Chapter 14—Intersections

14.1. INTRODUCTION

Chapter 14 presents the Crash Modification Factors (CMFs) applicable to intersection types, access management characteristics near intersections, intersection design elements, and intersection traffic control and operational elements. Pedestrian- and bicyclist-related treatments and the corresponding effects on pedestrian and bicyclist crash frequency are integrated into the topic areas noted above. The information presented in this chapter is used to identify effects on expected average crash frequency resulting from treatments applied at intersections.

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

Chapter 14 is organized into the following sections:

- Definition, Application, and Organization of CMFs (Section 14.2);
- Definition of an Intersection (Section 14.3);
- Crash Effects of Intersection Types (Section 14.4);
- Crash Effects of Access Management (Section 14.5);
- Crash Effects of Intersection Design Elements (Section 14.6);
- Crash Effects of Intersection Traffic Control and Operational Elements (Section 14.7); and
- Conclusion (Section 14.8).

Appendix 14A 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 known.

14.2. 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. Section 3.5.3 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.

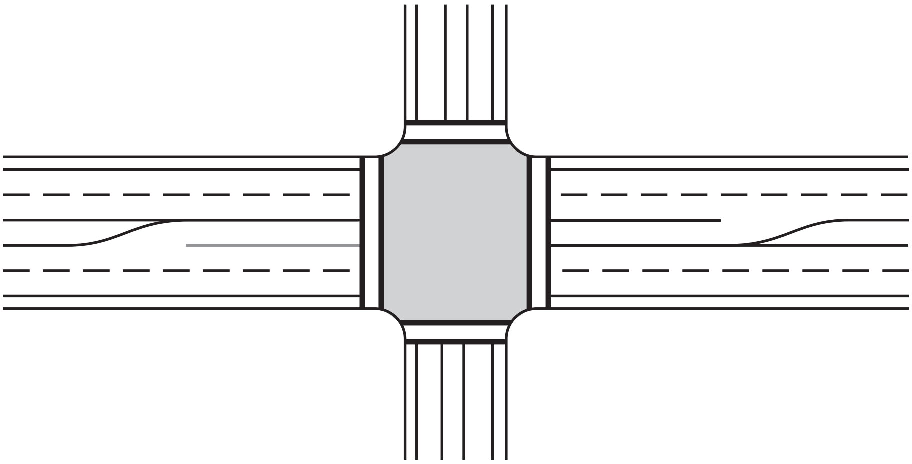
Treatments for which CMFs are not presented (Categories 2 and 3 above) indicate that quantitative information currently available did not meet the criteria for inclusion in the HSM. The absence of a CMF indicates additional research is needed to reach a level of statistical reliability and stability to meet the criteria set forth within the HSM. Treatments for which CMFs are not presented are discussed in Appendix 14A.

14.3. DEFINITION OF AN INTERSECTION

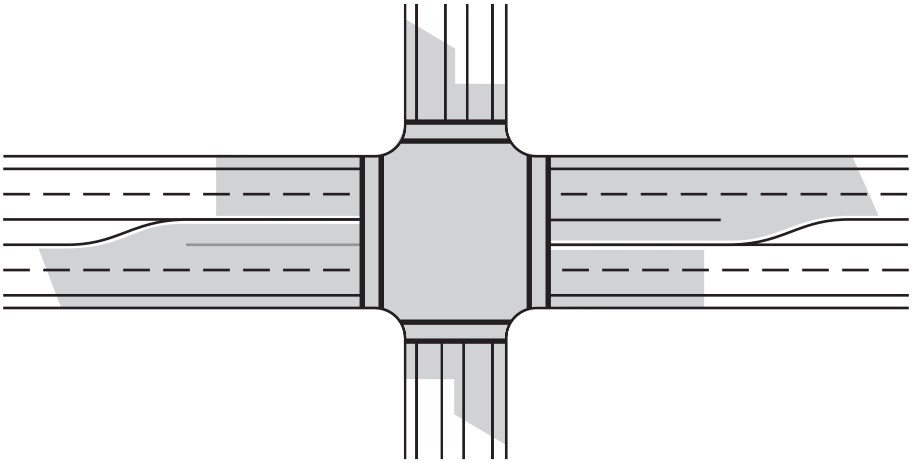
An intersection is defined as "the general area where two or more roadways join or cross, including the roadway and roadside facilities for traffic movements within the area" (1). This chapter deals with at-grade intersections, including signalized, stop-controlled, and roundabout intersections.

An at-grade intersection is defined "by both its physical and functional areas", as illustrated in Figure 14-1 (1). The functional area "extends both upstream and downstream from the physical intersection area and includes any auxiliary lanes and their associated channelization" (1). As illustrated in Figure 14-2, the functional area on each approach to an intersection consists of three basic elements (1):

- Decision distance;
- Maneuver distance; and
- Queue-storage distance.



Intersection Physical Area



Intersection Functional Area

Figure 14-1. Intersection Physical and Functional Areas (1)

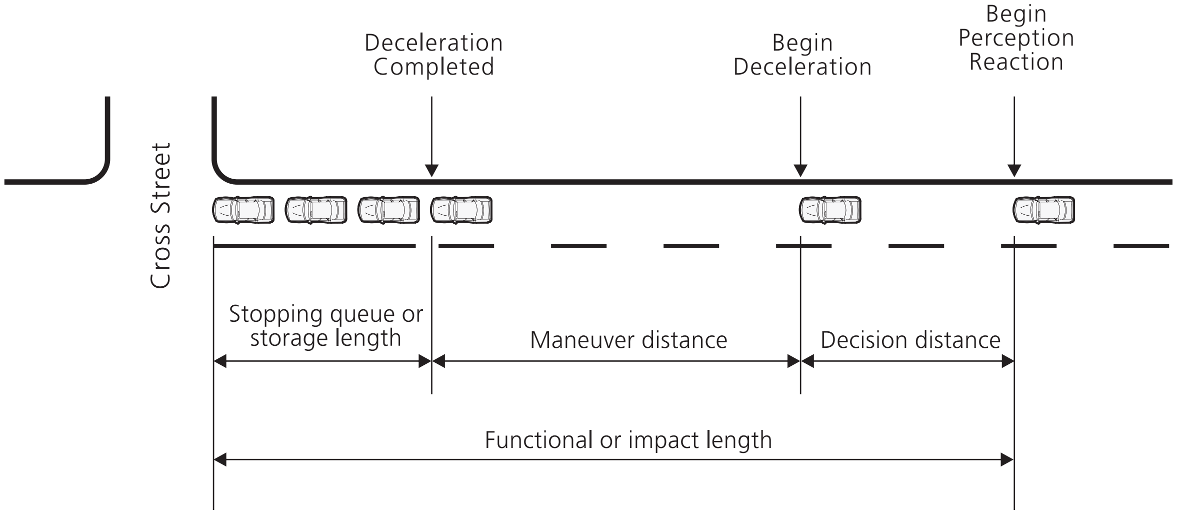


Figure 14-2. Elements of the Functional Area of an Intersection (1)

The definition of an intersection crash tends to vary between agencies (5). Some agencies define an intersection crash as one which occurs within the intersection crosswalk limits or physical intersection area. Other agencies consider all crashes within a specified distance, such as 250 ft, from the center of an intersection to be intersection crashes (5). However, not all crashes occurring within 250 ft of an intersection can be considered intersection crashes because some of these may have occurred regardless of the existence of an intersection. Consideration should be given to these differences in definitions when evaluating conditions and seeking solutions.

14.4. CRASH EFFECTS OF INTERSECTION TYPES

14.4.1. Background and Availability of CMFs

The following section provides information on the CMFs for different intersection types (e.g., stop-controlled, signalized, and roundabout). The different intersection types are defined by their basic geometric characteristics and the governing traffic control device at the intersection. Types of traffic control for at-grade intersections include traffic control signals, stop control, and yield control.

The CMFs are summarized in Table 14-1. This exhibit also contains the section number where each CMF can be found.

Table 14-1. Treatments Related to Intersection Types

		Urban				Suburban				Rural			
		Stop		Signal		Stop		Signal		Stop		Signal	
HSM Section	Treatment	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg
14.4.2.1	Convert four-leg intersection to two three-leg intersections	✓	—	—	—	—	—	—	—	—	—	—	—
14.4.2.2	Convert signalized intersection to a modern roundabout	N/A	N/A	✓	✓	N/A	N/A	✓	✓	N/A	N/A	✓	✓
14.4.2.3	Convert stop-controlled intersection to a modern roundabout	✓	✓	N/A	N/A	✓	✓	N/A	N/A	✓	✓	N/A	N/A
14.4.2.4	Convert minor-road stop control to all-way stop control	✓	—	—	—	—	—	—	—	✓	—	—	—
14.4.2.5	Remove unwarranted signal on one-way streets (i.e., convert from signal to stop control on one-way street)	—	—	✓	✓	—	—	—	—	—	—	—	—
14.4.2.6	Convert stop control to signal control	✓	T	N/A	N/A	—	—	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 14A.
— = 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.

14.4.2. Intersection Type Treatments with Crash Modification Factors

14.4.2.1. Convert Four-Leg Intersection to Two Three-Leg Intersections

At specific sites where the opportunity exists, four-leg intersections with minor-road stop control can be converted into a pair of three-leg intersections (4). These “offset” or “staggered” intersections can be constructed in one of two ways: right-left (R-L) staggering or left-right (L-R) staggering as shown in Figure 14-3.

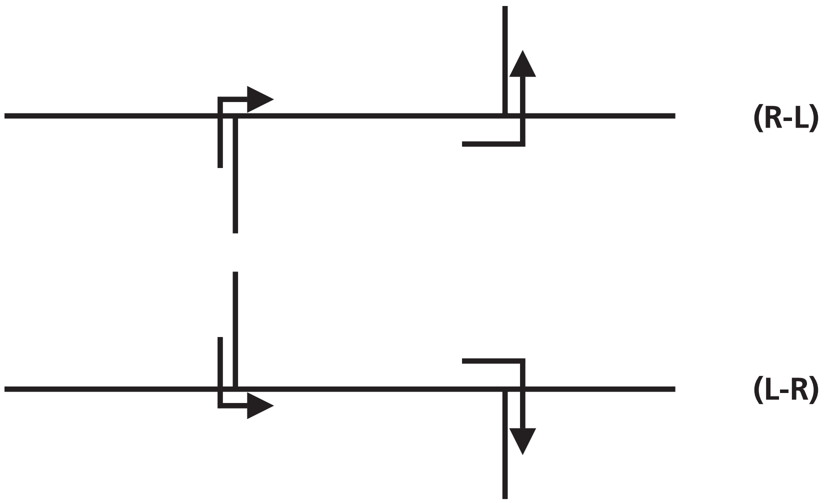


Figure 14-3. Two Ways of Converting a Four-Leg Intersection into Two Three-Leg Intersections

The effect on crash frequency of converting an urban four-leg intersection with minor-road stop control into a pair of three-leg intersections with minor-road stop control is dependent on the proportion of minor-road traffic at the intersection prior to conversion (9). However, no conclusive results about the difference in crash effect between right-left or left-right staging of the two resulting three-leg intersections were found for this edition of the HSM.

Urban minor-road stop-controlled intersections

Table 14-2 summarizes the CMFs known for converting an urban intersection from a four-leg intersection with minor-road stop control into a pair of three-leg intersections with minor-road stop control. The crash effects are organized based on the proportion of the minor-road traffic compared to the total entering volume as follows:

- Minor-road traffic > 30% of Total Entering Traffic
- Minor-road traffic = 15% to 30% of Total Entering Traffic
- Minor-road traffic < 15% of Total Entering Traffic

The study from which this information was obtained did not indicate a distance or range of distances between the two three-leg intersections nor did it indicate whether or not the effect on crash frequency changed based on the distance between the two three-leg intersections.

The base condition for the CMFs summarized in Table 14-2 (i.e., the condition in which the CMF = 1.00) is an urban four-leg, two-way-stop-controlled intersection.

Table 14-2. Potential Crash Effects of Converting a Four-Leg Intersection into Two Three-Leg Intersections (9)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Convert four-leg intersection into two three-leg intersections	Urban (Four-leg)	Minor-road traffic >30% of total entering	All types (Injury)	**0.67**	**0.1**
			All types (Non-injury)	**0.90***	**0.09**
		Minor-road traffic = 15–30% of total entering	All types (Injury)	**0.75**	**0.08**
			All types (Non-injury)	**1.00***	**0.09**
		Minor-road traffic <15% of total entering	All types (Injury)	*1.35*	*0.3*
			All types (Non-injury)	**1.15**	**0.1**

Base Condition: Urban four-leg intersection with minor-road stop control.

NOTE: Based on U.S. studies: Hanna, Flynn and Tyler 1976; Montgomery and Carstens 1987; and international studies: Lyager and Loschenkohl 1972; Johannessen and heir 1974; Vaa and Johannessen 1978; Brude and larsson 1978; Cedersund 1983; Vodahl and Giaever 1986; Brude and Larsson 1987.
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.

The box illustrates how to apply the information in Table 14-2 to calculate the crash frequency effects of converting a four-leg intersection to two three-leg intersections.

Effectiveness of Converting a Four-Leg Intersection into Two Three-Leg Intersections

Question:
A minor street crosses a major urban arterial forming a four-leg intersection. The minor street approaches are stop-controlled and account for approximately 10 percent of the total intersection entering traffic volume. A development project has requested that one approach of the minor street be vacated and replaced with a parallel connection at another location. The governing agency is investigating the effect of the replacement of the four-way intersection with two new three-way intersections. What will be the likely change in expected average crash frequency?

Given Information:
- Existing two-way, stop-controlled intersection at a major urban road and a minor street
- Existing minor street intersection entering volume is approximately 10 percent of total intersection entering volume
- Expected average crash frequency without treatment (assumed value) = 7 crashes/year

Find:
- Expected average crash frequency with two three-way, stop-controlled intersections
- Change in expected average crash frequency

Answer:

1) Identify the Applicable CMF

CMF = 1.15 (Table 14-2)

2) Calculate the 95th Percentile Confidence Interval Estimation of Crashes with the Treatment

Expected crashes with treatment: = [1.15 ± (2 x 0.10)] x (7 crashes/year) = 6.7 or 9.5 crashes/year

The multiplication of the standard error by 2 yields a 95 percent probability that the true value is between 6.7 and 9.5 crashes/year. See Section 3.5.3 for a detailed explanation.

3) 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:

High Estimate = 7 – 6.7 = 0.3 crashes/year decrease

Low Estimate = 9.5 – 7 = 2.5 crashes/year increment

4) Discussion: This example shows that it is more probable that the treatment will result in an increase in crashes, however, a slight crash decrease may also occur.

14.4.2.2. Convert Signalized Intersection to a Modern Roundabout

Roundabouts reduce traffic speeds as a result of their small diameters, deflection angle on entry, and circular configuration. Roundabouts also change conflict points from crossing conflicts to merging conflicts. Their circular configuration requires vehicles to circulate in a counterclockwise direction. The reduced speeds and conflict points contribute to the crash reductions experienced compared to signalized intersections.

The reduced vehicle speeds and motor vehicle conflicts are the reason roundabouts are also considered a traffic calming treatment for locations experiencing characteristics such as higher than desired speeds and/or cut through traffic.

Figure 14-4 is a schematic figure of a modern roundabout with the key features labeled.

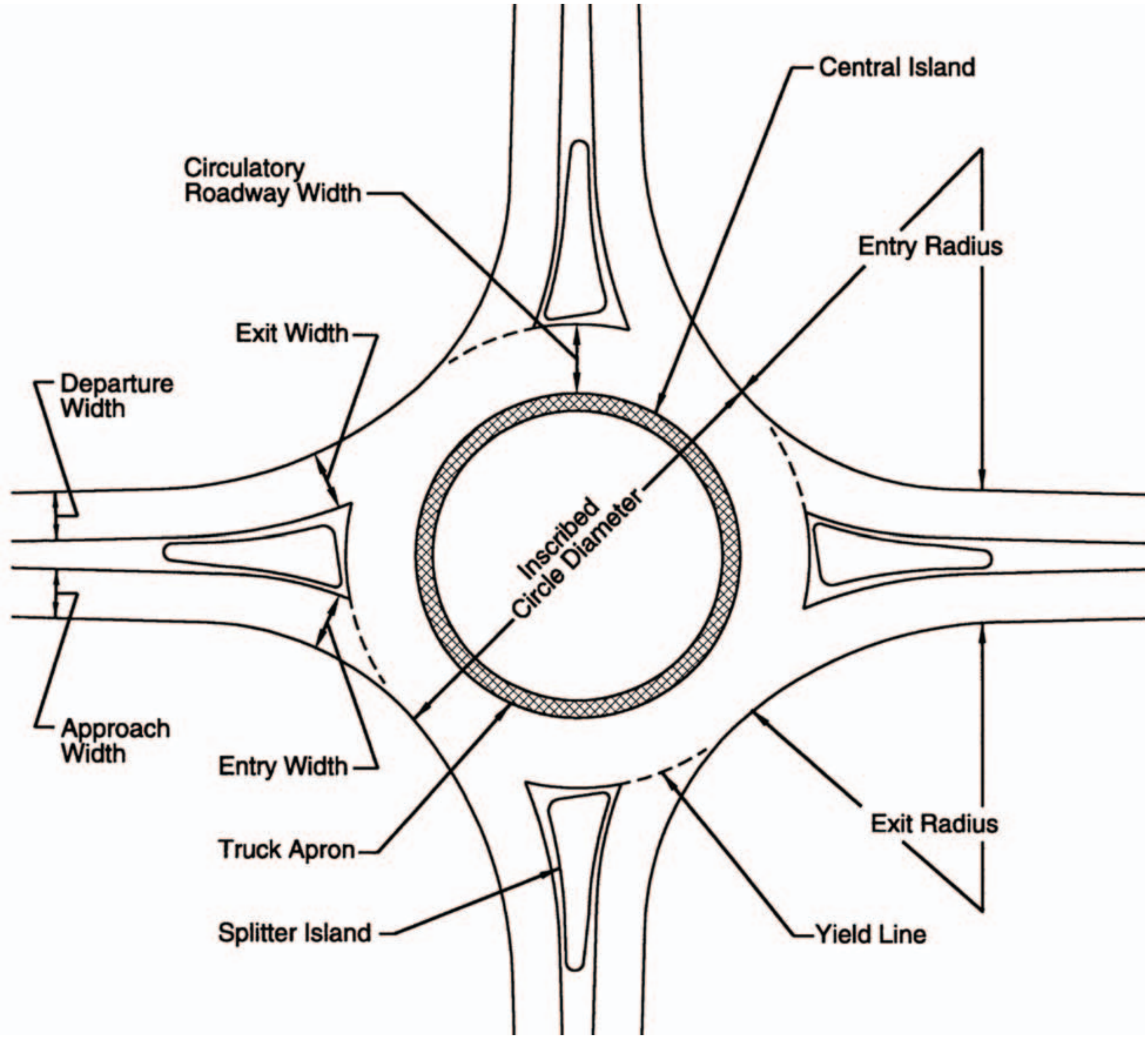


Figure 14-4. Modern Roundabout Elements (11)

Urban, suburban, and rural signalized intersections
Table 14-3 summarizes the effects on crash frequency related to:

- Converting an urban signalized intersection to a single lane or multilane modern roundabout; and
- Converting a signalized intersection in any setting (urban, rural, or suburban) into a single lane or multilane modern roundabout.

The predictive method for urban and suburban arterials in Chapter 12 includes a procedure for roundabouts at intersections that were previously signalized that is based on the CMF in Table 14-3 for installing modern roundabouts in all settings. The base condition for the CMFs summarized in Table 14-3 is a signalized intersection.

Table 14-3. Potential Crash Effects of Converting a Signalized Intersection into a Modern Roundabout (29)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Convert signalized intersection to modern roundabout	Urban (One or two lanes)	Unspecified	All types (All severities)	**0.99***	**0.1**
			All types (Injury)	**0.40**	**0.1**
	Suburban (Two lanes)		All types (All severities)	**0.33**	**0.05**
	All settings (One or two lanes)		All types (All severities)	**0.52**	**0.06**
			All types (Injury)	**0.22**	**0.07**
Base Condition: Signalized intersection.					

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.
The study from which this information was obtained does not contain information related to the posted or observed speeds at or on approach to the intersections that were converted to a modern roundabout.

If the setting is known, it is recommended that the corresponding urban/suburban CMF be used rather than the CMF for “All settings.”

Information regarding pedestrians and bicyclists at modern roundabouts is contained in Appendix 14A.

14.4.2.3. Convert a Stop-Controlled Intersection to a Modern Roundabout

Urban, suburban, and rural stop-controlled intersections

Table 14-4 summarizes the crash effects related to:

- Converting an intersection with minor-road stop control into a modern roundabout;
- Converting a rural intersection with minor-road stop control into a one-lane modern roundabout;
- Converting an urban intersection with minor-road stop control into a one-lane modern roundabout;
- Converting an urban intersection with minor-road stop control into a two-lane modern roundabout;
- Converting a suburban intersection with minor-road stop control into a one-lane or two-lane modern roundabout; and
- Converting an all-way, stop-controlled intersection in any setting into a modern roundabout.

The predictive method for urban and suburban arterials in Chapter 12 includes a procedure for roundabouts at intersections that previously had minor-road stop control. This procedure is based on the CMF for installing modern roundabouts in all settings presented in Table 14-4.

The base condition for the CMFs shown in Table 14-4 (i.e., the condition in which the CMF = 1.00) is a stop-controlled intersection.

Table 14-4. Potential Crash Effects of Converting a Stop-Controlled Intersections into a Modern Roundabout (29)

Treatment	Setting (Intersection Iype)	Traffic Volume	Crash Iype (Severity)	CMF	Std. Error
Convert intersection with minor-road stop control to modern roundabout	All settings (One or two lanes)	Unspecified	All types (All severities)	**0.56**	**0.05**
			All types (Injury)	**0.18**	**0.04**
	Rural (One lane)		All types (All severities)	**0.29**	**0.04**
			All types (Injury)	**0.13**	**0.04**
	Urban (One or two lanes)		All types (All severities)	**0.71**	**0.1**
			All types (Injury)	**0.19**	**0.1**
	Urban (One lane)		All types (All severities)	**0.61**	**0.1**
			All types (Injury)	**0.22**	**0.1**
	Urban (Two lanes)		All types (All severities)	*0.88*	*0.2*
	Suburban (One or two lanes)		All types (All severities)	**0.68**	**0.08**
			All types (Injury)	**0.29**	**0.1**
	Suburban (One lane)		All types (All severities)	**0.22**	**0.07**
			All types (Injury)	**0.22**	**0.1**
	Suburban (Two lanes)		All types (All severities)	**0.81**	**0.1**
			All types (Injury)	**0.32**	**0.1**
Convert all-way, stop-controlled intersection to roundabout	All settings (One or two lanes)		All types (All severities)	*1.03**	*0.2*
Base Condition: Stop-controlled intersection.					

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.
* 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 study from which this information was obtained does not contain information related to the posted or observed speeds at or on approach to the intersections that were converted to a modern roundabout.

Information regarding pedestrians and bicyclists at modern roundabouts is contained in Appendix 14A.

14.4.2.4. Convert Minor-Road Stop Control into All-Way Stop Control

The *Manual on Uniform Traffic Control Devices* (MUTCD) contains warrants to determine when it is appropriate to convert an intersection with minor-road stop control into an all-way stop control. The effects on crash frequency described below assume that MUTCD warrants for converting a minor-road stop-controlled intersection to an all-way stop-control intersection are met.

Urban and rural minor-road stop-controlled intersections

Table 14-5 provides specific information regarding the crash effects of converting urban intersections with minor-road stop control to all-way stop control when established MUTCD warrants are met. The effect on pedestrian crashes is also shown in Table 14-5.

The base condition for the CMFs below (i.e., the condition in which the CMF = 1.00) is an intersection with minor-road stop control that meets MUTCD warrants to become an all-way, stop-controlled intersection.

Table 14-5. Potential Crash Effects of Converting a Minor-Road Stop Control into an All-Way Stop Control (21)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Convert minor-road stop control to all-way stop control (22)	Urban (MUTCD warrants are met)	Unspecified	Right-angle (All severities)	**0.25**	**0.03**
			Rear-end (All severities)	**0.82**	**0.1**
			Pedestrian (All severities)	*0.57*	*0.2*
			All types (Injury)	**0.30**	**0.06**
Convert minor-road stop control to all-way stop control (16)	Rural (MUTCD warrants are met)		All types (All severities)	**0.52**	**0.04**
Base Condition: Intersection with minor-road stop control meeting MUTCD warrants for an all-way, stop-controlled intersection.					

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.
Conversions from two-way to all-way, stop control meet established MUTCD warrants.

14.4.2.5. Remove Unwarranted Signals on One-Way Streets

Unwarranted signals are those that do not meet the warrants outlined in the MUTCD.

Urban Signalized Intersections

Table 14-6 summarizes the specific CMFs related to removing unwarranted traffic signals. This CMF may not be applicable to major arterials and is not intended to indicate the crash effects of installing unwarranted signals.

The base condition for the CMFs summarized in Table 14-6 (i.e., the condition in which the CMF = 1.00) is an unwarranted traffic signal located on an urban one-way street.

Table 14-6. Potential Crash Effects of Removing Unwarranted Signals (24)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Remove unwarranted signal	Urban (one-lane, one-way streets, excluding major arterials)	Unspecified	All types (All severities)	**0.76**	**0.09**
			Right-angle and turning (All severities)	**0.76**	**0.1**
			Rear-end (All severities)	*0.71*	*0.2*
			Pedestrian (All severities)	*0.82*	*0.3*
Base Condition: Unwarranted traffic signal on an urban one-way street.					

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.

14.4.2.6. Convert Stop Control to Signal Control

Prior to installing a traffic signal, an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location is typically performed to determine whether installing a traffic signal is warranted at a particular location as outlined in the MUTCD. The satisfaction of a traffic signal warrant or warrants does not in itself require installing a traffic signal.

Urban and rural minor-road stop-controlled intersections

Table 14-7 summarizes the CMFs related to converting a stop-controlled intersection to a signalized intersection. The CMF presented for urban intersections applies only to intersections with a major road speed limit at least 40 mph.

The base condition for the CMFs summarized in Table 14-7 (i.e., the condition in which the CMF = 1.00) is a minor-road, stop-controlled intersection in an urban or rural area.

Table 14-7. Potential Crash Effects of Converting from Stop Control to Signal Control (8,15)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Install a traffic signal	Urban (major road speed limit at least 40 mph; four leg (8))	Unspecified	All types (All severities)	**0.95***	**0.09**
			Right-angle (All severities)	**0.33**	**0.06**
			Rear-end (All severities)	*2.43*	*0.4*
	Rural (three leg and four leg (15))	Major road 3,261 to 29,926; Minor road 101 to 10,300	All types (All severities)	**0.56**	**0.03**
			Right-angle (All severities)	**0.23**	**0.02**
			Left-turn (All severities)	**0.40**	**0.06**
			Rear-end (All severities)	*1.58*	*0.2*
Base Condition: Minor-road, stop-controlled intersection.					

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

14.5. CRASH EFFECTS OF ACCESS MANAGEMENT

14.5.1. Background and Availability of CMFs

Access management is a set of techniques designed to manage the frequency and type of conflict points at public intersections and at residential and commercial access points. The management of access, namely the location, spacing, and design of private and public intersections, is an important element 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 while balancing mobility and access across various facility types (12, 26).

The effects on crash frequency of access management at or near intersections are not known to a sufficient degree to present quantitative information in this edition of the HSM. Trends regarding the potential crash effects or changes in user behavior are discussed in Appendix 14A. The material focuses on the location of access points relative to the functional area of an intersection (see Figures 14-1 and 14-2). AASHTO's *Policy on Geometric Design of Highways and Street* states that *"driveways should not be situated within the functional boundary of at-grade intersections"* (2). In the HSM, access points include minor or side-street intersections and private driveways. Table 14-8 summarizes common access management treatments; there are currently no CMFs available for these treatments. Appendix 14A presents general information and a potential change in crash trends for these treatments.

Table 14-8. Treatments Related to Access Management

		Urban				Suburban				Rural			
		Stop		Signal		Stop		Signal		Stop		Signal	
HSM Section	Treatment	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg
Appendix 14A.3.1.1	Close or relocate access points in intersection functional area	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.3.1.2	Provide corner clearance	T	T	T	T	T	T	T	T	T	T	T	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 14A.

14.6. CRASH EFFECTS OF INTERSECTION DESIGN ELEMENTS

14.6.1. Background and Availability of CMFs

The following sections provide information on the crash effects of treatments related to intersection design elements. The treatments discussed in this section and the corresponding CMFs available are summarized below in Table 14-9.

Table 14-9. Treatments Related to Intersection Design Elements

		Urban				Suburban				Rural			
		Stop		Signal		Stop		Signal		Stop		Signal	
HSM Section	Treatment	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg	Minor Road	All-Way	3-Leg	4-Leg
14.6.2.1	Reduce intersection skew angle	—	—	—	—	—	—	—	—	✓	—	—	—
14.6.2.2	Provide a left-turn lane on approach(es) to three -leg intersections	✓	—	✓	N/A	—	—	—	—	✓	—	✓	N/A
14.6.2.3	Provide a left-turn lane on approach(es) to four-leg intersections	✓	—	N/A	✓	—	—	—	—	✓	—	N/A	✓
14.6.2.4	Provide a channelized left-turn lane at four-leg intersections	—	—	N/A	—	—	—	N/A	—	✓	✓	N/A	✓
14.6.2.5	Provide a channelized left-turn lane at three-leg intersections	—	—	—	N/A	—	—	—	N/A	✓	✓	✓	N/A
14.6.2.6	Provide a right-turn lane on approach(es) to an intersection	✓	—	✓	✓	—	—	—	—	✓	—	✓	✓
14.6.2.7	Increase intersection median width	✓	✓	—	✓	✓	✓	—	✓	✓	✓	—	—
14.6.2.8	Provide intersection lighting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Appendix 14A.4.2.1	Provide bicycle lanes or wide curb lanes at intersections	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.4.2.2	Narrow roadway at pedestrian crossing	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.4.2.3	Install raised pedestrian crosswalk	T	T	—	—	T	T	—	—	—	—	—	—
Appendix 14A.4.2.4	Install raised bicycle crossing	—	—	T	T	—	—	T	T	—	—	T	T
Appendix 14A.4.2.5	Mark crosswalks at uncontrolled locations (intersection or mid-block)	T	—	—	—	T	—	—	—	T	—	—	—
Appendix 14A.4.2.6	Provide a raised median or refuge island at marked and unmarked crosswalks	T	T	T	T	T	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 14A.
— = 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.

14.6.2. Intersection Design Element Treatments with Crash Modification Factors

14.6.2.1. Reduce Intersection Skew Angle

A skewed intersection has an angle of less than 90 degrees between the legs of the intersection; an intersection's skew is measured as the absolute value of the difference between 90 degrees and the actual intersection angle. Figure 14-5 illustrates a skewed intersection and how the skewed angle is measured.

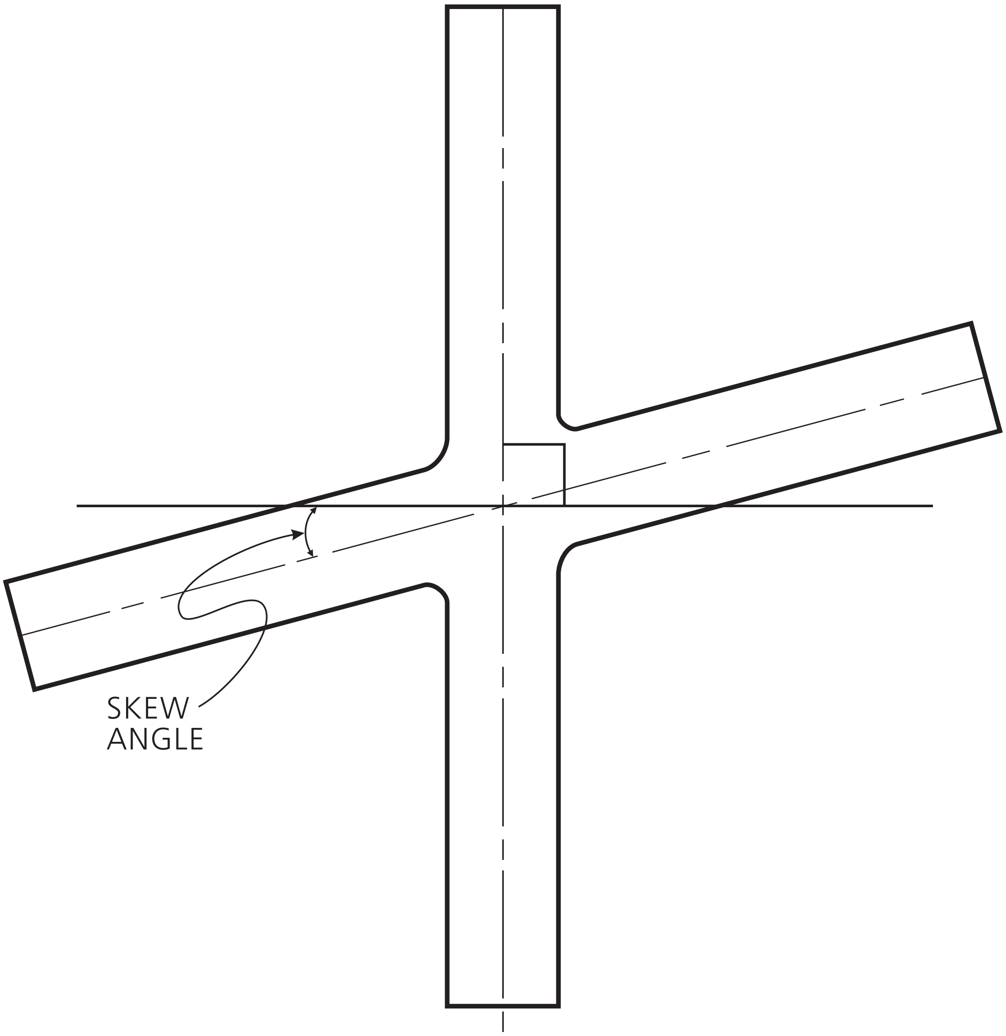


Figure 14-5. Skewed Intersection

An intersection that is closer to perpendicular reduces the extent to which drivers must turn their head and neck to view approaching vehicles. Reducing the intersection skew angle can be particularly beneficial to older drivers, and can also result in increased sight distance for all drivers. Drivers may then be better able to stay within the designated lane and better able to judge gaps in the crossing traffic flow (3). Reducing the intersection skew angle can reduce crossing distances for pedestrians and vehicles, which reduces exposure to conflicts.

Intersection skew angle may be less important for signalized intersections than for stop-controlled intersections. A traffic signal separates most conflicting movements, so the risk of crashes related to the skew angle between the intersecting approaches is limited (15). The crash effect of the skew angle at a signalized intersection may, however, also depend on the operational characteristics of the traffic signal control.

Rural stop-controlled intersections

Presented below are CMFs in the form of a function. One set is applicable to intersections on rural two-lane highways (Equations 14-1 and 14-2); the second set is applicable to intersections on rural multilane highways (Equations 14-3 through 14-6).

Intersections on rural two-lane highways

The crash effect of changing intersection skew angle at rural three-leg intersections with minor-road stop control is represented by (15):

$$CMF = e^{(0.0040 \times skew)} \quad (14\text{-}1)$$

Where:

CMF = crash modification factor for total crashes; and

$skew$ = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

An analogous CMF for the crash effect of changing intersection skew angle at rural four-leg intersections with minor-road stop control is represented by (15):

$$CMF = e^{(0.0054 \times skew)} \quad (14\text{-}2)$$

The CMFs in Equations 14-1 and 14-2 are used in the predictive method for rural two-lane highways in Chapter 10. The base condition for these CMFs (i.e., the condition in which the CMF = 1.00) is the absence of intersection skew (i.e., a 90-degree intersection). The standard error of these CMFs is unknown.

Figure 14-6 illustrates the relationship between the skew angle and the CMF value.

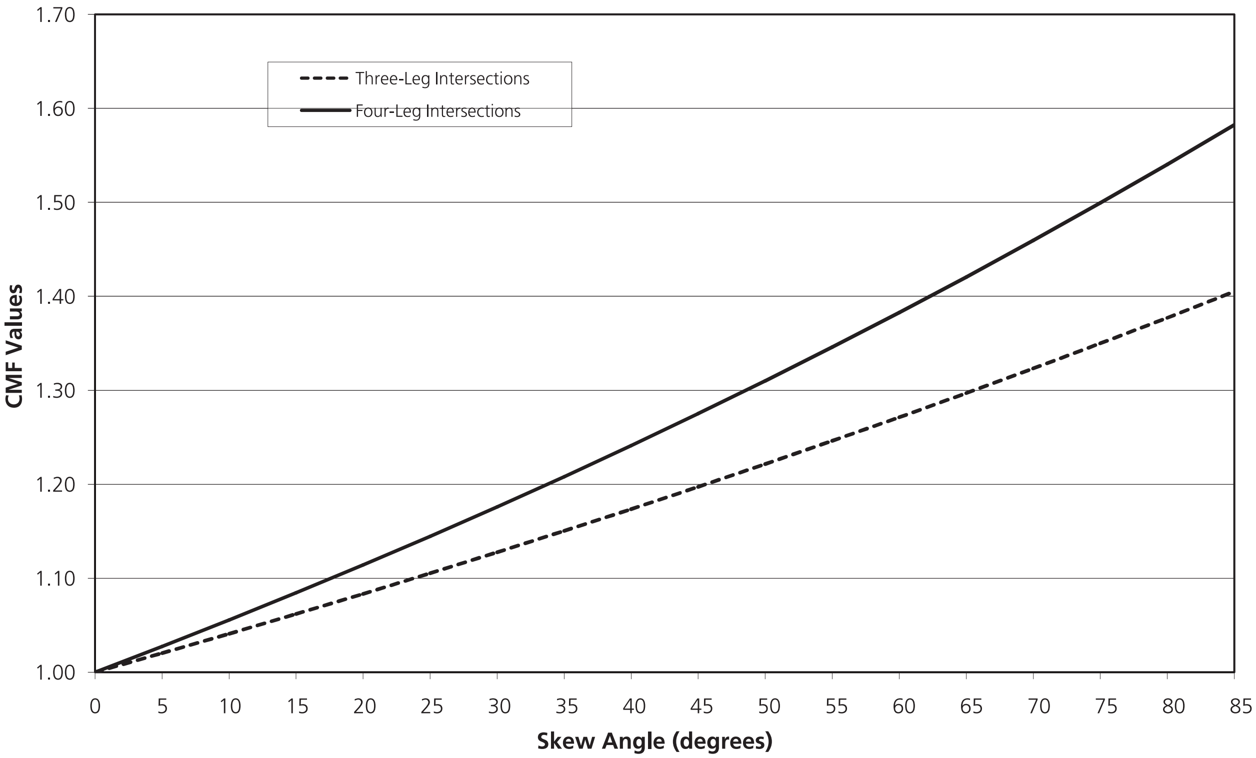


Figure 14-6. Potential Crash Effects of Skew Angle for Intersections with Minor-Road Stop Control on Rural Two-Lane Highways

Figure 14-6 indicates that as the skew angle increases, the value of the CMF increases above 1.0, indicating an increase in crash frequency as the angle between the intersecting roadways deviates further from 90 degrees.

The box presents an example of how to apply the preceding equations to assess the crash effects of reducing intersection skew angle at rural two-lane highway intersections with minor-road stop control.

Effectiveness of Reducing Intersection Skew Angles

Question:
A three-leg intersection with minor-road stop control on a rural two-lane highway has an intersection skew angle of approximately 45 degrees. Due to redevelopment adjacent to the intersection, the governing jurisdiction has an opportunity to reduce the skew angle to 10 degrees. What will be the likely change in expected average crash frequency?

Given Information:
- Existing intersection skew angle = 45 degrees
- Reduced intersection skew angle = 10 degrees
- Expected average crash frequency without treatment (assumed value) = 15 crashes/year

Find:
- Expected average crash frequency with reduced skew angle
- Change in expected average crash frequency

Answer:
1) Identify the applicable CMF equation

$$CMF = e^{(0.0040 \times skew)} \qquad \text{(Equation 14-1 or Figure 14-6)}$$

2) Calculate the CMF for the existing condition

$$CMF = e^{(0.0040 \times 45)} = 1.20$$

3) Calculate the CMF for the after condition

$$CMF = e^{(0.0040 \times 10)} = 1.04$$

4) Calculate the treatment CMF ($CMF_{treatment}$) corresponding to the change in skew angle

$$CMF_{treatment} = 1.04/1.20 = 0.87$$

The CMF corresponding to the treatment condition (reduced skew angle) is divided by the CMF corresponding to the existing condition yielding the treatment CMF ($CMF_{treatment}$). The division is conducted to quantify the difference between the existing condition and the treatment condition. Part D—Introduction and Applications Guidance contains additional information.

5) Apply the $CMF_{treatment}$ to the expected average crash frequency at the intersection without the treatment.

Expected crashes with treatment = 0.87 x 15 crashes/year = 13.0 crashes/year

6) Calculate the difference between the expected average crash frequency without the treatment and with the treatment.

Change in Expected Average Crash Frequency:
15.0 – 13.0 = 2.0 crashes/year reduction

7) Discussion: This example shows that expected average crash frequency may potentially be reduced by 2.0 crashes/year with the skew angle variation from 45 to 10 degrees. A standard error was not available for this CMF, therefore a confidence interval for the reduction cannot be calculated.

Intersections on rural multilane highways

The crash effect of skew angle for three-leg intersections with minor-road stop control is represented by (20):

$$CMF = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0 \tag{14-3}$$

This CMF applies to total intersection crashes. The analogous CMF for four-leg intersections with minor-road stop control is (20):

$$CMF = \frac{0.053 \times skew}{(1.43 + 0.53 \times skew)} + 1.0 \tag{14-4}$$

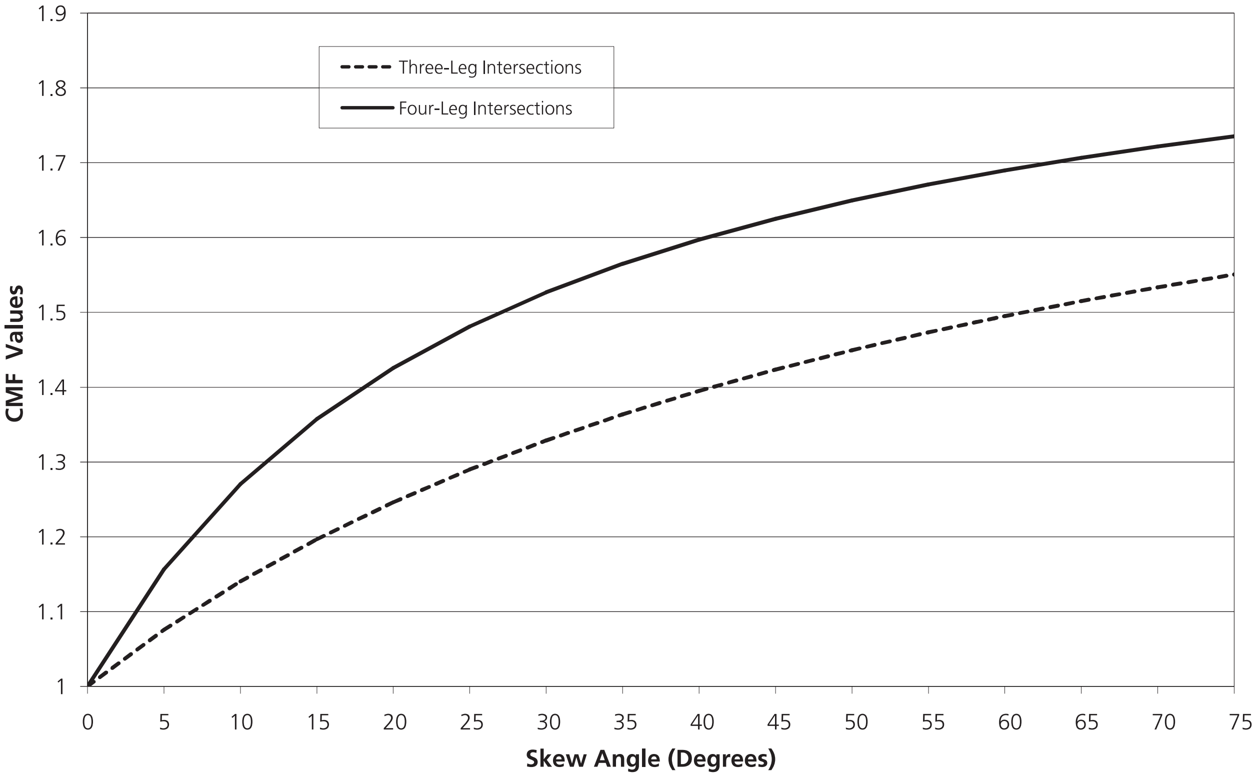


Figure 14-7. Potential Crash Effects of Skew Angle of Three- and Four-Leg Intersections with Minor-Road Stop Control on Rural Multilane Highways

Equivalent CMFs for the crash effect of intersection skew on fatal-and-injury crashes (excluding possible-injury crashes, also known as C-injury crashes) for three-leg intersections with minor-road stop control are presented as Equations 14-5 and 14-6 (20):

$$CMF_{kab} = \frac{0.017 \times skew}{0.52 + 0.17 \times skew} + 1.0 \tag{14-5}$$

Where:

CMF_{kab} = CMF for fatal-and-injury crashes (excluding possible-injury crashes, also known as C-injury crashes).

For four-leg intersections with minor-road stop control (20):

$$CMF_{kab} = \frac{0.048 \times skew}{(0.72 + 0.48 \times skew)} + 1.0 \tag{14-6}$$

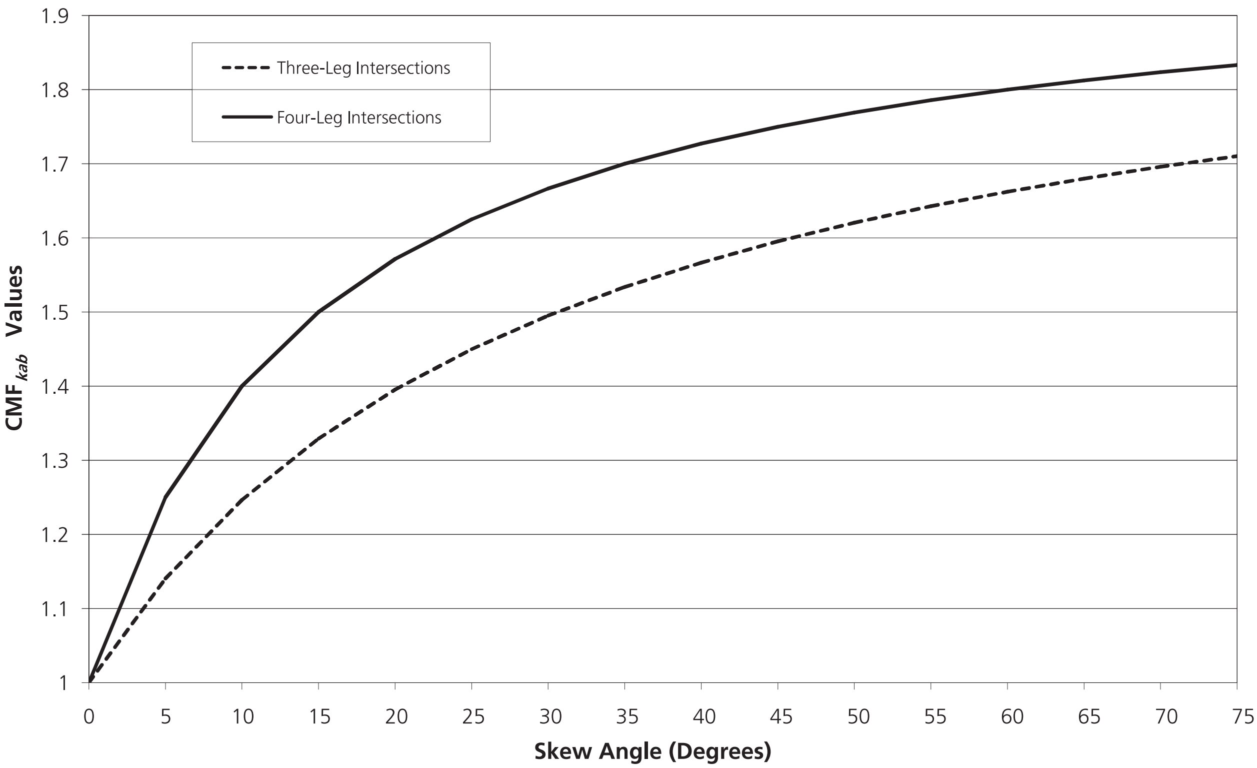


Figure 14-8. Potential Crash Effects of Skew Angle on Fatal-and-Injury Crashes for Three- and Four-Leg Intersections with Minor-Road Stop Control

The CMFs presented in Equations 14-3 through 14-6 are used in the predictive method for rural multilane highways in Chapter 11 to represent the effect of intersection skew at intersections with minor-road stop control. The variability of these CMFs is unknown.

14.6.2.2. Provide a Left-Turn Lane on One or More Approaches to Three-Leg Intersections

Urban and rural three-leg, minor-road, stop-controlled intersections, and urban and rural three-leg signalized intersections

By removing left-turning vehicles from the through-traffic stream, conflicts with through vehicles can be reduced or even eliminated depending on the signal timing and phasing scheme. Providing a left-turn lane allows drivers to wait in the turn lane until a gap in the opposing traffic allows them to turn safely. The left-turn lane helps to reduce conflicts with opposing through traffic (3).

Table 14-10 summarizes the crash effects of providing a left-turn lane on one approach of three-leg intersections under the following settings:

- Rural intersections with minor-road stop control;
- Urban intersections with minor-road stop control; and
- Rural or urban signalized intersections.

The CMFs in Table 14-10 are used to represent the crash effects of providing left-turn lanes at three-leg intersections in the predictive method in Chapters 10, 11, and 12. These CMFs apply to installing left-turn lanes on approaches without stop control at unsignalized intersections and on any approach at signalized intersections. The CMFs for installing left-turn lanes on two intersection approaches would be the CMF values shown in Table 14-10 squared.

The base condition for the CMFs summarized in Table 14-10 (i.e., the condition in which the CMF = 1.00) is a three-leg intersection approach without a left-turn lane.

Table 14-10. Potential Crash Effects of Providing a Left-Turn Lane on One Approach to Three-Leg Intersections (15,16)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Provide a left-turn lane on one major-road approach	Rural (Minor-road, stop-controlled three-leg intersection) (16)	Major road 1,600 to 32,400, minor road 50 to 11,800	All types (All severities)	**0.56**	**0.07**
			All types (Injury)	**0.45**	**0.1**
	Urban (Minor-road, stop-controlled three-leg intersection) (16)	Major road 1,500 to 40,600, minor road 200 to 8,000	All types (All severities)	*0.67*	*0.2*
	Rural (Signal-controlled three-leg intersection) (16)	Unspecified	All types (All severities)	0.85	N/A°
	Urban (Signal-controlled three- leg intersection) (16)			0.93	N/A°
	Urban (Signal-controlled three-leg intersection) (15)	Unspecified	All types (Injury)	0.94	N/A°
	Urban (Minor-road, stop-controlled three-leg intersection) (15)			0.65	N/A°
Base Condition: A three-leg intersection without left-turn lanes.					

NOTE: CMFs apply to installing left-turn lanes for uncontrolled approaches at unsignalized intersections and for any approach at signalized intersections.
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.
N/A° Standard error of the CMF is unknown.

14.6.2.3. Provide a Left-Turn Lane on One or More Approaches to Four-Leg Intersections

This section addresses the crash effects of providing a left-turn lane on one or two approaches to a four-leg intersection. The left-turn lanes addressed in this section may be defined by either painted or raised channelization.

Urban and rural four-leg, minor-road, stop-controlled intersections, and urban and rural four-leg signalized intersections

By removing left-turning vehicles from the through-traffic stream, conflicts with through vehicles can be reduced or even eliminated depending on the signal timing and phasing scheme. Providing a left-turn lane allows drivers to wait in the turn lane until a gap in the opposing traffic allows them to turn safely. The left-turn lane helps to reduce conflicts with opposing through traffic (3).

Left-turn lane on one approach

Providing a left-turn lane on one approach to a four-leg intersection reduces crashes of various types and severities under the following settings:

- Rural or urban intersection with minor-road stop control;
- Rural signalized intersection;
- Urban signalized intersection; and
- Urban intersection with recently implemented signal control (i.e., newly signalized) (16).

Table 14-11 provides specific information regarding the CMFs that are used to calculate change in crashes. The CMFs in Table 14-11 are used to represent the crash effects of providing left-turn lanes at four-leg intersections in the predictive method in Chapters 10, 11, and 12. These CMFs apply to installing left-turn lanes on approaches without stop control at unsignalized intersections and on any approach at signalized intersections.

The base condition for the CMFs summarized in Table 14-11 (i.e., the condition in which the CMF = 1.00) is a four-leg intersection without left-turn lanes on the major-road approaches.

Table 14-11. Potential Crash Effects of Providing a Left-Turn Lane on One Approach to Four-Leg Intersections (16)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Provide a left-turn lane on one major-road approach	Rural (Four-leg, minor-road stop-controlled intersection)	Major road 1,600 to 32,400, minor road 50 to 11,800	All types (All severities)	**0.72**	**0.03**
			All types (Injury)	**0.65**	**0.04**
	Urban (Four-leg, minor-road stop-controlled intersection)	Major road 1,500 to 40,600, minor road 200 to 8,000	All types (All severities)	**0.73**	**0.04**
			All types (Injury)	**0.71**	**0.05**
	Rural (Four-leg signalized intersection)	Unspecified	All types (All severities)	0.82	N/A°
	Urban (Four-leg signalized intersection)	Major road 7,200 to 55,100, minor road 550 to 2,600	All types (All severities)	**0.90***	**0.1**
			All types (Injury)	**0.91**	**0.02**
	Urban (Four-leg newly signalized intersection)	Major road 4,600 to 40,300, minor road 100 to 13,700	All types (All severities)	**0.76**	**0.03**
			All types (Injury)	**0.72**	**0.06**
Base Condition: A four-leg intersection without left-turn lanes.					

NOTE: CMFs apply to installing left-turn lanes for uncontrolled approaches at unsignalized intersections and for any approach at signalized intersections.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less
° Standard error of CMF is unknown.
* Observed variability suggests that this treatment could result in an increase, decrease, or no change in crashes. See Part D—Introduction and Applications Guidance.

Left-turn lanes on two approaches

Table 14-12 provides CMFs, analogous to those in Table 14-11, for installing left-turn lanes on two approaches to a four-leg intersection. The CMFs in Table 14-12 are generally equivalent to the CMF values for one approach, shown in Table 14-11, squared. For four-leg signalized intersections where left-turn lanes are provided on three or four approaches, the CMF for providing left-turn lanes on three or four approaches is equal to the CMF for installing left-turn lanes on one approach, from Table 14-11, raised to the third or fourth power, respectively.

The base condition for the CMFs summarized in Table 14-12 (i.e., the condition in which the CMF = 1.00) is a four-leg intersection without left-turn lanes on the major-road approaches.

Table 14-12. Potential Crash Effects of Providing a Left-Turn Lane on Two Approaches to Four-Leg Intersections (16)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Provide a left-turn lane on both major-road approaches	Rural (Four-leg, minor-road stop-controlled intersection)	Major road 1,500 to 32,400, minor road 50 to 11,800	All types (All severities)	**0.52**	**0.04**
			All types (Injury)	**0.42**	**0.04**
	Urban (Four-leg, minor-road stop-controlled intersection)	Major road 1,500 to 40,600, minor road 200 to 8,000	All types (All severities)	**0.53**	**0.04**
			All types (Injury)	**0.50**	**0.06**
	Rural (Four-leg signalized intersection)	Unspecified	All types (All severities)	0.67	N/A°
	Urban (Four-leg Signalized intersection)	Major road 7,200 to 55,100, minor road 550 to 2,600	All types (All severities)	**0.81**	**0.1**
			All types (Injury)	**0.83**	**0.02**
	Urban (Four-leg newly signalized[a] intersection)	Major road 4,600 to 40,300, minor road 100 to 13,700	All types (All severities)	**0.58**	**0.04**
			All types (Injury)	**0.52**	**0.07**
Base Condition: A four-leg intersection without a left-turn lane					

NOTE: CMFs apply to installing left-turn lanes for uncontrolled approaches at unsignalized intersections and for any approach at signalized intersections.
[a] A newly signalized intersection is an intersection where the signal was installed in conjunction with left-turn installation.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
° Standard error of CMF is unknown.

The box illustrates how the information in Table 14-12 is used to estimate the crash effects of providing a left-turn lane on two approaches to a four-leg intersection.

Effectiveness of Installing Left-Turn Lanes on Two Approaches to a Four-Leg Intersection

Question:
An urban minor street with an estimated 2,000 vpd traffic volume intersects a major arterial with an estimated 35,000 vpd traffic volume. The minor street is stop-controlled. The governing jurisdiction has an opportunity to add left-turn lanes to both major street approaches as part of a redevelopment project. What will be the likely change in the expected average injury crash frequency?

Given Information:
- Existing roadways = an urban minor street and a major arterial
- Existing intersection type = four-leg intersection
- Existing intersection control = minor-street stop-controlled
- Expected average injury crash frequency without treatment (assumed value) = 12 crashes/year

Find:
- Expected average injury crash frequency with installation of left-turn lanes
- Change in expected average injury crash frequency

Answer:
1) Identify the applicable CMF

CMF = 0.50 (Table 14-12)

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

= [0.50 ± (2 x 0.06)] x (12 crashes/year) = 4.6 or 7.4 crashes/year

The multiplication of the standard error by 2 yields a 95 percent probability that the true value is between 4.6 and 7.4 crashes/year. See Section 3.5.3 in Chapter 3—Fundamentals for a detailed explanation of standard error application.

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

Change in Expected Average Crash Frequency:

Low Estimate = 12 – 7.4 = 4.6 crashes/year reduction

High Estimate = 12 – 4.6 = 7.4 crashes/year reduction

4) Discussion: This example illustrates that the construction of left-turn lanes on both approaches of the major arterial may potentially cause a reduction of 4.6 to 7.4 crashes per year. The confidence interval estimation yields a 95 percent probability that the reduction will be between 4.6 and 7.4 crashes per year.

14.6.2.4. Provide a Channelized Left-Turn Lane at Four-Leg Intersections

Channelization is the separation of conflicting traffic movements into definite travel paths. Channelization is achieved by traffic islands, (i.e., physical channelization) or by pavement markings (i.e., painted channelization) (1,9). Both physical and painted channelization are used to demarcate shared and exclusive lanes.

Rural four-leg signalized, minor-road stop-controlled, and all-way stop -controlled intersections
The crash effects of providing a physically channelized left-turn lane on both major- and minor-road approaches to a rural four-leg intersection are shown Table 14-13 (9).

The crash effect of providing a physically channelized left-turn lane on only the major-road approaches to a rural four-leg intersection is also shown in Table 14-13 (9).

The base condition for the CMFs summarized in Table 14-13 (i.e., the condition in which the CMF = 1.00) is a rural four-leg intersection without channelized left-turn lanes.

Table 14-13. Potential Crash Effects of a Channelized Left-Turn Lane on Both Major- and Minor-Road Approaches at Four-Leg Intersections (9)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide a channelized left-turn lane on both major- and minor-road approaches	Rural (four-leg intersection two-lane roads)	5,000 to 15,000 vpd	All types (Injury)	**0.73**	**0.1**
Provide a channelized left-turn lane on both major-road approaches				*0.96**	*0.2*
Base Condition: Rural four-leg intersection without channelized left-turn lanes.					

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

14.6.2.5. Provide a Channelized Left-Turn Lane at Three-Leg Intersections

Rural three-leg signalized, minor-road stop-controlled, and all-way stop-controlled intersections
Table 14-14 summarizes the crash effects of providing a physically channelized left-turn lane on:

1. One major-road approach, and

2. One major-road approach and the minor-road approach to a rural three-leg intersection (9).

The base condition for the CMFs below (i.e., the condition in which the CMF = 1.00) is a rural three-leg intersection without channelized left-turn lanes.

Table 14-14. Potential Crash Effects of a Channelized Left-Turn Lane at Three-Leg Intersections (9)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide a channelized left-turn lane on major-road approach	Rural (three-leg intersection two-lane roads)	5,000 to 15,000 vpd	All types (Injury)	*0.73*	*0.2*
Provide a channelized left-turn lane on major-road approach and minor-road approach			All types (Injury)	*1.16*	*0.2*
Base Condition: Rural three-leg intersection without channelized left-turn lanes.					

NOTE: *Italic* text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.
vpd = vehicles per day

14.6.2.6. Provide a Right-Turn Lane on One or More Approaches to an Intersection

This section addresses the effects on crash frequency of providing a right-turn lane on one approach to an intersection. The right-turn lanes addressed in this section may be defined by either painted or raised channelization.

Urban and rural signalized intersections, and urban and rural minor-road stop-controlled intersections

Right-turn lane on one intersection approach

Table 14-15 summarizes the crash effects of providing a right-turn lane on one intersection approach by setting and intersection type.

The base condition for the CMFs in Table 14-15 (i.e., the condition in which the CMFs = 1.00) is an intersection without right-turn lanes on the major-road approaches.

Table 14-15. Potential Crash Effects of Providing a Right-Turn Lane on One Approach to an Intersection (16)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (vpd)	Crash Type (Severity)	CMF	Std. Error
Provide a right-turn lane on one major-road approach	Rural and urban (three- or four-leg, minor-road stop-controlled intersection)	Major road 1,500 to 40,600, minor road 25 to 26,000 vpd	All types (All severities)	**0.86**	**0.06**
			All types (Injury)	**0.77**	**0.08**
	Rural and urban (three- or four-leg signalized intersection)	Major road 7,200 to 55,100, minor road 550 to 8,400	All types (All severities)	**0.96**	**0.02**
			All types (Injury)	**0.91**	**0.04**
Base Condition: Intersection without right-turn lanes on major-road approaches.					

NOTE: CMFs apply to installing right-turn lanes for uncontrolled approaches at unsignalized intersections and for any approach at signalized intersections.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.

Right-turn lane on two approaches to an intersection

Table 14-16 summarizes the crash effects of providing a right-turn lane on two approaches to a rural or urban intersection.

The CMFs in Table 14-16 apply to providing a right-turn lane on an uncontrolled approach to an unsignalized intersection or any approach to a signalized intersection. The CMFs for providing right-turn lanes on approaches to an intersection in Table 14-16 are equivalent to the CMF values for one approach, shown in Table 14-15, squared. For signalized intersections where right-turn lanes are provided on three or four approaches, the CMF values for installing right-turn lanes is equal to the CMF value for installing a right-turn lane on one approach, shown in Table 14-15, raised to the third or fourth power, respectively.

The base condition for the CMFs in Table 14-16 (i.e., the condition in which the CMF = 1.00) is an intersection without right-turn lanes on the major-road approaches.

Table 14-16. Potential Crash Effects of Providing a Right-Turn Lane on Two Approaches to an Intersection (16)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (Veh/Day)	Crash Type (Severity)	CMF	Std. Error
Provide a right-turn lane on both major-road approaches	Rural and urban (Minor-road stop-controlled intersection)	Major road 1,500 to 40,600, minor road 25 to 26,000	All types (All severities)	**0.74**	**0.08**
	Rural and urban (Signalized intersection)	Major road 7,200 to 55,100, minor road 550 to 8,400		**0.92**	**0.03**
	Rural and urban (Minor-road stop-controlled intersection (15))	Unspecified	All types Injury	0.59	N/A°
	Rural and urban (Signalized intersection (15))			0.83	N/A °
Base Condition: Intersection without right-turn lanes on major-road approaches.					

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

14.6.2.7. Increase Intersection Median Width

This section presents the crash effects related to median width. Medians are intended to perform several functions. Some of the main functions are:

- To separate opposing traffic;
- To allow space for the storage of left-turning, U-turning vehicles;
- Minimize headlight glare; and
- Provide width for future lanes (1,25)

At an intersection, the following definitions of the median apply.

- Median width is the total width between the edges of opposing through lanes, including the left shoulder and the left-turn lanes, if any (18).
- Median opening length is the total length of break in the median provided for cross street and turning traffic (18). The design of a median opening is generally based on traffic volumes, urban/rural area characteristics, and type of turning vehicles (1).
- Median roadway is the paved area in the center of the divided highway at an intersection defined by the median width and the median opening length (18).
- Median area is the median roadway plus the major-road left-turn lanes, if any (18).
- The median width, length, roadway, and area are illustrated in Figure 14-9.

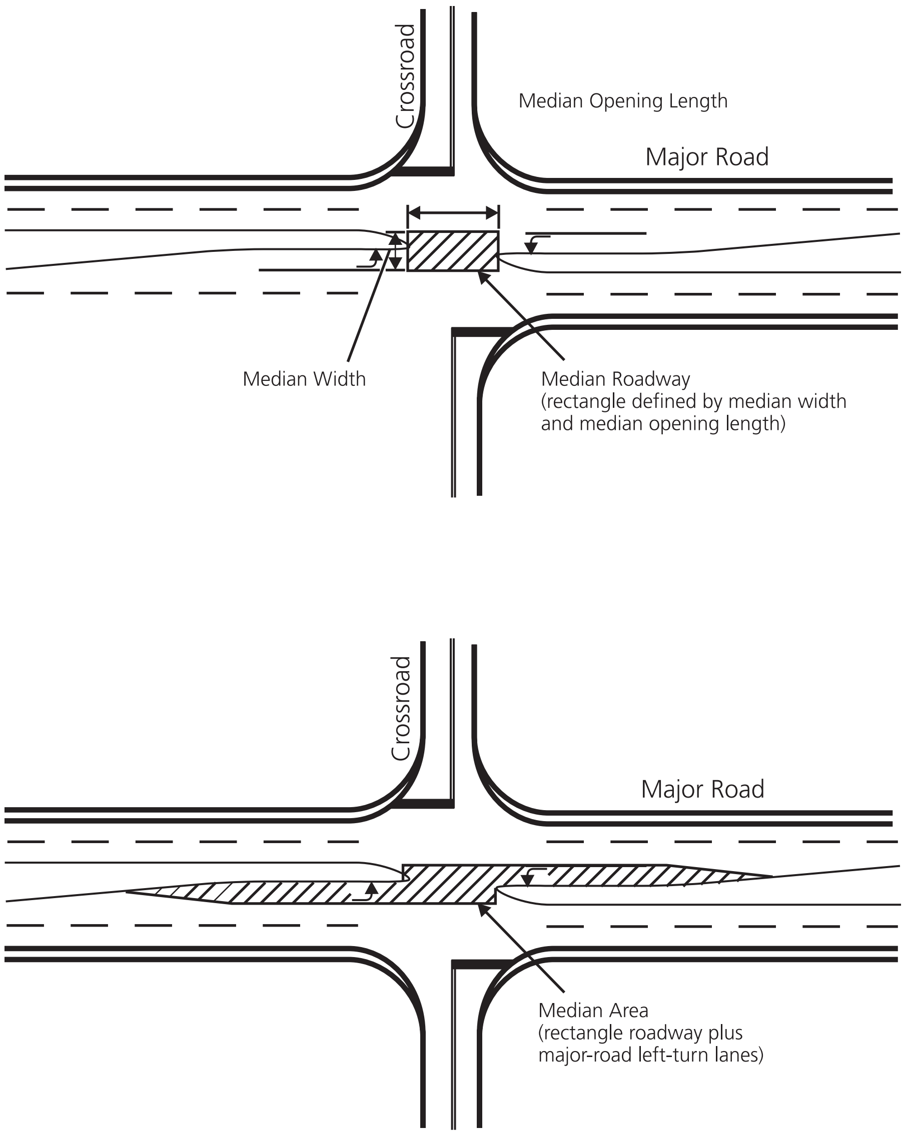


Figure 14-9. Median Width, Median Roadway, Median Opening Length, and Median Area (18)

- Urban, suburban, and rural four-leg unsignalized intersections,
- urban and suburban three-leg unsignalized intersections, and
- urban and suburban four-leg signalized intersections

Table 14-17 summarizes the crash effects of increasing intersection median width by 3-ft increments at intersections where existing medians are between 14 and 80 ft wide (18).

The base condition for the CMFs summarized in Table 14-17 (i.e., the condition in which the CMF = 1.00) is a 14-ft-wide to 80-ft-wide median.

Table 14-17. Potential Crash Effects of Increasing Intersection Median Width (18)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Increase intersection median width by 3-ft increments	Rural (Four-leg unsignalized)	Unspecified	Multiple-vehicle (All severities)	**0.96^**	**0.02**
			Multiple-vehicle (Injury)	**0.96^**	**0.02**
	Urban and suburban (Four-leg unsignalized)		Multiple-vehicle (All severities)	**1.06**	**0.01**
			Multiple-vehicle (Injury)	**1.05**	**0.02**
	Urban and suburban (Three-leg unsignalized)		Multiple-vehicle (All severities)	**1.03**	**0.01**
	Urban and suburban (Four-leg signalized)		Multiple-vehicle (All severities)	**1.03**	**0.01**
			Multiple-vehicle (Injury)	**1.03**	**0.01**
Base Condition: A 14-ft-wide to 80-ft-wide median.					

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
These values are valid for median widths between 14 and 80 ft.
^ Observed variability suggests that this treatment could result in no effect on crashes. See Part D—Introduction and Applications Guidance.

14.6.2.8. Provide Intersection Lighting

Intersection lighting includes conventional forms of installing luminaires to illuminate the intersection proper and approach to the intersection.

All intersections

The base condition for the CMFs shown in Table 14-18 (i.e., the condition in which the CMF = 1.00) is an intersection without illumination (i.e., artificial lighting).

Table 14-18. Potential Crash Effects of Providing Intersection Illumination (9,10,12,26)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide intersection illumination	All settings (All types)	Unspecified	All types Nighttime (Injury)	**0.62**	**0.1**
			Pedestrian Nighttime (Injury)	*0.58*	*0.2*
Base Condition: An intersection without lighting.					

NOTE: Based on U.S. studies: Griffith 1994, Preston 1999, and international studies: Wanvik 2004; Elvik and Vaa 2004.
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.

Non-injury crashes may also be reduced by installing illumination. Intersection illumination appears to have the greatest effect on fatal pedestrian nighttime crashes. However, the magnitude of the crash effect is not certain at this time.

14.7. CRASH EFFECTS OF INTERSECTION TRAFFIC CONTROL AND OPERATIONAL ELEMENTS

14.7.1. Background and Availability of CMFs

The following sections provide information on the crash effects of treatments related to intersection traffic control and operational elements. Traffic control devices at an intersection include signs, signals, warning beacons, and pavement markings. Operational elements of an intersection include the type of traffic control, traffic signal operations, speed limits, traffic calming, and on-street parking.

The treatments discussed in this section and the corresponding CMFs available are summarized in Table 14-19.

Table 14-19. Treatments Related to Intersection Traffic Control and Operational Elements

		Urban				Suburban				Rural			
		Stop		Signal		Stop		Signal		Stop		Signal	
HSM Section	Treatment	Minor Road	All-Way	Three-Leg	Four-Leg	Minor Road	All-Way	Three-Leg	Four-Leg	Minor Road	All-Way	Three-Leg	Four-Leg
14.7.2.1	Prohibit left-turns and/or U-turns with “No Left Turn”, “No U-Turn” signs	✓	—	✓	✓	✓	—	✓	✓	—	—	—	—
14.7.2.2	Provide “Stop Ahead” pavement markings	—	—	—	—	—	—	—	—	✓	✓	—	—
14.7.2.3	Provide flashing beacons at stop- controlled intersections	✓	✓	N/A	N/A	✓	✓	N/A	N/A	✓	✓	N/A	N/A
14.7.2.4	Modify left-turn phase	—	—	—	✓	—	—	—	—	—	—	—	—
14.7.2.5	Replace direct left-turns with right-turn/U-turn combination	✓	—	—	—	✓	—	—	—	✓	—	—	—
14.7.2.6	Permit right-turn on red	—	—	✓	✓	—	—	✓	✓	—	—	✓	✓
14.7.2.7	Modify change and clearance interval	—	—	—	✓	—	—	—	✓	—	—	—	✓
14.7.2.8	Install red-light cameras	—	—	✓	✓	—	—	—	—	—	—	—	—
Appendix 14A.5.1.1	Place transverse markings on roundabout approaches	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.2	Install pedestrian signal heads at signalized intersections	N/A	N/A	T	T	N/A	N/A	—	—	N/A	N/A	—	—
Appendix 14A.5.1.3	Modify pedestrian signal heads	N/A	N/A	T	T	N/A	N/A	—	—	N/A	N/A	—	—
Appendix 14A.5.1.4	Install pedestrian countdown signals	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T

Appendix 14A.5.1.5	Install automated pedestrian detectors	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T
Appendix 14A.5.1.6	Install stop lines and other crosswalk enhancements	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.7	Provide exclusive pedestrian signal timing pattern	—	—	T	T	—	—	—	—	—	—	—	—
Appendix 14A.5.1.8	Provide leading pedestrian interval signal timing pattern	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T
Appendix 14A.5.1.9	Provide actuated control	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T
Appendix 14A.5.1.10	Operate signals in “night-flash” mode	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T
Appendix 14A.5.1.11	Provide advance static warning signs and beacons	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.12	Provide advance warning flashers and warning beacons	N/A	N/A	T	T	N/A	N/A	T	T	N/A	N/A	T	T
Appendix 14A.5.1.13	Provide advance overhead guide signs	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.14	Install additional pedestrian signs	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.15	Modify pavement color for bicycle crossings	T	T	—	—	T	T	—	—	T	T	—	—
Appendix 14A.5.1.16	Place “slalom” profiled pavement markings on bicycle lanes	T	T	T	T	T	T	T	T	T	T	T	T
Appendix 14A.5.1.17	Install rumble strips on intersection approaches	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 14A.
— = 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.

14.7.2. Intersection Traffic Control and Operational Element Treatments with Crash Modification Factors

14.7.2.1. Prohibit Left-Turns and/or U-Turns by Installing “No Left Turn” and “No U-Turn” Signs

Prohibiting left-turns and/or U-turns at an intersection is one means to increase an intersection’s capacity and reduce the number of vehicle conflict points at the intersection. The crash effects of prohibiting these movements via signing are discussed in this section.

Urban and suburban minor-road stop-controlled and signalized intersections

Table 14-20 summarizes the crash effects of prohibiting left-turns and U-turns at intersections through the use of “No Left-Turn” and/or “No U-Turn” signs for urban and suburban three- and four-leg intersections and median crossovers.

Crash migration is a possible result of prohibiting left-turns and U-turns at intersections and median crossovers because drivers may use different streets or take different routes to reach a destination.

The base condition for the CMFs summarized in Table 14-20 (i.e., the condition in which the CMF = 1.00) is not clear and was not specified in the original compilation of the material.

Table 14-20. Potential Crash Effects of Prohibiting Left-Turns and/or U-Turns by Installing “No Left Turn” and “No U-Turn” Signs (6)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Prohibit left-turns with “No Left Turn” sign	Urban and suburban (Arterial three- and four-leg, and median crossovers)	Entering AADT 19,435 to 42,000 vpd	Left-turn (All severities)	*0.36*	*0.20*
			All intersection crashes (All severities)	**0.32**	**0.10**
Prohibit left-turns and U-turns with “No Left Turn” and “No U-Turn” signs			Left-turn and U-turn crashes (All severities)	*0.23*	*0.20*
			All intersection crashes (All severities)	*0.28*	*0.20*
Base Condition: Unspecified.					

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.

Prohibiting U-Turns by only installing “No U-Turn” signs appears to reduce U-turn crashes of all severities and all intersection crashes of all severities (6). However, the magnitude of the crash effect is not certain at this time.

14.7.2.2. Provide “Stop Ahead” Pavement Markings

Providing “Stop Ahead” pavement markings can alert drivers to the presence of an intersection. These markings can be especially useful in rural areas at unsignalized intersections with patterns of crashes which suggest that drivers may not be aware of the presence of the intersection.

Rural stop-controlled intersections

Table 14-21 summarizes the crash effects of providing “Stop Ahead” pavement markings on approaches to stop-controlled intersections in rural areas. The base condition for the CMFs summarized in Table 14-21 (i.e., the condition in which the CMF = 1.00) is a stop-controlled intersection in a rural area without a “Stop Ahead” pavement marking.

Table 14-21. Potential Crash Effects of Providing "Stop Ahead" Pavement Markings (13)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide "Stop Ahead" pavement markings	Rural (Stop-controlled)	Unspecified	Right angle (All severities)	*1.04**	*0.3*
			Rear-end (All severities)	*0.71*	*0.3*
			All types (Injury)	*0.78*	*0.2*
			All types (All severities)	**0.69**	**0.1**
	Rural (Stop-controlled three-leg)		All types (Injury)	*0.45*	*0.3*
			All types (All severities)	*0.40*	*0.2*
	Rural (Stop-controlled four-leg)		All types (Injury)	*0.88*	*0.3*
			All types (All severities)	*0.77*	*0.2*
	Rural (All-way stop-controlled)		All types (Injury)	*0.58*	*0.3*
			All types (All severities)	*0.44*	*0.2*
	Rural (Minor-road stop-controlled)		All types (Injury)	*0.92**	*0.3*
			All types (All severities)	*0.87*	*0.2*
Base condition: Stop-controlled intersection in a rural area without a "Stop Ahead" pavement marking.					

Notes: **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.

14.7.2.3. Provide Flashing Beacons at Stop-Controlled Intersections

Flashing beacons can help alert drivers to the presence of unsignalized intersections that may be unexpected or may not be visible. Flashing beacons may be particularly appropriate for intersections with patterns of angle collisions related to lack of driver awareness of the intersection. Flashing beacons could be installed overhead or mounted on the stop sign. There are two major types of beacons: (1) standard beacons that flash all the time, and (2) actuated beacons that are triggered by an approaching vehicle. The CMFs presented in this section apply to standard beacons that flash all the time.

Urban, suburban, and rural stop-controlled intersections

Table 14-22 summarizes the effects on crash frequency of providing flashing beacons at stop-controlled, four-leg intersections on two-lane roads.

The base condition for the CMFs summarized in Table 14-22 (i.e., the condition in which the CMF = 1.00) is a stop-controlled, four-leg intersection without flashing beacons on a two-lane road.

Table 14-22. Potential Crash Effects of Providing Flashing Beacons at Stop-Controlled, Four-Leg Intersections on Two-Lane Roads (31)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Provide flashing beacons at stop-controlled intersections	All settings (Stop-controlled)	Major road volume 250 to 42,520, minor road volume 90 to 13,270	All types (All severities)	**0.95***	**0.04**
			All types (Injury)	**0.90***	**0.06**
			Rear-end (All severities)	**0.92***	**0.1**
			Angle (All severities)	**0.87**	**0.06**
	Rural (Stop-controlled)		Angle (All severities)	**0.84**	**0.06**
	Suburban (Stop-controlled)		Angle (All severities)	**0.88**	**0.1**
	Urban (Stop-controlled)		Angle (All severities)	*1.12*	*0.3*
	All settings (Minor-road stop-controlled)		Angle (All severities)	**0.87**	**0.06**
	All settings (All-way stop-controlled)		Angle (All severities)	*0.72*	*0.2*
	All settings (Standard overhead beacons)		Angle (All severities)	**0.88**	**0.06**
	All settings (Standard stop-mounted beacons)		Angle (All severities)	*0.42*	*0.2*
	All settings (Standard overhead and stop-mounted beacons)		Angle (All severities)	**0.87**	**0.06**
	All settings (Actuated beacons)		Angle (All severities)	**0.86**	**0.1**
Base condition: Stop-controlled, four-leg intersection on a two-lane road without flashing beacons.					

Notes: **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 a increase, decrease, or no change in crashes. See Part D—Introduction and Applications Guidance.

14.7.2.4. Modify Left-Turn Phase

Left-turn phasing at a traffic signal is generally determined by considering traffic flows at the intersection and the intersection design. The following types of left-turn signal phases may be used:

- Permissive;
- Protected/permissive;
- Permissive/protected;
- Protected leading (protected left phase before through phase);
- Protected lagging (through phase before protected left phase); or
- Split phasing (left turns operate independently of each other and concurrently with the through movements).

Alternatively, under certain conditions, left-turns at intersections can be replaced with a combined right-turn/U-turn maneuver. This subsection addresses the effects on crash frequency of replacing permissive, permissive/protected, or protected/permissive with protected left-turn phase, and replacing permissive phasing with permissive/protected or protected/permissive phasing.

Urban, four-leg, signalized intersections

Table 14-23 summarizes the crash effects of modifying the left-turn phase at one or more approaches to a four-leg intersection.

The base condition for the CMFs summarized in Table 14-23 (i.e., the condition in which the CMF = 1.00) for changing to protected phasing is permissive, permissive/protected, or protected/permissive phasing. The base condition for changing to permissive/protected or protected/permissive phasing is permitted phasing.

Table 14-23. Potential Crash Effects of Modifying Left-Turn Phase at Urban Signalized Intersections (8,15,22)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Change to protected phasing (8,15)	Urban (Four- and three-leg signalized)	Unspecified	Left-turn crashes on treated approach (All severities)	**0.01+**	**0.01**
			All types (All severities)	**0.94*+**	**0.1**
Change from permissive to protected/permissive or permissive/protected phasing (15,22)	Urban (Four-leg signalized)	Major road 3,000 to 77,000 and minor road 1 to 45,500	Left-turn (Injury)	**0.84**	**0.02**
Change from permissive to protected/permissive or permissive/protected phasing (15)	Urban (Four-leg signalized)	Unspecified	All types (All severities)	0.99	N/A°
Base Condition: For changing to protected phasing, the base condition is permissive, permissive/protected, or protected/permissive phasing. For changing to permissive/protected or protected/permissive phasing, the base condition is permitted phasing.					

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.
° Standard error of CMF is unknown.
+ Combined CMF, see Part D—Introduction and Applications Guidance.

The CMFs in Table 14-23 are difficult to apply in practice because the number of approaches for which left-turn phasing is provided is not specified. Table 14-24 shows the CMF for left-turn phasing developed by an expert panel from an extensive literature review (17,19). Where left-turn phasing is provided on two, three, or four approaches to an intersection, the CMF values shown in Table 14-24 may be multiplied together. For example, where protected left-turn phasing is provided on two approaches to a signalized intersection, the applicable CMF would be the CMF shown in Table 14-24 squared. The base condition for the CMFs summarized in Table 14-24 (i.e., the condition in which the CMF = 1.00) is the use of permissive left-turn signal phasing.

Table 14-24. Potential Crash Effects of Modifying Left-Turn Phase on One Intersection Approach (17,19)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Change from permissive to protected/ permissive or permissive/protected phasing	Unspecified (Unspecified)	Unspecified	Unspecified (All severities)	0.99	N/A°
Change from permissive to protected	Unspecified (Unspecified)	Unspecified	Unspecified (All severities)	0.94	N/A°
Base Condition: Permissive left-turn phase.					

NOTE: Use CMF = 1.00 for all unsignalized intersections. If several approaches to a signalized intersection have left-turn phasing, the values of the CMF for each approach should be multiplied together.

The box illustrates how to apply the information in Table 14-24 to assess the crash effects of providing protected leading left-turn phasing.

Effectiveness of Modifying Left-Turn Phasing

Question:

An urban signalized intersection has permissive/protected, east-west left-turn phases and permissive, north/south left-turn phases. As part of a signal retiming project, the governing jurisdiction looked into providing only leading protected left-turn phases on the east-west approaches and maintaining the permissive north/south left-turn phasing. What will be the likely change in expected average crash frequency?

Given Information:

- Existing intersection control = urban four-leg traffic signal
- Existing left-turn signal phasing = permissive/protected on the east/ west approaches, permissive on the north/south approaches.
- Intersection expected average crash frequency with the existing treatment (assumed value) = 14 crashes/year

Find:

- Expected average crash frequency with implementation of leading protected left-turn phases at the east and west approaches
- Change in expected average crash frequency

Answer:

1) Calculate the existing conditions CMF

CMF = 0.99 for each permissive/protected left-turn approach (Table 14-24)

CMF = 1.00 for each permissive left-turn approach (Table 14-24)

$CMF_{existing}$ = 0.99 x 0.99 x 1.00 x 1.00 = 0.98

The intersection-wide CMF for existing conditions is computed by multiplying the individual CMFs at each approach to account for the combined effect of left-turn phasing treatments. Each approach is assigned a CMF from Table 14-24 which corresponds to individual left-turn phasing treatments at each approach.

2) Calculate the future conditions CMF

CMF = 0.94 per protected left-turn approach

CMF_{future} = 0.94 x 0.94 x 1.00 x 1.00 = 0.88

Calculations for future conditions are similar to the calculations for existing conditions.

3) Calculate the treatment CMF ($CMF_{treatment}$)

$CMF_{treatment} = CMF_{future} / CMF_{existing}$ = 0.88/0.98 = 0.90

The CMF corresponding to the treatment condition is divided by the CMF corresponding to the existing condition yielding the treatment CMF ($CMF_{treatment}$). The division is conducted to quantify the difference between the existing condition and the treatment condition. See Part D—Introduction and Applications Guidance.

4) Apply the treatment CMF ($CMF_{treatment}$) to the expected average crash frequency at the intersection with the existing treatment.

= 0.90 x (14 crashes/year) = 12.6 crashes/year

5) Calculate the difference between the expected average crash frequency with the existing treatment and with the future treatment.

Change in Expected Average Crash Frequency Variation:
14.0 – 12.6 = 1.4 crashes/year reduction

6) Discussion: This example shows that expected average crash frequency may potentially be reduced by 1.4 crashes/year with implementing protected left-turn phasing on the east and west approaches. A standard error was not available for this CMF; therefore, a confidence interval for the reduction cannot be calculated.

14.7.2.5. Replace Direct Left-Turns with Right-Turn/U-turn Combination

Replacing direct left-turns with right-turn/u-turn combination is applied to minor streets and driveways intersecting with divided arterials. A directional median is typically used to eliminate left-turns off of the minor street. Closing the side-street left-turn using directional median openings effectively forms a T-intersection with a closed median, eliminating direct left-turns at unsignalized intersections and driveways onto divided arterials. Drivers must turn right and then perform a U-turn on the divided arterial at a downstream location to access the desired side street or access point (32). Figure 14-10 illustrates a conceptual example of closing a side street left-turn and serving the left-turn movement through a right-turn and U-turn movement.

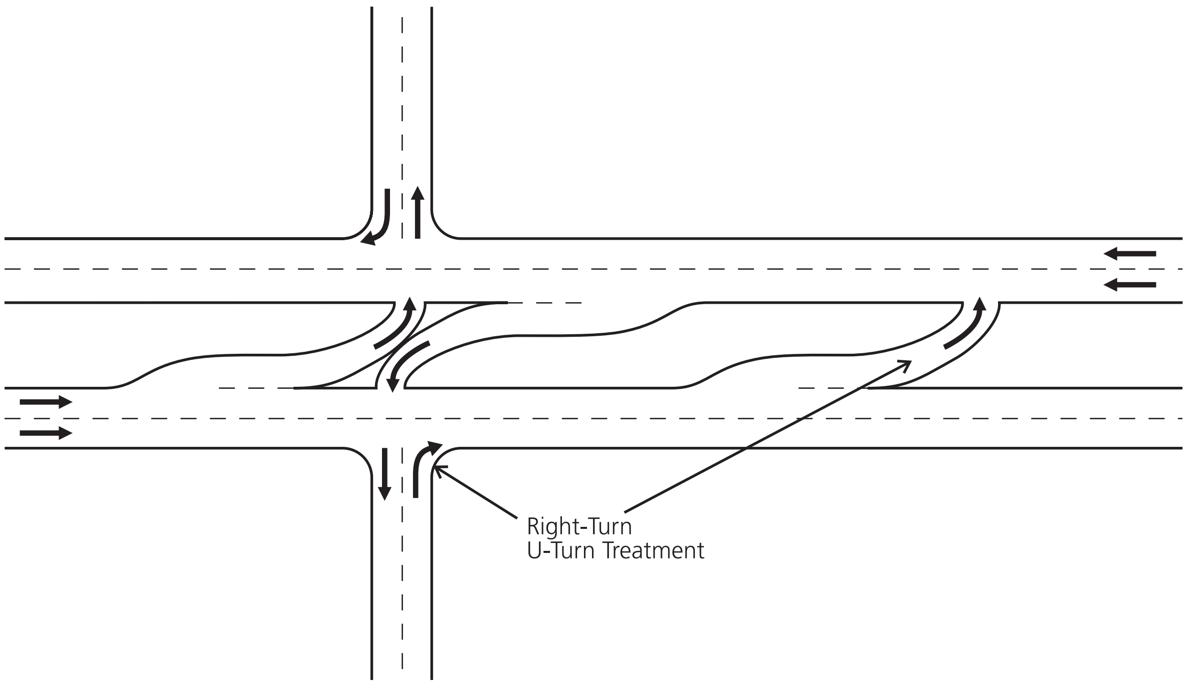


Figure 14-10. Right-Turn/U-Turn Combination

Urban, suburban, and rural stop-controlled intersections

The crash affects of this treatment on four-, six-, and eight-lane divided arterials with AADT greater than 34,000 vehicles/day are shown in Table 14-25 (32). Table 14-25 also summarizes the effects on non-injury, injury, rear-end, and angle crashes. The information in Table 14-25 is based on arterials with the following characteristics:

- Posted speed limits between 40 and 55 mph,
- No on-street parking, and
- Segments 0.1 to 0.25 miles long.

Additional information regarding the setting of the intersections, median width, and the minor street volume are not specified in the original studies.

The base condition for the CMFs summarized in Table 14-25 (i.e., the condition in which the CMF = 1.00) consists of an unsignalized intersection that provides direct left-turns.

Table 14-25. Potential Crash Effects of Replacing Direct Left-Turns with Right-Turn/U-Turn Combination (32)

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Std. Error
Replace direct left-turn with right-turn/U-turn	Unspecified (Unsignalized intersections- access points on 4-, 6-, and 8-lane divided arterial)	Arterial AADT > 34,000 Minor road/ access point volume unspecified	All types (All severities)	**0.80**	**0.1**
			All types (Non-injury)	*0.89*	*0.2*
			All types (Injury)	*0.64*	*0.2*
			Rear-end (All severities)	*0.84*	*0.2*
			Angle (All severities)	*0.64*	*0.2*
	Unspecified (Unsignalized intersections- access points on 4-lane divided arterial)		All types (All severities)	*0.49*	*0.3*
	Unspecified (Unsignalized intersections- access points on 6-lane divided arterial)		All types (All severities)	*0.86*	*0.2*
			All types (Non-injury)	*0.95**	*0.2*
			All types (Injury)	*0.69*	*0.2*
			Rear-end (All severities)	*0.91**	*0.3*
			Angle (All severities)	*0.67*	*0.3*
Base Condition: An unsignalized intersection that provides direct left-turns.					

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

14.7.2.6. Permit Right-Turn-on-Red Operation

Right-turn operations are generally determined by considering traffic flows at the intersection and the intersection design. Right-turn operations at traffic signals may include restricted, permitted, or right-turn-on-red phasing.

Urban, suburban, and rural signalized intersections

Permitting right-turn-on-red operation at signalized intersections:

- Increases pedestrian and bicyclist crashes (27);
- Increases injury and non-injury crashes involving right-turning vehicles (9); and
- Increases the total number of crashes of all types and severities (7).

The effects on crash frequency of permitting right-turn-on-red operations at signalized intersections are presented in Table 14-26.

Alternatively, right-turn operations can be considered from the perspective of prohibiting right-turn-on-red operations, rather than permitting right-turn-on-red. The CMF for prohibiting right-turn-on-red on one or more approaches to a signalized intersection is determined as:

$$CMF = (0.98)_{nprohib} \tag{14-7}$$

Where:

CMF = crash modification factor for the effect of prohibiting right-turn-on-red on total crashes (not including vehicle-pedestrian and vehicle-bicycle collision); and

$nprohib$ = number of signalized intersection approaches for which right-turn-on-red is prohibited.

Both forms of the CMFs are consistent with one another.

Care should be taken to recognize the base conditions for this treatment (i.e., the condition in which the CMF = 1.00). When considering the crash effects of permitting right-turn-on-red operations, the base condition for the CMFs above is a signalized intersection prohibiting right-turns-on-red. Alternatively, when considering the CMF for prohibiting right-turn-on-red operations at one or more approaches to a signalized intersection, the base condition is permitting right-turn-on-red at all approaches to a signalized intersection.

Table 14-26. Potential Crash Effects of Permitting Right-Turn-On-Red Operation (7,27)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Permit right-turn-on-red	Unspecified (Signalized)	Unspecified	Pedestrian and bicyclist (All severities) (27)	**1.69+**	**0.1**
			Pedestrian (All severities) (27)	*1.57*	*0.2*
			Bicyclist (All severities) (27)	*1.80*	*0.2*
			Right-turn (Injury) (9)	**1.60**	**0.09**
			Right-turn (Non-injury) (9)	**1.10**	**0.01**
			All types (All severities) (7)	**1.07**	**0.01**
Base Condition: A signalized intersection with prohibited right-turn-on-red operation.					

NOTE: (6) Based on U.S. studies: McGee and Warren 1976; McGee 1977; Preusser, Leaf, DeBartolo, Blomberg and Levy 1982; Zador, Moshman and Marcus 1982; Hauer 1991.
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.
+ Combined CMF, see Part D—Introduction and Applications Guidance.

14.7.2.7. Modify Change Plus Clearance Interval

Intersection signal operational characteristics, such as cycle lengths and change plus clearance intervals, are typically based on the established practices and standards of the jurisdiction. Intersection-specific characteristics, such as traffic flows and intersection design, influence certain signal operational changes. Signal timings, clearance intervals, and cycle lengths at intersections can vary greatly. This section addresses modifications to the change plus clearance interval of an intersection and the corresponding effects on crash frequency.

Urban, suburban, and rural four-leg intersections

The ITE "Proposed Recommended Practice for Determining Vehicle Change Intervals" suggests determining the change plus clearance interval based on:

- Driver perception/reaction time;
- Velocity of approaching vehicles;
- Deceleration rate;
- Grade of the approach;
- Intersection width;
- Vehicle length;
- Velocity of approaching vehicle; and
- Pedestrian presence (28).

Table 14-27 summarizes the specific CMFs related to modifying the change plus clearance interval. The base condition for the CMFs summarized in Table 14-27 (i.e., the condition in which the CMF = 1.00) was unspecified.

Table 14-27. Potential Crash Effects of Modifying Change Plus Clearance Interval (28)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Modify change plus clearance interval to ITE 1985 Proposed Recommended Practice	Unspecified (Four-leg signalized)	Unspecified	All types (All severities)	__0.92*__	**0.07**
			All types (Injury)	**0.88**	**0.08**
			Multiple-vehicle (All severities)	__0.95*__	**0.07**
			Multiple-vehicle (Injury)	__0.91*__	**0.09**
			Rear-end (All severities)	_1.12_[?]	_0.2_
			Rear-end (Injury)	_1.08*_[?]	_0.2_
			Right angle (All severities)	_0.96*_[?]	_0.2_
			Right angle (Injury)	_1.06_[?]	_0.2_
			Pedestrian and Bicyclist (All severities)	_0.63_	_0.3_
			Pedestrian and Bicyclist (Injury)	_0.63_	_0.3_
Base Condition: Unspecified.					

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.

* 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 rear-end crashes and right-angle injury crashes and a decrease in other crash types and severities. See Chapter 3.
Change plus clearance interval is the yellow-plus-all-red interval.

14.7.2.8. Install Red-Light Cameras at Intersections

Various Intelligent Transportation System (ITS) treatments are available for at-grade intersections. Treatments include signal coordination, red-light hold systems, queue detection systems, automated enforcement, and red-light cameras. At the time of this edition of the HSM, red-light cameras were the only treatment for which the crash effects were better understood. This section discusses the effects on crash frequency of installing red-light cameras.

Red-light cameras are positioned along the approaches to intersections with traffic signals to detect and record the occurrence of red-light violations. Installing red-light cameras and the associated enforcement program is generally accompanied by signage and public information programs.

Urban signalized intersections

The crash effects of installing red-light cameras at urban signalized intersections are shown in Table 14-28. The base condition for the CMFs shown in Table 14-28 (i.e., the condition in which the CMF = 1.00) is a signalized intersection without red-light cameras.

Table 14-28. Potential Crash Effects of Installing Red-Light Cameras at Intersections (23,30)

Treatment	Setting (Intersection Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Install red-light cameras	Urban (Unspecified)	Unspecified	Right-angle and left-turn opposite direction (All severities) (23,30)	**0.74**[?+]	**0.03**
			Right-angle and left-turn opposite direction (Injury) (23)	**0.84**[?]	**0.07**
			Rear-end (All severities) (23,30)	**1.18?**[+]	**0.03**
			Rear-end (Injury) (23)	**1.24**[?]	**0.1**
Base Condition: A signalized intersection without red-light cameras.					

NOTE: **Bold** text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
vpd = vehicles per day
\+ Combined CMF, see Part D—Introduction and Applications Guidance.
? Treatment results in a decrease in right-angle crashes and an increase in rear-end crashes. See Chapter 3.

It is possible that installing red-light cameras at intersections will result either in a positive spillover effect or in crash migration at nearby intersections or throughout a jurisdiction. A positive spillover effect is the reduction of crashes at adjacent intersections without red-light cameras due to drivers' sensitivity to the possibility of a red-light camera being present. Crash migration is a reduction in crash occurrence at the intersections with red-light cameras and an increase in crashes at adjacent intersections without red-light cameras as travel patterns shift to avoid red-light camera locations. However, the existence and/or magnitude of the crash effects are not certain at this time.

14.8. CONCLUSION

The treatments discussed in this chapter focus on the crash effects of characteristics, design elements, traffic control elements, and operational elements related to intersections. 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 intersection treatments is contained in Appendix 14A.

The remaining chapters in Part D present treatments related to other site types such as roadway segments 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.

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APPENDIX 14A—TREATMENTS WITHOUT CMFs

14A.1. INTRODUCTION

This 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:

- Intersection Types (Section 14A.2);
- Access Management (Section 14A.3);
- Intersection Design Elements (Section 14A.4);
- Traffic Control and Operational Elements (Section 14A.5); and
- Treatments with Unknown Crash Effects (Section 14A.6).

14A.2. INTERSECTION TYPES

14A.2.1. Intersection Type Elements with No CMFs—Trends in Crashes or User Behavior

14A.2.1.1. Convert a Signalized Intersection to a Modern Roundabout

European experience suggests that single-lane modern roundabouts appear to increase safety for pedestrians and bicyclists (13,37). ADA requirements to serve pedestrians with disabilities can be incorporated through roundabout planning and design.

There are some specific concerns related to visually impaired pedestrians and the accessibility of roundabout crossings. Concerns are related to the ability to detect audible cues that may not be as distinct as those detected at rectangular intersections; these concerns are similar to the challenges visually impaired pedestrians also encounter at channelized, continuous flowing right-turn lanes and unsignalized midblock crossings. At the time of this edition of the HSM, specific safety information related to this topic was not available.

14A.2.1.2. Convert a Stop-Control Intersection to a Modern Roundabout

See Section 14A.2.1.1.

14A.3. ACCESS MANAGEMENT

14A.3.1. Access Management Elements with No CMFs—Trends in Crashes or User Behavior

14A.3.1.1. Close or Relocate Access Points in Intersection Functional Area

Access points are considered minor-street, side-street, and private driveways intersecting with a major roadway. The intersection functional area (Figures 14-1 and 14-2) is defined as the area extending upstream and downstream from the physical intersection area and includes auxiliary lanes and their associated channelization (1).

It is intuitive and generally accepted that reducing the number of access points within the functional areas of intersections reduces the potential for crashes (5,34). Restricting access to commercial properties near intersections by closing private driveways on major roads or moving them to a minor-road approach reduces conflicts between through and turning traffic. This reduction in conflicts may lead to reductions in rear-end crashes related to speed changes near the driveways, and angle crashes related to vehicles turning into and out of driveways (5).

In addition to the reduction in conflicts, it is possible that locating driveways outside of the intersection functional area also provides more time and space for vehicles to turn or merge across lanes (21). It is generally accepted that access points located within 250 ft upstream or downstream of an intersection are undesirable (34).

14A.3.1.2. Provide Corner Clearance

Corner clearances are the minimum distances required between intersections and driveways along arterials and collector streets. *"Driveways should not be situated within the functional boundary of at-grade intersections* (1)." Corner clearances vary greatly, from 16 ft to 350 ft, depending on the jurisdiction.

It is generally accepted that driveways that are located too close to intersections result in an increase in crashes, and as many as one half of crashes within the functional area of an intersection may be driveway-related (17).

14A.4. INTERSECTION DESIGN ELEMENTS

14A.4.1. General Information

The material below provides an overview of considerations related to shoulders/sidewalks and roadside elements at intersections. These two categories of intersection design elements are integral parts of intersection design; however, crash effects are not known to a statistically reliable and/or stable level to include as CMFs, or to identify trends within this edition of the HSM.

14A.4.1.1. Shoulders and Sidewalks

Shoulders are intended to perform several functions. Some of the main functions are: to provide a recovery area for out-of-control vehicles, to provide an emergency stopping area, and to improve the structural integrity of the pavement surface (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 control of stray vehicles.

Motorized vehicle perspective and considerations

Some concerns when increasing shoulder width include:

- Wider shoulders on the approach to an intersection may result in higher operating speeds through the intersection 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 turn lane.

Geometric design standards for shoulders are generally based on the intersection setting, amount of traffic, and right-of-way constraints (23).

Shoulders at mid-block or along roadway segments are discussed in Chapter 13.

14A.4.1.2. Roadside Elements

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 (4)". The AASHTO *Roadside Design Guide* is an invaluable resource for roadside design, including clear zones, geometry, features, and barriers (4).

The following sections discuss the general characteristics and considerations related to roadside geometry and roadside features.

Roadside geometry

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

AASHTO's *Policy on Geometric Design of Highways and Streets* states that a "a curb, by definition, incorporates some raised or vertical element (1)." Curbs are used primarily on low-speed urban highways, generally with a design speed of 45 mph or less (1).

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 AASHTO's *Roadside Design Guide* (4).

Chapter 13 includes information on clear zones, forgiving roadsides, and roadside geometry for roadway segments.

Roadside Elements—Roadside Features

Roadside features include signs, signals, luminaire supports, utility poles, trees, driver-aid call boxes, railroad crossing warning devices, fire hydrants, mailboxes, bus shelters, 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 (4). It is generally accepted that the best treatment for all roadside objects is to remove them from the clear zone (35). Because removal is not always possible, the objects may be relocated farther from the traffic flow, shielded with roadside barriers, or replaced with breakaway devices (35).

Roadside features on roadway segments are discussed in Chapter 13.

14A.4.2. Intersection Design Elements with No CMFs—Trends in Crashes and/or User Behavior

14A.4.2.1. Provide bicycle lanes or wide curb lanes at intersections

Bicycle lane is defined as a part of the roadway that is designated for bicycle traffic and separated by pavement markings from motor vehicles in adjacent lanes. Most often, bicycle lanes are installed near the right edge or curb of the road, although they are sometimes placed to the left of right-turn lanes or on-street parking (3). An alternative to providing a dedicated bicycle lane is to provide a wide curb lane. A wide curb lane is defined as a shared-use curb lane that is wider than a standard lane and can accommodate both vehicles and bicyclists.

Table 14A-1 below summarizes the crash effects and other observations known, at this time, related to bicycle lanes and wide curb lanes.

Table 14A-1. Summary of Bicycle Lanes and Wide Curb Lanes Crash Effects

Application	Crash Effect	Other Comments
Bicycle lanes at signalized intersections	Appears to have no crash effect on bicycle-motor vehicle crashes or overall crashes (29).	None
Bicycle lanes at minor-road stop-controlled intersections	May increase bicycle-motor vehicle crashes (29).	Magnitude of increase is uncertain.
Wide curb lane greater than 12 ft	Appears to improve the interaction between bicycles and motor vehicles in the shared lane (33).	There is likely a lane width beyond which safety may decrease due to misunderstanding of shared space (33).
Bicycle lane versus wide curb lane	No trends indicating which may be better than the other in terms of safety.	Bicyclists appear to ride farther from the curb in bike lanes that are 5.2-ft wide or greater compared to wide curb lanes under the same traffic volume (28).
		Bicyclist's compliance at traffic signals does not appear to differ between bicycle lanes and wide lanes (33).
		More bicyclists may comply at stop signs with bike lanes compared to wide curb lanes (33).
		At wide curb lane locations, bicyclists may perform more pedestrian style left- and right-turns (i.e., dismounting and use crosswalk) compared to bike lanes (33). At this time, it is not clear which turning maneuver (as a car or a pedestrian) is safer.

14A.4.2.2. Narrow Roadway at Pedestrian Crossing

Narrowing the roadway width using curb extensions, sometimes called chokers, curb bulbs, neckdowns, or nubs, extends the curb line or sidewalk out into the parking lane, and thus reduces the street width for pedestrians crossing the road. Curb extensions can also be used to mark the start and end of on-street parking lanes.

Reducing the street width at intersections appears to reduce vehicle speeds, improve visibility between pedestrians and oncoming motorists, and reduce the crossing distance for pedestrians (24).

14A.4.2.3. Install Raised Pedestrian Crosswalk

Common locations of crosswalks are at intersections on public streets and highways where there is a sidewalk on at least one side of the road. Marked crosswalks are typically installed at signalized intersections, school zones, and stop-controlled intersections (14). The specific application of raised pedestrian crosswalks most often occurs on local, urban, two-lane streets in residential or commercial areas. They may be applied at intersections or midblock.

Raised pedestrian crosswalks are often considered as a traffic calming treatment to reduce vehicle speeds at locations where vehicle and pedestrian movements conflict with each other.

On urban and suburban two-lane roads, this treatment appears to reduce injury crashes (13). It is reasonable to conclude that raised pedestrian crosswalks have an overall positive effect on crash frequency because they are designed to reduce vehicle operating speed (13). However, the magnitude of the crash effect is not certain at this time. The manner in which the crosswalks were raised is not provided in the original study from which the above information was gathered.

14A.4.2.4. Install Raised Bicycle Crossing

Installing a raised bicycle crossing can be considered a form of traffic calming as a means to slow vehicle speeds and create a defined physical separation of a bicycle crossing relative to the travel way provided for motor vehicles.

Installing raised bicycle crossings at signalized intersections appears to reduce bicycle-motor vehicle crashes (29). However, the magnitude of the crash effect is not certain at this time.

14A.4.2.5. Mark Crosswalks at Uncontrolled Locations (Intersection or Midblock)

Common locations of crosswalks are at intersections on public streets and highways where there is a sidewalk on at least one side of the road. Marked crosswalks are typically installed at signalized intersections, school zones, and stop-controlled intersections (14). This section discusses the crash effects of providing marked crosswalks at uncontrolled locations – the uncontrolled approaches of stop-controlled intersection or uncontrolled midblock locations.

Table 14A-2 summarizes the effects on crash frequency and other observations related to marking crosswalks at uncontrolled locations.

Table 14A-2. Potential Crash Effects of Marked Crosswalks at Uncontrolled Locations (Intersections or Midblock)

Application	Crash Effect	Other Comments
Two-lane roads and multilane roads with < 12,000 AADT	A marked crosswalk alone, compared to an unmarked crosswalk, appears to have no statistically significant effect on pedestrian crash rate (pedestrian crashes per million crossings) (45).	The magnitude of the crash effect is not certain at this time.
Approaches with a 35 mph speed limit on recently resurfaced roads	No specific crash effects are apparent or known.	Marking pedestrian crosswalks appears to slightly reduce vehicle approach speeds (10,31). Drivers at lower speeds are generally more likely to stop and yield to pedestrians than higher-speed drivers (10).
Two- or three-lane roads with speed limits from 35 to 40 mph and AADT < 12,000 veh/day	Marking pedestrian crosswalks appears to have no measurable negative crash effect on either pedestrians or motorists (32).	Crosswalk usage appears to increase after markings are installed (32).
		Pedestrians walking alone appear to stay within marked crosswalk lines (32).
		Pedestrians walking in groups appear to take less notice of markings (32).
		There is no evidence that pedestrians are less vigilant or more assertive in the crosswalk after markings are installed (32).
Multilane roads with AADT > 12,000 veh/day	A marked crosswalk alone appears to result in a statistically significant increase in pedestrian crash rates compared to uncontrolled sites with unmarked crosswalks (45).	None.

When deciding whether to mark or not mark crosswalks, the results summarized in Table 14A-2 indicate the need to consider the full range of elements related to pedestrian needs when crossing the roadway (45).

14A.4.2.6. Provide a Raised Median or Refuge Island at Marked and Unmarked Crosswalks

Table 14A-3 summarizes the crash effects known related to the crash effects of providing a raised median or refuge island at marked or unmarked crosswalks.

Table 14A-3. Potential Crash Effects of Providing a Raised Median or Refuge Island at Marked and Unmarked Crosswalks

Application	Crash Effect	Other Comments
Multilane roads marked or unmarked intersection and midblock locations	Treatment appears to reduce pedestrian crashes (45).	None.
Urban or suburban multilane roads (4 to 8 lanes) with marked crosswalks and an AADT of 15,000 veh/day or greater	Pedestrian crash rate is lower with a raised median than without a raised median (45).	The magnitude of the crash effect is not certain at this time.
Unsignalized four-leg intersections across streets that are two-lane with parking on both sides and use zebra crosswalk markings	No specific crash effect known.	Refuge islands appear to increase the percentage of pedestrians who cross in the crosswalk and the percentage of motorists who yield to pedestrians (24).

14A.5. TRAFFIC CONTROL AND OPERATIONAL ELEMENTS

14A.5.1. Traffic Control and Operational Elements with No CMFs—Trends in Crashes or User Behavior

14A.5.1.1. Place Transverse Markings on Roundabout Approaches

Transverse pavement markings are sometimes placed on the approach to roundabouts that are preceded by long stretches of highway (18). One purpose of transverse markings is to capture the motorists attention of the need to slow down on approach to the intersection. In this sense, transverse markings can be considered a form of traffic calming. Transverse pavement markings are one potential calming measure; in this section, the crash effect of its application to roundabout approaches is discussed.

This treatment appears to reduce all speed-related injury crashes, during wet or dry conditions, daytime and nighttime (18). However, the magnitude of the crash effect is not certain at this time.

14A.5.1.2. Install Pedestrian Signal Heads at Signalized Intersections

Pedestrian signal heads are generally desirable at certain types of locations, including school crossings, wide streets, or places where the vehicular traffic signals are not visible to pedestrians (14).

Providing pedestrian signal heads, with a concurrent or standard pedestrian signal timing pattern, at urban signalized intersections with marked crosswalks appears to have no effect on pedestrian crashes compared with traffic signals without pedestrian signal heads for those locations where vehicular traffic signals are visible to pedestrians (43,44).

14A.5.1.3. Modify Pedestrian Signal Heads

Pedestrian signal heads may be modified by adding a third pedestrian signal head with the message DON’T START, or by changing the signal displays to be steady or flashing during the pedestrian “don’t walk” phase. Table 14A-4 summarizes the crash effects known regarding modifying pedestrian signal heads.

Table 14A-4. Potential Crash Effects of Modifying Pedestrian Signal Heads

Application	Specific Modification to Pedestrian Signal Heads	Crash Effect and/or Resulting User Behavior
Urban signalized intersections with moderate to high pedestrian volumes	Add a third pedestrian signal head—a steady yellow DON'T START to the standard WALK and flashing DON'T WALK signal heads.	Treatment appears to reduce pedestrian violations and conflicts (43).
Signalized intersections	Use a steady or flashing DON'T WALK signal display during the clearance and pedestrian prohibition intervals.	No difference in pedestrian behavior (43). Pedestrians may not readily understand the word messages.
Signalized intersections	Use a steady or a flashing WALK signal display during the pedestrian WALK phase.	No difference in pedestrian behavior (4). Pedestrians may not readily understand the word messages.
Signalized intersections	Use of symbols on pedestrian signal heads, such as a walking person or upheld hand.	Shown to be more readily comprehended by pedestrians than word messages (10).

14A.5.1.4. Install Pedestrian Countdown Signals

Pedestrian countdown signals are a form of pedestrian signal heads that displays the number of seconds pedestrians have to cross the street; this information is provided in addition to displaying WALK and DON'T WALK information in the form of either word messages or symbols.

Installing pedestrian countdown signals appears to reduce pedestrian-motor vehicle conflicts at intersections (12). There appears to be no effect on vehicle approach speeds during the pedestrian clearance interval (i.e., the flashing DON'T WALK) with the countdown signals (12).

14A.5.1.5. Install Automated Pedestrian Detectors

Automated pedestrian detection systems can sense the presence of people standing at the curb waiting to cross the street. The system activates the WALK signal without any action from the pedestrian. The detectors in some systems can monitor slower walking pedestrians in the crossing so that clearance intervals can be extended until the pedestrians reach the curb. Infrared and microwave sensors appear to provide similar results. Fine tuning of the detection equipment at the location is required to achieve an appropriate detection level and zone.

Installing automated pedestrian detectors at signalized intersections appears to reduce pedestrian-vehicle conflicts as well as the percentage of pedestrian crossings initiated during the "don't walk" phase (26).

14A.5.1.6. Install Stop Lines and Other Crosswalk Enhancements

Installing pedestrian crossing ahead signs, a stop line, and yellow lights activated by pedestrians at marked intersection crosswalks appears to reduce the number of conflicts between motorists and pedestrians. This treatment also appears to increase the percentage of motorists that yield to pedestrians (11).

At marked intersection crosswalks, other treatments such as installing additional roadway markings and signs, providing feedback to pedestrians regarding compliance, and police enforcement, appear to increase the percentage of motorists who yield to pedestrians (11).

14A.5.1.7. Provide Exclusive Pedestrian Signal Timing Pattern

An exclusive pedestrian signal timing pattern provides a signal phase in which pedestrians are permitted to cross while motorists on the intersection approaches are prohibited from entering or traveling through the intersection.

At urban signalized intersections with marked crosswalks and pedestrian volumes of at least 1,200 people per day, this treatment appears to reduce pedestrian crashes when compared with concurrent timing or traffic signals with no pedestrian signals (43,44). However, the magnitude of the crash effect is not certain at this time.

14A.5.1.8. Provide Leading Pedestrian Interval Signal Timing Pattern

A leading pedestrian interval (LPI) is a pre-timed allocation to allow pedestrians to begin crossing the street in advance of the next cycle of vehicle movements. For example, pedestrians crossing the western leg of an intersection are traditionally permitted to cross during the north-south vehicle green phase. Implementing an LPI would provide pedestrians crossing the western leg of the intersection a given amount of time to start crossing the western leg after the east-west vehicle movements and before the north-south vehicle movements. The LPI provides pedestrians an opportunity to begin crossing without concern for turning vehicles (assuming right-on-red is permitted).

Providing a three-second LPI at signalized intersections with pedestrian signal heads and a one-second, all-red interval appears to reduce conflicts between pedestrians and turning vehicles (40). In addition, a three-second LPI appears to reduce the incidence of pedestrians yielding the right-of-way to turning vehicles, making it easier for pedestrians to cross the street by allowing them to occupy the crosswalk before turning vehicles are permitted to enter the intersection (40).

14A.5.1.9. Provide Actuated Control

The choice between actuated or pre-timed operations is influenced by the practices and standards of the jurisdiction. Intersection-specific characteristics such as traffic flows and intersection design also influence the use of actuated or pre-timed phases.

For the same traffic flow conditions at an actuated signal and pre-timed signal, actuated control appears to reduce some types of crashes compared with pre-timed traffic signals (7). However, the magnitude of the crash effect is not certain at this time.

14A.5.1.10. Operate Signals in "Night-Flash" Mode

Night-flash operation or mode is the use of flashing signals during low-volume periods to minimize delay at a signalized intersection.

Research indicates that replacing night-flash with regular phasing operation may reduce nighttime and nighttime right-angle crashes (19). However, the results are not sufficiently conclusive to determine a CMF for this edition of the HSM.

The crash effect of providing "night-flash" operations appears to be related to the number of approaches to the intersection (8).

14A.5.1.11. Provide Advance Static Warning Signs and Beacons

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) (14), 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 signage 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. This section discusses the crash effects of providing advance static warning signs with beacons.

Providing advance static warning signs with beacons prior to an intersection appears to reduce crashes (9). This treatment may have a larger crash effect when drivers do not expect an intersection or have limited visibility to the intersection ahead (5). However, the magnitude of the crash effect is not certain at this time.

14A.5.1.12. Provide Advance Warning Flashers and Warning Beacons

An advance warning flasher (AWF) is a traffic control device that provides drivers with advance information on the status of a downstream traffic signal. AWFs may be responsive (i.e., linked to the signal timing mechanism) or continuous. Continuous AWFs are also called warning beacons.

The crash effects of responsive AWFs appear to be related to entering traffic flows from minor- and major-road approaches (38).

14A.5.1.13. Provide Advance Overhead Guide Signs

The crash effect of advance overhead directional or guide signs appears to reduce crashes. However, the magnitude of the crash effect is not certain at this time (9).

14A.5.1.14. Install Additional Pedestrian Signs

Additional pedestrian signs include YIELD TO PEDESTRIAN WHEN TURNING signs for motorists and PEDESTRIANS WATCH FOR TURNING VEHICLES signs for pedestrians.

In general, additional signs may reduce conflicts between pedestrians and motorists. However, it is generally accepted that signage alone does not have a substantial effect on motorist or pedestrian behavior without education and enforcement (25).

Table 14A-5 summarizes the known and/or apparent crash effects or changes in user behavior as the result of installing additional pedestrian signs.

Table 14A-5. Potential Crash Effects of Installing Additional Pedestrian Signs

Application	Specific Pedestrian Signs	Crash Effect and/or Resulting User Behavior
Intersections permitting pedestrians crossings	Install a red and white triangle YIELD TO PEDESTRIAN WHEN TURNING sign (36″ x 36″ x 36″)	Reduces conflicts between pedestrians and turning vehicles (44).
Intersections permitting pedestrians crossings	Provide a black-on-yellow PEDESTRIANS WATCH FOR TURNING VEHICLES sign	Decreases conflicts between turning vehicles and pedestrians (44).
Intersections with a history of pedestrian violations such as crossing against the signal	Install a sign explaining the operation of pedestrian signal	Appears to increase pedestrian compliance and reduce conflicts with turning vehicles (44).
Signalized intersections permitting pedestrian crossings	Provide a three-section signal that displays the message WALK WITH CARE during the crossing interval to warn pedestrians about turning vehicles or potential red-light running vehicles	Reduces pedestrian signal violations and reduces conflicts with turning vehicles (44).
Marked crosswalks at unsignalized locations	Provide an overhead CROSSWALK sign	Increases the percentage of motorists that stop for pedestrians (25).
Narrow low-speed roadways, unsignalized intersections	Install overhead, illuminated CROSSWALK sign with high-visibility ladder crosswalk markings	Increases the percentage of motorists who yield to pedestrians (36).
		Increases the percentage of pedestrians who use the crosswalk (36).
Marked crosswalks at unsignalized locations	Install pedestrian safety cones reading STATE LAW – YIELD TO PEDESTRIANS IN CROSSWALK IN YOUR HALF OF ROAD	Increases the percentage of motorists that stop for pedestrians (25).

14A.5.1.15. Modify Pavement Color for Bicycle Crossings

Modifying the pavement color at locations where bicycle lanes cross through an intersection is intended to increase the bicycle lanes conspicuity to motorists turning through or across the bicycle lane that is passing through the intersection. Increasing the conspicuity of the bicycle lane is intended to increase awareness of the presence of bicyclists, thereby reducing the number of vehicle-bicycle crashes.

Modifying the pavement color of bicycle path crossing points at unsignalized intersections (e.g., blue pavement) increases bicyclist compliance with stop signs and crossing within the designated area (28). In addition, there is a reduction in vehicle-bicycle conflicts (27).

Modifying the pavement color of bicycle lanes at exit ramps, right-turn lanes, and entrance ramps has the following effects:

- Increases the proportion of motorists yielding to cyclists;
- Increases bicyclists' use of the designated area;
- Increases the incidence of motorists slowing or stopping on the approach to conflict areas;
- Decreases the incidence of bicyclists slowing on the approach to conflict areas;
- Decreases motorists' use of turn signals; and
- Decreases hand signaling and head turning by bicyclists (27).

14A.5.1.16. Place "Slalom" Profiled Pavement Markings on Bicycle Lanes

Placing profiled pavement markings on the pavement between bicycle lanes and motor vehicles lanes is intended to increase the lateral distance between bicyclists and motorists on intersection approaches, and to increase the attentiveness of both types of road users (27). Profiled pavement markings can be applied to create a "slalom" effect, first directing bicyclists closer to the vehicle lane and then diverting bicyclists away from the vehicle lanes close to the stop bar.

Placing "slalom" profiled pavement markings at four-leg and T-intersections appears to regulate motorist speed to that of the bicyclists (27). These markings also result in more motorists staying behind the stop line at the intersection and reduce the number of motorists who turn right in front of a bicyclist (27).

14A.5.1.17. Install Rumble Strips on Intersection Approaches

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. They are designed so that each vehicle will encounter them. Transverse rumble strips have been used as part of traffic calming or speed management programs, in work zones, and in advance of toll plazas, intersections, railroad-highway grade crossings, bridges, and tunnels. They are also considered a form of traffic calming that can be used with the intent of capturing motorists' attention and slowing speeds sufficiently enough to provide drivers additional time for decision-making tasks.

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.

On the approach to intersections of urban roads with unspecified traffic volumes, this treatment appears to reduce all crashes of all severities (13). However, the magnitude of the crash effect is not certain at this time.

14A.6. TREATMENTS WITH UNKNOWN CRASH EFFECTS

14A.6.1. Treatments Related to Intersection Types

- Convert stop-control intersection to yield-control intersection (not a roundabout)
- Convert uncontrolled intersection to yield, minor-road, or all-way stop control
- Remove unwarranted signals on two-way streets
- Close one or more intersection legs
- Convert two three-leg intersections to one four-leg intersection
- Install right-left or left-right staggering of two three-leg intersections
- Convert intersection approaches from urban two-way streets to a couplet or vice versa

14A.6.2. Treatments Related to Intersection Design Elements

Approach Roadway Elements

- Eliminate through vehicle path deflection
- Increase shoulder width
- Provide a sidewalk or shoulder at an intersection
- Increase pedestrian storage at intersection via sidewalks, shoulders, and/or pedestrian refuges
- Modify sidewalk width or walkway width
- Provide separation between the walkway and the roadway (i.e., buffer zone)
- Change the type of walking surface provided for pedestrians on sidewalks and/or crosswalks
- Modify sidewalk cross-slope, grade, curb ramp design
- Provide a left-turn bypass lane or combined bypass right-turn lane
- Modify lane width
- Provide positive offset for left-turn lanes
- Provide double or triple left-turn lanes
- Provide median left-turn acceleration lane
- Provide right-turn acceleration lanes
- Change length of left-turn and right-turn lanes
- Change right-turn curb radii
- Provide double right-turn lanes
- Provide positive offset for right-turn lanes
- Provide shoulders or improve continuity at intersections
- Provide sidewalks or increase sidewalk width at intersections
- Provide a median, or change median shape or change length of median opening
- Provide a flush median at marked and unmarked crosswalks
- Modify pedestrian refuge island design (e.g., curb extensions, refuge island width)
- Presence of utility poles and vegetation on medians
- Provide grade separation for bicyclists
- Improve continuity of bicycle lanes

Roadside Elements

- Increase intersection sight triangle distance
- Flatten sideslopes
- Modify backslopes
- Modify transverse slopes

- Increase clear roadside recovery distance
- Provide a curb
- Change curb offset from the traveled way
- Change curb type
- Change curb material
- Increase the distance to the utility poles and decrease utility pole density
- Increase the distance to/or remove roadside features
- Change the location of tress, poles, posts, newsracks and other roadside features—crash effect from pedestrian and/or bicyclist perspective
- Increase sight distance for left-turning vehicles
- Delineate roadside features
- Modify drainage structures or features
- Modify location and support types of signs, signals, and luminaries
- Install breakaway devices
- Modify location and type of driver-aid call boxes, mailboxes, newspaper boxes, fire hydrants

14A.6.3. Treatments Related to Intersection Traffic Control and Operational Elements

- Provide signage for pedestrian and bicyclist information
- Provide illuminated pedestrian push buttons
- Provide late-release pedestrian signal timing pattern
- Install in-pavement lights at crosswalks
- Place advanced stop line or bike box pavement markings at bicycle lanes on intersection approaches
- Provide near-side pedestrian signal heads
- Adjust pedestrian signal timing for various pedestrian crossing speeds
- Install bicycle signal heads at signalized intersections
- Modify signalized intersection spacing
- Restrict turning movement at access points
- Install pedestrian half-signals at minor-road, stop-controlled intersections
- Convert pre-timed phases to actuated phases
- Convert protected/permitted to permitted/protected left-turn operations
- Convert leading protected to lagging protected left-turn operations
- Provide protected or protected-permitted left-turn phasing with the addition of a left-turn lane
- Reduce left-turn conflicts with pedestrians
- Install all-red clearance interval

- Modify cycle length
- Modify phase durations
- Implement split phases
- Install more conspicuous pavement markings
- Extend edgelines and centerlines through median openings and unsignalized intersections
- Place lane assignment markings
- Place stop bars at previously unmarked intersections
- Increase stop bar width at marked intersections
- Install post-mounted delineators at intersections
- Install markers and/or markings on curbs at intersections
- Install raised median
- Install speed humps or speed tables on intersection approaches
- Close the intersection or one leg of the intersection (e.g., diagonal diverters, half closures, full closures, median barriers)
- Implement or improve signal coordination
- Implement or improve queue detection system
- Implement automated speed enforcement

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