **0.93*** | **0.06** |
| Base Condition: Maintain existing deceleration lane that is less than 690 ft in length. | | | | | |

NOTE: **Bold** text is used for the more statistically 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.

No quantitative information about the crash effect of increasing the length of existing deceleration lanes that are already greater than 690-ft in length was found for this edition of the HSM.

The box illustrates how to apply the information in Table 15-4 to calculate the crash effects of extending deceleration lanes.

## Effectiveness of Extending Deceleration Lanes

**Question:**
An urban grade-separated interchange has an off-ramp with a 650-ft-long deceleration lane. The governing jurisdiction is considering lengthening the ramp by 100 ft as part of a roadway rehabilitation project. What is the likely change in average crash frequency?

**Given Information:**
- Existing 650-ft-long deceleration lane
- Average crash frequency without treatments on the ramp = 15 crashes/year

**Find:**
- Crash frequency with the longer deceleration lane
- Change in crash frequency

**Answer:**
1) Identify the applicable CMFs

   $CMF_{deceleration}$ = 0.93 (Table 15-4)

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

   Crashes with treatment: = [0.93 ± (2 x 0.06)] x (15 crashes/year) = 12.2 or 15.8 crashes/year

   The multiplication of the standard error by 2 yields a 95 percent probability that the true value is between 12.2 and 15.8 crashes/year. See Section 3.5.3 in Chapter 3—Fundamentals for a detailed explanation of standard error application.

   This range of values (12.2 to 15.8) contains the original 15.0 crashes/year suggesting a possible increase, decrease, or no change in crashes. An asterisk next to the CMF in Table 15-4 indicates this possibility. See Part D—Introduction and Applications Guidance for additional information on the standard error and notation accompanying CMFs.

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 = 15.8 – 15.0 = 0.8 crashes/year increase**

   **High Estimate = 15.0 – 12.2 = 2.8 crashes/year reduction**

**4) Discussion: This example illustrates that lengthening the deceleration lane by 100 ft in the vicinity of the subject interchange may potentially increase, decrease, or cause no change in average crash frequency.**

### 15.4.2.4. Modify Two-Lane-Change Merge/Diverge Area into One-Lane-Change

Merge/diverge areas are defined as those portions of the freeway at an interchange where vehicles entering and exiting must change lanes to continue traveling in their chosen direction. The terms "ramp-freeway junction" or "weaving sections" may be used to describe merge/diverge areas (7). Figure 15-2 illustrates a one-lane-change and a two-lane-change merge/diverge area. The crash effects of modifying two-lane-change merge/diverge area to a one-lane-change are shown in Table 15-5 (3).

The base condition of the CMFs above (i.e., the condition in which the CMF = 1.00) consists of a merge/diverge area requiring two lane changes.

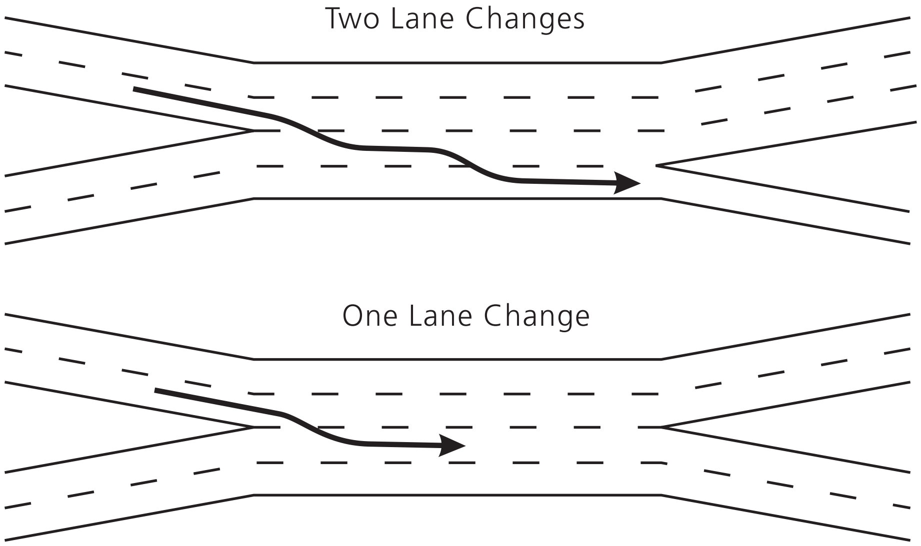


**Figure 15-2.** Two-Lane-Change and One-Lane-Change Merge/Diverge Area

**Table 15-5.** Potential Crash Effects of Modifying Two-Lane-Change Merge/Diverge Area into One-Lane-Change (3)

| Treatment | Setting (Interchange Type) | Traffic Volume | Crash Type (Severity) | CMF | Std. Error |
|---|---|---|---|---|---|
| Modify two-lane-change to one-lane-change merge/diverge area | Unspecified (Unspecified) | Unspecified | Crashes in the merging lane (All severities) | **0.68** | **0.04** |
| Base Condition: Merge/diverge area requiring two lane changes. | | | | | |

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

## 15.5. CONCLUSION

The treatments discussed in this chapter focus on the CMFs of design elements related to interchanges. The material presented consists of the CMFs known to a degree of statistical stability and reliability for inclusion in this edition of the HSM. Potential treatments for which quantitative information was not sufficient to determine a CMF or trend in crashes, in accordance with HSM criteria, are listed in Appendix 15A. 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.

## 15.6. REFERENCES


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

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# APPENDIX 15A

## 15A.1. INTRODUCTION

The material included in this appendix contains information regarding treatments for which CMFs are not available.

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:

- Interchange Design Elements (Section 15A.2); and
- Treatments with Unknown Crash Effects (Section 15A.3).

## 15A.2. INTERCHANGE DESIGN ELEMENTS

### 15A.2.1. General Information

The material provided below provides an overview of considerations related to bicyclists and pedestrians at interchanges and freeways.

#### 15A.2.1.1. Bicyclist Considerations

Some agencies permit bicyclist travel on freeway shoulders, toll bridges, and tunnels in the absence of a suitable alternative route (5). Agencies may require bicyclists who use high-speed roadways to wear a helmet and to have a driver's license (5). In addition, drain inlets can be modified to bicycle-friendly designs that reduce challenges for bicyclists. At locations not intended for bicycles, agencies may choose to install prohibitory signs and alternative route information (5).

**15A.2.1.2. Pedestrian Considerations**

Most agencies do not permit pedestrians on freeways. Pedestrians using the cross-street at interchanges may, however, cross the ramp or the interchange ramp terminal. Grade-separated crossings may be an option (12). Providing these crossings depends on the benefits, costs, and likelihood of pedestrian use. At locations not intended for pedestrian use, agencies may choose to install prohibitory signs and alternative route information (5).

## 15A.2.2. Trends in Crashes or User Behavior for Treatments without CMFs

**15A.2.2.1. Redesign Interchange to Modify Interchange Configuration**

The designers of new freeway systems have an opportunity to choose the most appropriate configuration for each interchange. The configuration of an interchange may also be changed as part of a freeway reconstruction project. Examples of typical interchange configurations are shown in Figure 15-1. Guidance on the selection of interchange configurations can be found in the AASHTO *Policy on Geometric Design of Highways and Streets* (1) and the ITE *Freeway and Interchange Geometric Design Handbook* (8). Both new construction and reconstruction of interchanges represent major highway agency investment decisions that must consider many factors, including safety, traffic operations, air quality, noise, effects on existing development, cost, and more.

Further information on the differences between specific intersection types can be found in the work of Elvik and Vaa (4) and Elvik and Erke (3). FHWA has developed Interchange Safety Analysis Tool (ISAT) software for assessing the crash effect of changing interchange configurations (10). ISAT was assembled from existing models developed in previous research and should be considered as a preliminary tool until more comprehensive analysis tools can be developed.

**15A.2.2.2. Modify Interchange Spacing**

Interchange spacing refers to the distance from one interchange influence area to the next.

Decreasing interchange spacing appears to increase crashes (11). However, the magnitude of the crash effect is not certain at this time.

**15A.2.2.3. Provide Right-Hand Exit and Entrance Ramps**

The configuration of ramps and the consistency of design along a corridor (e.g., all exit ramps are found on the right side) have key safety implications when considering driver expectations (2). Drivers expect exit and entrance ramps on freeways to be on the right hand side of the freeway (6). Providing left-hand exit or entrance ramps contradicts driver expectations. In general, ramp design is directly related to the type of interchange.

**15A.2.2.4. Increase Horizontal Curve Radius of Ramp Roadway**

Many ramps at freeway interchanges incorporate horizontal curves. Increasing a ramp roadway's curve radius from that which is currently less then 650 ft appears to decrease all crashes on the ramp roadway. However, the magnitude of the crash effect is not certain at this time (3).

**15A.2.2.5. Increase Lane Width of Ramp Roadway**

The roadway and lane widths for ramps at freeway interchanges are generally greater than for conventional roads and streets.

Increasing lane width on off-ramps appears to decrease crashes (2). However, the magnitude of the crash effect is not certain at this time.

**15A.2.2.6. Increase Length of Weaving Areas between Adjacent Entrance and Exit Ramps**

A weaving area between adjacent entrance and exit ramps is essentially a combined acceleration and deceleration area, usually with a combined acceleration and deceleration lanes running from one ramp to the next. Such weaving areas are inherent in the design of full cloverleaf interchanges but can occur in or between other interchange types. Short weaving areas between adjacent entrance and exit ramps have been found to be associated with increased crash frequencies. Research indicates that providing longer weaving areas will reduce crashes (1). However, the available research is not sufficient to develop a quantitative CMF.

**15A.2.2.7. Redesign Interchange to Provide Collector-Distributor Roads**
Crashes associated with weaving areas within an interchange or between adjacent interchanges can be reduced by redesigning the interchange(s) to provide collector-distributor roads. This design moves weaving from the mainline freeway to an auxiliary roadway, typically reducing both the volumes and the traffic speeds in the weaving area. The addition of collector-distributor roads has been shown to reduce crashes (7,9). However, the available research is not sufficient to develop a quantitative CMF.

**15A.2.2.8. Provide Bicycle Facilities at Interchange Ramp Terminals**
Continuity of bicyclist facilities can be provided at interchange ramp terminals. Bicyclists are considered vulnerable road users as they are more susceptible to injury when involved in a traffic crash than vehicle occupants. Vehicle occupants are usually protected by the vehicle.

Bicyclists must sometimes cross interchange ramps at uncontrolled locations. Encouraging bicyclists to cross interchange ramps at right angles appears to increase driver sight distance and reduce the bicyclists' risk of a crash (5).

## 15A.3. TREATMENTS WITH UNKNOWN CRASH EFFECTS

### 15A.3.1. Treatments Related to Interchange Design

**Merge/Diverge Areas**
- Modify merge/diverge design (e.g., parallel versus taper, left-hand versus right-hand)
- Modify roadside design or elements at merge/diverge areas
- Modify horizontal and vertical alignment of the merge or diverge area
- Modify gore area design

**Ramp Roadways**
- Increase shoulder width of ramp roadway
- Modify shoulder type of ramp roadway
- Provide additional lanes on the ramp
- Modify roadside design or elements on ramp roadways
- Modify vertical alignment of the ramp roadway
- Modify superelevation of ramp roadway
- Provide two-way ramps
- Provide directional ramps
- Modify ramp design speed
- Provide high-occupancy vehicle lanes on ramp roadways
- Modify ramp type or configuration

**Ramp Terminals**
- Modify ramp terminal intersection type
- Modify ramp terminal approach cross-section

- Modify ramp terminal roadside elements
- Modify ramp terminal alignment elements
- Provide direct connection or access to commercial or private sites from ramp terminal
- Provide physically channelized right-turn lanes

**Bicyclists and Pedestrians**

- Provide pedestrian and/or bicyclist traffic control devices at ramp terminals
- Provide refuge islands
- Provide pedestrian facilities on ramp terminals
- Develop policies related to pedestrian and bicyclist activity at interchanges

### 15A.3.2. Treatments Related to Interchange Traffic Control and Operational Elements

**Traffic Control at Ramp Terminals**

- Provide traffic signals at ramp terminal intersection
- Provide stop-control or yield-control signs at ramp terminal intersections

## 15A.4. APPENDIX REFERENCES

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