PART D— ACCIDENT MODIFICATION FACTORS

CHAPTER 15— INTERCHANGES

EXHIBITS

APPENDIX A

CHAPTER 15 INTERCHANGES

15.1. INTRODUCTION

Chapter 15 presents Accident Modification Factors (AMFs) 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.

Chapter 15 presents design, traffic control and operational elements at interchanges and ramps with AMFs.

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 AMFs (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 A presents the crash effects of treatments for which AMFs are not currently known.

15.2. DEFINITION, APPLICATION, AND ORGANIZATION OF AMFS

Chapter 3 provides a thorough definition and explanation of AMFs.

AMFs quantify the change in expected average crash frequency (crash effect) at a site caused by implementing a particular treatment (also known as a countermeasure, intervention, action, or alternative), design modification, or change in operations. AMFs are used to estimate the potential change in expected crash frequency or crash severity plus or minus a standard error due to implementing a particular action. The application of AMFs involves evaluating the expected average crash frequency with or without a particular treatment, or estimating it with one treatment versus a different treatment.

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

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

The treatments are organized into 3 categories: treatments with AMFs; treatments with trend information; and, no trend or AMF information.

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

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

Treatments for which AMFs are not presented (Categories 2 and 3 above) indicate that quantitative information currently available did not pass the AMF screening test established for inclusion in the HSM. The absence of an AMF indicates additional research is needed to reach a level of statistical reliability and stability to meet the criteria set forth within the HSM. Treatments for which AMFs are not presented are discussed in Appendix A.

15.3. DEFINITION OF AN INTERCHANGE AND RAMP TERMINAL

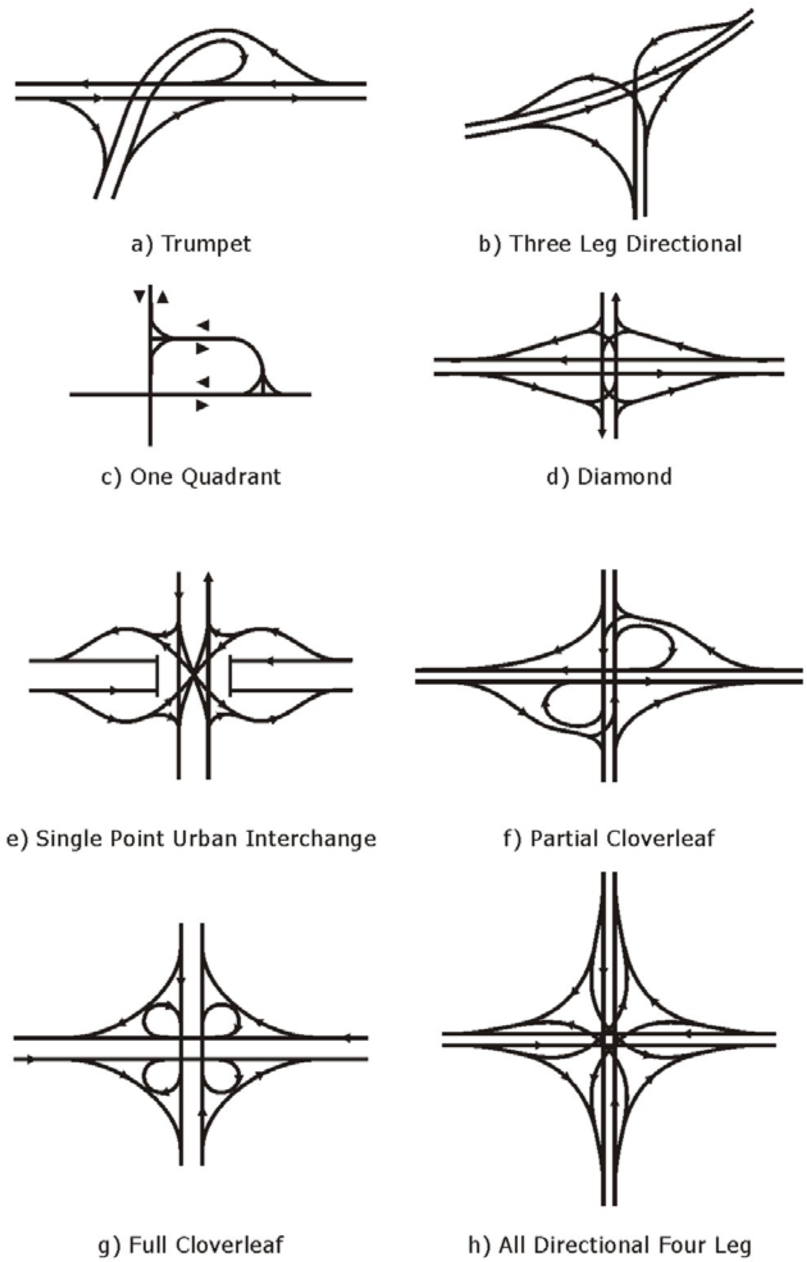
Section 15.3 provides a definition of facilities under consideration in this chapter.

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.

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

Exhibit 15-1: Interchange Configurations(1)



15.4. CRASH EFFECTS OF INTERCHANGE DESIGN ELEMENTS

15.4.1. Background and Availability of AMFs

Exhibit 15-2 lists common treatments related to interchange design and the AMFs available in this edition of the HSM. Exhibit 15-2 also contains the section number where each AMF can be found.

Exhibit 15-2: 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 A	Redesign interchange to modify interchange configuration	T	T	T	T	T	T	T
Appendix A	Modify interchange spacing	T	T	T	T	T	T	T
Appendix A	Modify ramp type or configuration	T	T	T	T	T	T	T
Appendix A	Provide right-hand exit and entrance ramps	T	T	T	T	T	T	T
Appendix A	Increase horizontal curve radius of ramp roadway	T	T	T	T	T	T	T
Appendix A	Increase lane width of ramp roadway	T	T	T	T	T	T	T
Appendix A	Increase length of weaving areas between adjacent entrance and exit ramps	T	T	T	T	T	T	T
Appendix A	Redesign interchange to provide collector-distributor roads	T	T	T	T	T	T	T
Appendix A	Provide bicycle facilities at interchange ramp terminals	T	T	T	T	T	T	T
Appendix A	Provide pedestrian facilities on ramp terminals	T	T	T	T	T	T	T

NOTE: ✓ = Indicates that an AMF is available for this treatment.

T = Indicates that an AMF is not available but a trend regarding the potential change in crashes or user behavior is known and presented in Appendix A.

\- = Indicates that an AMF is not available and a crash trend is not known.

15.4.2. Interchange Design Element Treatments with AMFs

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 to a grade-separated interchange is shown in Exhibit 15-3.[3] The base condition for the AMFs summarized in Exhibit 15-3 (i.e. the condition in which the AMF = 1.00) is maintaining the subject intersection at-grade.

Exhibit 15-3: Potential Crash Effects of Converting an At-Grade Intersection To a Grade-Separated Interchange[3]

Treatment	Setting (Intersection type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Convert at-grade intersection to grade-separated interchange	Setting unspecified (Four-leg intersection, traffic control unspecified)	Unspecified	All accidents in the area of the intersection (All severities)	**0.58**	**0.1**
			All accidents in the area of the intersection (Injury)	**0.43**	**0.05**
			All accidents in the area of the intersection (Non-injury)	**0.64**	**0.1**
	Setting unspecified (Three-leg intersection, traffic control unspecified)		All accidents in the area of the intersection (All severities)	*0.84*	*0.2*
	Setting unspecified (Three-leg or Four-leg, signalized intersection)		All accidents in the area of the intersection (All severities)	**0.73**	**0.08**
			All accidents 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 AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.

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 Exhibit 15-4.[4]

The base condition of the AMFs summarized in Exhibit 15-4 (i.e. the condition in which the AMF = 1.00) consists of designing a diamond, trumpet, or cloverleaf interchange with the crossroad below the freeway.

Exhibit 15-4: Potential Crash Effects of Designing an Interchange with Crossroad Above Freeway[4]

Treatment	Setting (Interchange type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Design diamond, trumpet or cloverleaf interchange with crossroad above freeway	Unspecified (Unspecified)	Unspecified	All accidents 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 AMFs. These AMFs have a standard error of 0.1 or less.

* Observed variability suggests that this treatment could result in fewer crashes, more crashes, or the same frequency of 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.

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

For total accidents (all severity levels combined):

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

For fatal-and-injury accidents:

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

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 AMFs in Equations 15-1 and 15-2 is an acceleration lane length of 0.1 mi (528 ft). The variability of these AMFs is unknown.

If an acceleration lane with an existing length other than 0.1 mi (528 ft) is lengthened, an AMF 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 AMF for total accidents would be the ratio of the AMF determined with Equation 15-1 for the existing length of 0.20 mi (1,056 ft) to the AMF determined with Equation 15-1 for the proposed length of 0.12 mi (634 ft), this calculation is illustrated in Equation 15-3.

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

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 Exhibit 15-5.[(4)]

The base condition of the AMFs in Exhibit 15-5 (i.e. the condition in which the AMF = 1.00) is maintaining the existing deceleration lane length of less than 690-ft. The AMF in Exhibit 15-5 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.

Exhibit 15-5: Potential Crash Effects of Extending Deceleration Lanes[(4)]

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

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

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

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 gray box below illustrates how to apply the information in Exhibit 15-5 to calculate the crash effects of extending speed change lanes.

Effectiveness of Extending Speed Change Lanes

Question:

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

Given Information:

- Existing 650-foot long deceleration lane
- Expected average crash frequency without treatments on the ramp (See Part C Predictive Method) = 15 crashes/year

Find:

- Crash frequency with the longer deceleration lane
- Change in crash frequency

Answer:

1) Identify the applicable AMFs

   $AMF_{deceleration}$ = 0.93 (Exhibit 15-5)

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

   Expected 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% 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 AMF in Exhibit 15-5 indicates this possibility. See the *Part D Introduction and Applications Guidance* for additional information on the standard error and notation accompanying AMFs.

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

   Change in expected average crash frequency:

   Low Estimate = 15.8 – 15.0 = 0.8 crashes/year increment

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

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

15.4.2.4. Modify Two-Lane-Change Merge/Diverge Area to 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) Exhibit 15-6 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 Exhibit 15-7.(3)

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

Exhibit 15-6: Two-Lane-Change and One-Lane-Change Merge/Diverge Area

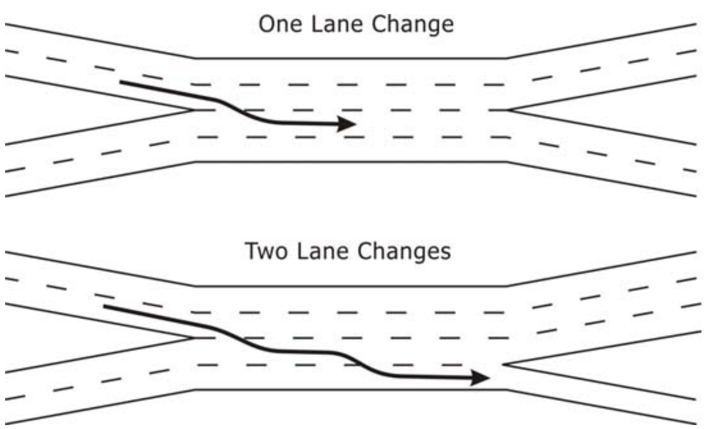


Exhibit 15-7: Potential Crash Effects of Modifying Two-Lane-Change Merge/Diverge Area to One-Lane-Change (3)

Treatment	Setting (Interchange type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Modify two-lane to one-lane merge/diverge area	Unspecified (Unspecified)	Unspecified	Accidents 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 AMFs. These AMFs have a standard error of 0.1 or less.

15.5. CONCLUSIONS

The treatments discussed in this chapter focus on the AMFs of design elements related to interchanges. The material presented consists of the AMFs 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 an AMF or trend in crashes, in accordance with HSM criteria, are listed in Appendix A. The material in this chapter can be used in conjunction with activities in *Chapter 6 Select Countermeasures*, and *Chapter 7 Economic Appraisal*. Some *Part D* AMFs are included in *Part C* for use in the predictive method. Other *Part D* AMFs are not presented in *Part C* but can be used in the methods to estimate change in crash frequency described in Section C.7 of the *Part C Introduction and Applications Guidance*.

Appendix A presents the treatments that have an identified trend or no known quantitative information.

15.6. 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.
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5. Garber, N. J. and M. D. Fontaine. *Guidelines for Preliminary Selection of the Optimum Interchange Type for a Specific Location.* VTRC 99-R15, Virginia Transportation Research Council, Charlottesville, 1999.
6. Torbic, D.J., D.W. Harwood, D.K. Gilmore, and K.R. Richard. *Interchange Safety Analysis Tool: User Manual*. Report No. FHWA-HRT-07-045, Federal Highway Administration, U.S. Department of Transportation, 2007.
7. TRB. *Highway Capacity Manual 2000.* TRB, National Research Council, Washington, DC, 2000.

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APPENDIX A

A.1 INTRODUCTION

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

This appendix is organized into the following sections:

- Interchange Design Elements (Section A.2)
- **Error! Reference source not found.** (Section **Error! Reference source not found.**)
- Treatments with Unknown Crash Effects (Section A.3)

A.2 INTERCHANGE DESIGN ELEMENTS

A.2.1 General Information

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

Bicyclist Considerations

Some agencies permit bicyclist travel on freeway shoulders, toll bridges and tunnels in the absence of a suitable alternate route.(5) Agencies may require cyclists 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 cyclists. At locations not intended for bicycles, agencies may choose to install prohibitory signs and alternate route information. (5)

Pedestrian Considerations

Most agencies do not permit pedestrian travel 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 alternate route information. (5)

A.2.2 Trends in Crashes or User Behavior for Treatments without AMFs

A.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 Exhibit 15-1. Guidance on the selection of interchange configurations can be found in the AASHTO Policy on Geometric Design of Highways and Streets(2) 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 a variety of other factors.

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 an Interchange Safety Analysis Tool (ISAT) 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.

A.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 accidents.(11) However, the magnitude of the crash effect is not certain at this time.

A.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 in the right side) have key safety implications when considering driver expectation.(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.

A.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 accidents on the ramp roadway. However, the magnitude of the crash effect is not certain at this time.(3)

A.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 accidents.(2) However, the magnitude of the crash effect is not certain at this time.

A.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 accident frequencies. Research indicates that providing longer weaving areas will reduce accidents.(1) However, the available research is not sufficient to develop a quantitative AMF.

A.2.2.7 Redesign Interchange to Provide Collector-Distributor Roads

Accidents 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 accidents.(7,9) However, the available research is not sufficient to develop a quantitative AMF.

A.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)

A.3 TREATMENTS WITH UNKNOWN CRASH EFFECTS

A.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; and,
- 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; and,
- Provide high occupancy vehicle lanes on ramp roadways.

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; and,
- Provide physically channelized right-turn lanes.

Bicyclists and Pedestrian

- Provide pedestrian and/or cyclist traffic control devices at ramp terminals;
- Provide refuge islands; and,
- Develop policies related to pedestrian and bicyclist activity at interchanges.

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

Traffic Control at Ramp Terminals

- Provide traffic signals at ramp terminal intersection; and,
- Provide stop-control or yield-control signs at ramp terminal intersections.

A.4 APPENDIX REFERENCES

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