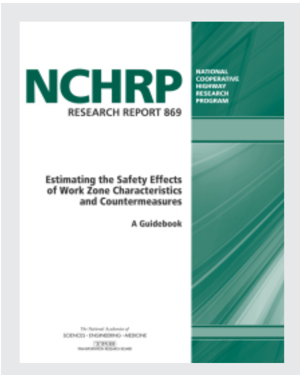

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 869

Estimating the Safety Effects of Work Zone Characteristics and Countermeasures

A Guidebook

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2018

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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NCHRP RESEARCH REPORT 869

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The authors also gratefully acknowledge the assistance of numerous state departments of transportation (DOT) personnel who participated in a survey of state practices. Lastly, this research could not have been completed without the special assistance of several members of the Virginia DOT, North Carolina DOT, Ohio DOT, Texas DOT, Utah DOT, and Washington State DOT who provided work zone project data for the various studies and analyses performed during the course of this research.

FOREWORD

By Waseem Dekelbab
Staff Officer
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NCHRP Research Report 869: Estimating the Safety Effects of Work Zone Characteristics and Countermeasures: A Guidebook will assist practitioners who develop phasing and staging plans for temporary traffic control through work zones in evaluating the safety impacts of their plan decisions. The material in this research report will be of immediate interest to agencies and consultants in their efforts to prepare and implement transportation management plans (TMPs) by providing a method for evaluating the potential safety benefits of certain impact mitigation countermeasures.

Work zone safety is of great concern to highway agencies, the construction industry, and the traveling public. Despite this concern, there is limited data on work zone crashes and fatalities that address trends, causality, and the best use of resources to improve work zone safety. Work zone crashes can occur both inside the work space and in the traffic space. There is no single solution to creating safer work zones. Effective countermeasures depend on understanding the characteristics of crashes (types of crashes, and where and when they are occurring), the characteristics of the work zone and roadway at the time of the crash, primary and contributing factors in the crash, measures of exposure, and the frequency with which certain characteristics occur. Having a greater understanding of this information will help in more effectively targeting efforts to improve work zone safety. Clear guidance was needed to encourage the use of a data-driven, comprehensive, collaborative planning approach for the selection and implementation of effective countermeasures to improve work zone safety. Over the last decade, numerous federal, state, and local initiatives to improve highway safety have resulted in the development of national and state Strategic Highway Safety Plans (SHSP), as well as the current Toward Zero Deaths initiative. Work zone safety is a component in many states' SHSPs. In spite of these efforts for comprehensive and collaborative safety planning, many institutional barriers still remain.

Under NCHRP Project 17-61, Texas A&M Transportation Institute was asked to develop comprehensive guidance on the characteristics of work zone crashes and the effectiveness of countermeasures in various categories (such as engineering, enforcement, education, emergency medical services, and public policy) to reduce work zone crash frequency and severity and improve overall work zone safety.

In addition to the guidebook published as *NCHRP Research Report 869*, the research agency's final report that documents the entire research effort is available as *NCHRP Web-Only Document 240: Analysis of Work Zone Crash Characteristics and Countermeasures.*

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

CHAPTER 1

Introduction

Work zones (WZs) are necessary to periodically maintain, rehabilitate, enhance, and reconstruct this nation's roadway network. The number of work zones that occur across the United States is significant. Over the course of 1 year, it was estimated that 26.5% of the National Highway System (NHS) experiences at least 1 day with a work zone in place on it (*1*). In the peak summer months, it was also estimated that 7.9% of the NHS had a work zone in place on it on any given workday. Unfortunately, evidence suggests that work zones tend to have an adverse effect on roadway safety. In 2013, a total of 527 fatal crashes occurred in work zones, leading to 579 fatalities (*2*). Overall, it was estimated that there were 67,523 crashes in work zones in 2013, of which 27.3% involved injuries or fatalities. These numbers also appear to be on the rise. In 2015, 642 fatal crashes occurred in work zones that resulted in 700 fatalities; both these figures are 20% higher than in 2013 (*3*).

How Do Work Zones Affect Safety?

In most situations, work must be performed at the same time that traffic is using the roadway. Depending on the work activities required, work zones can adversely affect the safety of traffic approaching and passing through them in several ways:

- Work zones often require workers, equipment, materials, barriers, and traffic control devices to be in close proximity to travel lanes (see Figure 1). This reduces the amount of space available for vehicles to maneuver and recover from small mistakes in vehicle control and guidance actions. In other words, crashes occur more frequently in a work zone because there are more objects in closer proximity to traffic than existed prior to the creation of the work zone.
- Work zones sometimes require the driver to make a temporary travel path change through a work zone when lanes are closed or shifted laterally (see Figure 2). Even if advance warning signs, channelization, and pavement markings are present to warn the driver, an increase in crashes can occur if the motorist is distracted from the driving task and fails to properly recognize the travel path changes. Crashes can also increase if the desired travel path itself is not clearly understood by all motorists.
- As Figure 3 depicts, lane closures and other restrictions in the work zone reduce the traffic-carrying capacity of the roadway. Depending on the traffic volumes, these changes can create traffic slowdowns or stoppages that are not expected by approaching motorists. These violations of driver expectancy can lead to collisions between vehicles as well as impacts with objects as drivers swerve to avoid running into the back of another vehicle.

Figure 1. Work zones often have objects in close proximity to open travel lanes.

Figure 2. Work zones often require drivers to make temporary travel path changes.

Figure 3. Work zones often create slowdowns and congestion by reducing the traffic-carrying capacity of the roadway.

How to Estimate the Expected Effects of Work Zones on Crashes

It would be beneficial for work zone designers and others to be able to predict the safety consequences of their proposed work zone design and management decisions prior to implementing them in the field. Examples of ways in which work zone crash estimates could be used include the following:

- Quantify the safety-related benefits of completing the work faster, which could be used to help establish accelerated contract incentives that are in line with those expected safety benefits.
- Estimate the expected impacts of safety countermeasures contemplated for use in the work zone as part of the transportation management plan (TMP).
- Predict the differences in safety effects of alternative work zone design options, for example, the safety consequences of narrowed lanes or closed shoulders, reductions in available entrance ramp acceleration lane lengths, and so forth.

Depending on the decision to be made, methods are needed to estimate the overall number of crashes expected to occur in a work zone and the incremental change in crashes resulting from different work zone features.

Options do exist for estimating the overall work zone crashes to be expected. These options vary in terms of the amount of data and level of effort required, as well as in the level of accuracy to be achieved. Planning-level work zone statistical crash models have been developed to provide rough approximations of the number of crashes expected at a particular work zone. Meanwhile, crash modification factors (CMFs) can be employed to estimate the incremental change in crashes due to alternative work zone features being considered, similar to procedures found in the *Highway Safety Manual* (HSM) (*4*). A CMF is a multiplicative factor used to indicate how a particular condition or feature increases or decreases the number of crashes expected from a set of base conditions. A CMF of 1.0 indicates that the feature has no incremental effect on crash risk. A CMF less than 1.0 indicates that the feature reduces crash risk, and a CMF above 1.0 indicates that the feature increases crash risk, relative to a set of base conditions. When multiple features are present, several CMFs are multiplied together to arrive at the overall estimate of the expected change in crashes. Although many CMFs have been developed for many different permanent roadway features in recent years, only a few work-zone-specific CMFs are currently available. In the absence of CMFs developed specifically for work zone features, the only available option is to utilize those that exist for permanent roadway features. In these cases, engineering judgment must then be applied when interpreting the results of the analysis.

Purpose and Organization of this Guidebook

This guidebook has been prepared to assist practitioners who develop phasing and staging plans for temporary traffic control through work zones to better evaluate the expected safety impacts of their plan decisions. The guidebook will also be useful to agencies, consultants, and contractors in their efforts to prepare and implement TMPs by providing a method for evaluating the potential benefits of certain safety countermeasures.

Chapter 2 describes planning-level work zone crash estimation approaches available to practitioners. Planning-level methods can provide a rough approximation of either (a) the total number of crashes expected to occur overall during a particular work zone or (b) the additional number of crashes expected to occur above that normally occurring on the roadway when the work zone is not present.

These approximations can be used in a number of ways—for example, estimating the safety benefits that would be achieved by accelerating work zone completion times by a certain amount or in determining an "expected" work zone crash rate per month that could be compared with actual crashes as a performance measure to see if the work zone is having a bigger safety impact than was expected.

Chapter 3 describes how trade-off analyses of the expected safety impacts of alternative work zone design features, operational strategies, and countermeasures can be performed. A trade-off analysis utilizes available CMFs together with planning-level estimates of overall work zone crashes to estimate the incremental changes in crashes that would be expected due to a change in a particular feature or the inclusion of a particular countermeasure. Examples are provided at the end of Chapters 2 and 3 to illustrate how the methods can be applied to answer different types of "what if" questions that a practitioner might encounter when developing a set of work zone plans or deciding whether or not to implement a particular work zone safety strategy.

Chapter 4 provides a comprehensive catalog of CMFs that are available for potential use in evaluating the expected safety effects of work zone features and strategies. Each CMF is described and its potential applicability to work zone analyses critiqued; however, some features of interest do not yet have CMFs developed for them. For those features, a discussion is provided of the known operational effects.

CHAPTER 2

Planning-Level Work Zone Crash Estimation Procedures

Rationale

Sometimes, an agency or contractor will have the need to estimate how many crashes are expected to occur in a work zone, or how many additional crashes are expected above and beyond what would normally occur on that roadway segment over the duration of the work zone. Consider the following examples:

Uses of Planning-Level Work Zone Crash Estimates

- Real-time crash frequency monitoring
- Road user cost computations
- Baseline for CMF analyses

- An agency might want to compare the cumulative number of crashes actually occurring at a work zone over time with a predicted rate of crashes expected. If more crashes begin to accrue in the work zone than what the estimate predicted, that may be a cue to the agency or contractor that a safety issue exists within the work zone and that additional investigation into the reasons for those crashes may be warranted.
- A planning-level estimate of the number of additional crashes expected at a work zone could also be useful to include as part of safety costs in road user cost computations when developing TMPs.
- Finally, planning-level work zone crash estimates will often be needed when comparing alternative design or operational strategies through a trade-off analysis because CMFs available for assessing the incremental effect of those alternatives require a baseline work zone crash estimate as a key input.

In this guidebook, two approaches are presented for generating overall planning-level work zone crash estimates:

1. Applying an overall work zone CMF to a pre-work-zone baseline estimate of crashes expected on the roadway segment where the work zone will occur. The pre-work-zone baseline may come from existing agency safety performance functions (SPFs) or another estimate of crash frequency on the route when a work zone is not present.
2. Utilizing a general SPF that has been created using work-zone-specific data.

Limitations

Significant limitations and caveats exist with the use of each approach. Both the overall work zone CMF and the general work zone SPF developed as part of this research effort were based on long-term Interstate and freeway work zone projects with the following characteristics before and during the work zones themselves:

- Pavement width = 40 ft in each direction for four-lane segments and 52 ft in each direction for six-lane segments (equal to 12-ft lanes, 6-ft inside shoulder, and 10-ft outer shoulder)
- No lane shifts present

- No long-term lane closures present
- Median width of 60 ft, which includes the inside shoulder width of 6 ft in both directions
- No longitudinal barriers present

The more that the pre-work-zone baseline conditions and work zone conditions differ from these ideal attributes, the more that the results of these planning-level analysis techniques will likely deviate from what actually occurs during the work zone. The practitioner must recognize the level of uncertainty inherent in the results obtained from these analyses. The results do not attempt to account for differences in work activities, work space operations, frequency of temporary lane closures, or other features that are believed to have some influence on crashes at a location during a work zone. The results also do not attempt to differentiate between severe (injury and fatal) crashes and property-damage-only (PDO) crashes. Finally, the results reflect work zones that were in place for several weeks at a time, which may or may not accurately reflect the effects of short-term or short-duration work zones. Nevertheless, for those agencies that do not have locally calibrated SPFs or work zone CMFs, these procedures provide at least an order-of-magnitude approximation of work zone safety impacts.

It is suggested that application of these procedures be limited to Interstate and freeway facilities, and potentially multilane divided highways with little or no driveway access and only infrequent non-signalized intersections. There has not been enough research conducted to date of work zones on other types of roadways to yield meaningful work zone SPFs or generic work zone CMFs. It is possible to perform some simplistic trade-off analyses of certain temporary changes to the roadway during the work zone, relying on baseline pre-work-zone SPFs, but the practitioner will again need to recognize the level of uncertainty associated with such analyses on these types of facilities.

Method 1: Using Pre-Work-Zone Crash Estimates and an Overall Work Zone CMF

For developing planning-level work zone crash estimates, the preferred approach is to apply an overall generic work zone CMF to the pre-work-zone baseline crash estimate for the roadway segment of interest. Although using a work-zone-based SPF to predict the number of crashes expected in a work zone may be simpler, estimates generated in that way do not take site-specific factors (other than the annual average daily traffic [AADT] value) into consideration. Therefore, applying an overall work zone CMF to a good pre-work-zone crash estimate would be expected to yield a better work zone crash estimate. Ideally, the normal (pre-work-zone) crash estimates would come from an SPF calibrated to the particular roadway segment utilizing methods contained in the HSM or agency-calibrated crash-prediction models. However, if that data is not available, the analyst may have to use other estimation methods. For example, the last 3 years of crashes occurring along the roadway segment could be used along with AADT values each year to determine a weighted yearly average of crashes.

An overall work zone CMF (WZCMF) for freeways and Interstate facilities has been developed from a multi-state dataset of four- and six-lane freeway and Interstate work zones. The CMF is based on a ratio of pre-work-zone and during-work-zone SPFs developed for those roadway segments. The ratios of those SPFs are given in the following equations:

Four-Lane Facilities

$$WZCMF_{4\text{-}lanes} = \frac{e^{-10.036+1.164\ln(AADT)}}{e^{-11.231+1.248\ln(AADT)}}$$

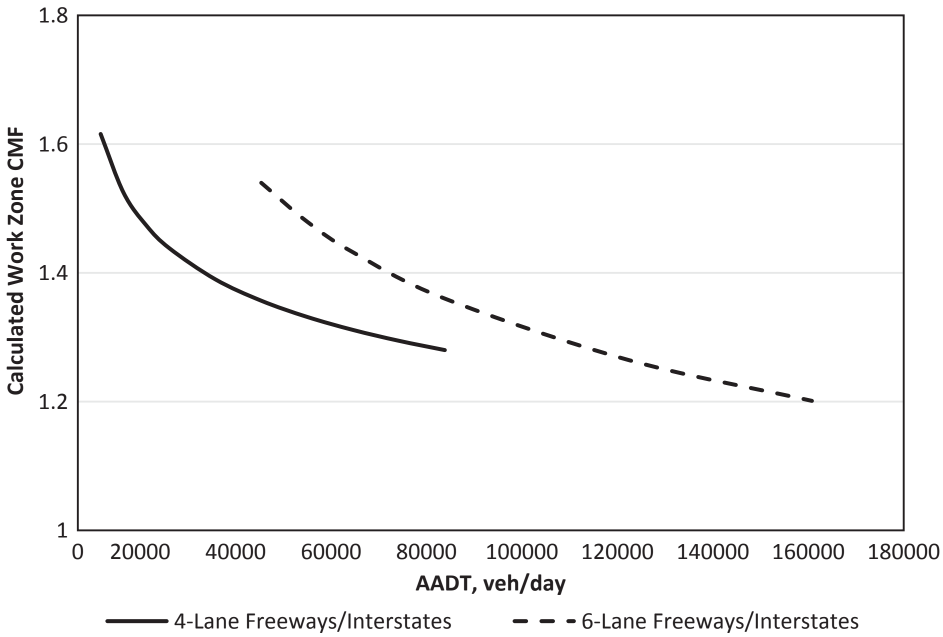

Figure 4. Planning-level work zone CMFs for freeways and Interstates.

Six-Lane Facilities

$$WZCMF_{6\text{-}lanes} = \frac{e^{-9.987+1.164\ln(AADT)}}{e^{-12.318+1.344\ln(AADT)}}$$

These equations result in very high CMFs at very low volumes, and taper off as traffic volumes increase. This is illustrated graphically in Figure 4. Even though the CMFs are higher at lower volumes, the number of additional crashes per mile per year that occur due to a work zone are lowest at the lower volumes and increase non-linearly as volumes increase.

To compute the total number of crashes expected during a work zone, the number of crashes normally occurring on the roadway segment each year is multiplied by the duration of the work zone and the overall work zone CMF calculated for the AADT of the roadway segment. If a crash rate is used, the rate is first multiplied by the length of the project, as shown following equation:

$$Expected\ WZ\ crashes = \left(\frac{Non\text{-}WZ\ crashes}{mile/year}\right)(Project\ length)\left(\frac{WZ\ duration\,(mo)}{12}\right)(WZCMF)$$

Method 2: Using a Work-Zone-Based SPF

If good data does not exist for the crash frequency that normally occurs on a section of freeway or Interstate where a work zone will be placed, a work-zone-based SPF can be used to develop a planning-level estimate of crashes expected during the work zone. The multi-state database of work zones performed on four- and six-lane Interstates and freeways was used to develop the following two predictive functions of the total number of work zone crashes expected to occur based on work zone length, work zone duration, and overall roadway AADT (*5*):

Four-Lane Freeway and Interstate Work Zones

$$Number\ of\ work\ zone\ crashes\ expected = L \times n \times e^{-10.036+1.164\ln(AADT)}$$

Six-Lane Freeway and Interstate Work Zones

$$\textit{Number of work zone crashes expected} = L \times n \times e^{-9.987+1.164\ln(AADT)}$$

where,

L = length of work zone, miles
n = number of years the work zone will require (or number of months/12)

The functions were developed with the following work zone conditions:

- Pavement width = 40 ft in each direction for four-lane segments and 52 ft in each direction for six-lane segments (equal to 12-ft lanes, 6-ft inside shoulder, and 10-ft outer shoulder)
- No lane shifts present
- No lane closures present
- Median width of 60 ft, which includes the inside shoulder width of 6 ft in both directions
- No longitudinal barriers present
- AADTs ranging between 5,000 and 70,000 vehicles per day (vpd) on the four-lane segments
- AADTs ranging between 50,000 and 150,000 vpd on the six-lane segments

Additional details regarding the development of these models (such as the standard errors of the parameters and overdispersion factors) are available in *NCHRP Web-Only Document 240*. Figure 5 illustrates these functions on a per-mile, per-year basis. One sees that the two functions are non-linear and nearly identical within the 50,000 to 70,000 vpd range where they overlap; however, similar work-zone-based functions do not exist for other roadway types at the present time.

Examples of Computing Planning-Level Work Zone Crash Estimates

The following examples illustrate how to calculate planning-level work zone crash estimates using these methods for a variety of possible purposes.

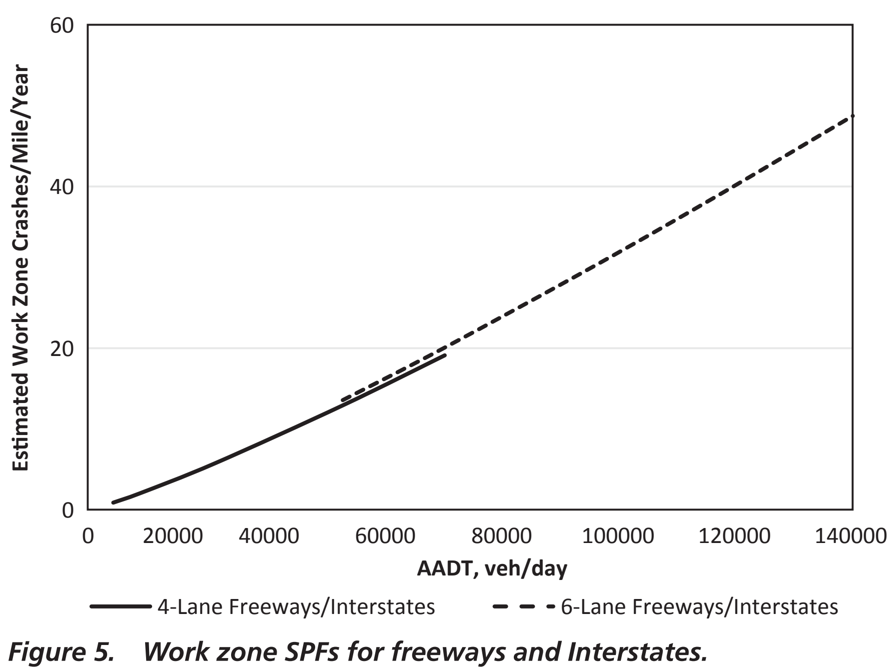

Figure 5. Work zone SPFs for freeways and Interstates.

Computing an Expected Crash Rate per Month During Construction

A project engineer plans to monitor crashes occurring during a 2-year, 3-mile Interstate widening construction project. The engineer will extract crashes from the statewide crash database for the roadway segment each month during the project, and wants to be able to detect if the number of crashes that occur becomes unusually high. The roadway has the following characteristics:

- Rural four-lane Interstate facility with typical Interstate standards (12-ft lanes, 6-ft inside shoulder, 10-ft outside shoulder, wide median)
- Expected traffic volume on the facility: 42,000 vpd during year 1 of the project and 45,000 vpd during year 2
- Based on a calibrated SPF developed by the agency, the normal non-work-zone crash rate on this facility is estimated to be 6.9 crashes per mile in year 1 and 7.4 crashes per mile in year 2

The project engineer decides to create a plot of cumulative crashes expected to occur over the duration of the project. Because good calibrated pre-work-zone crash models exist for the roadway segment, the project engineer chooses to use the overall WZCMF to estimate the number of crashes expected to occur during the project. A separate CMF is first computed for each of the 2 years of the project based on the following expected traffic volumes:

$$WZCMF_{4\text{-}lanes,\,year1} = \frac{e^{-10.036+1.164\ln(42{,}000)}}{e^{-11.231+1.248\ln(42{,}000)}} = 1.351$$

$$WZCMF_{4\text{-}lanes,\,year2} = \frac{e^{-10.036+1.164\ln(45{,}000)}}{e^{-11.231+1.248\ln(45{,}000)}} = 1.343$$

The project engineer then multiplies the normal expected crash rate each year by the length of the project, the duration of 1 year, and the work zone CMF computed for that year:

$$WZ\ crashes\ expected_{year\ 1} = \left(\frac{6.9\ crashes}{mile/year}\right)(3\ miles)(1\ year)(1.351) = 28.0\ crashes$$

$$WZ\ crashes\ expected_{year\ 2} = \left(\frac{7.4\ crashes}{mile/year}\right)(3\ miles)(1\ year)(1.351) = 29.8\ crashes$$

$$WZ\ crashes\ expected_{total} = 28.0 + 29.8 = 57.8\ crashes$$

In this example, the project engineer chose to utilize the AADT value for the entire year, and then divide the annual number by 12 to get a month-by-month crash estimate. If a more refined analysis is desired, seasonal factors can be applied to the AADT factors and seasonal WZCMFs can be developed and applied to determine the WZ crashes expected month-by-month of each season of each year.

Crashes actually occurring during the project could then be compared directly with the expected crashes month-by-month (or whatever time period was of interest to the agency) as well as cumulatively. Large deviations between the actual and expected crashes might be an indication that a safety issue exists at the site and additional investigation is needed.

For example, if the number of crashes actually occurring during the first 9 months of the project were as plotted against the expected number of crashes in Figure 6, the agency might conclude that actual crashes had tracked fairly closely to what was expected in the early months. However, crashes during the latest 2 months could be interpreted as trending somewhat higher than what would be expected. Based on this assessment, the project engineer might initiate a

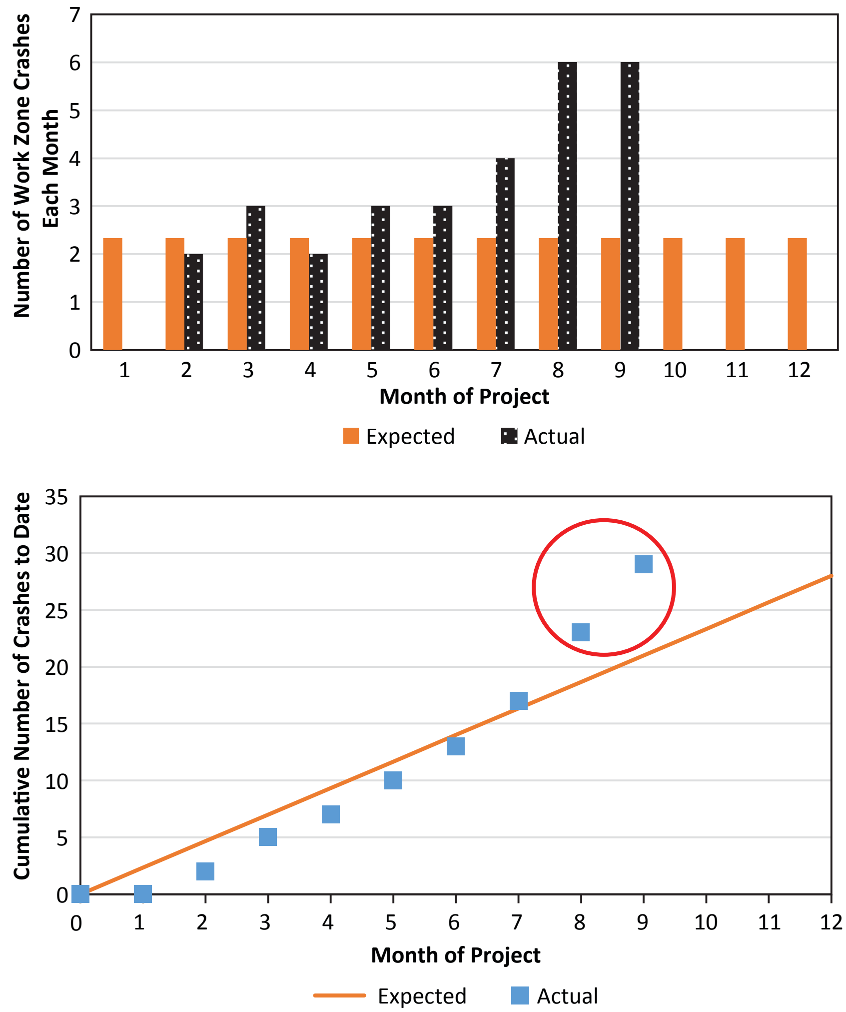

Figure 6. Expected versus actual work zone crashes using the work zone CMF method for this example.

more in-depth review of the crashes to determine potential reasons for the uptick in crashes. Perhaps the project has had a major traffic switch in recent months, work activities have involved more frequent deliveries of materials to the job site, or weather conditions have been particularly poor during this time.

Now, suppose that the project engineer does not have access to good non-work-zone crash data for the segment. In that case, the work zone SPF for four-lane facilities can have been applied instead. The computations would be as follows:

$$WZ\ crashes\ expected_{year\ 1} = (3\ miles)(1\ year)\left(e^{-10.036+1.164\ln(42{,}000)}\right) = 31.6\ crashes$$

$$WZ\ crashes\ expected_{year\ 2} = (3\ miles)(1\ year)\left(e^{-10.036+1.164\ln(45{,}000)}\right) = 34.3\ crashes$$

$$WZ\ crashes\ expected_{total} = 31.6 + 34.3 = 65.9\ crashes$$

Use of the work zone SPF would have yielded an estimate of 65.9 crashes expected over the 2-year project (2.75 crashes per month), approximately 14% higher than what was computed using the calibrated pre-work-zone crash rates and the overall work zone CMF. Plotting the

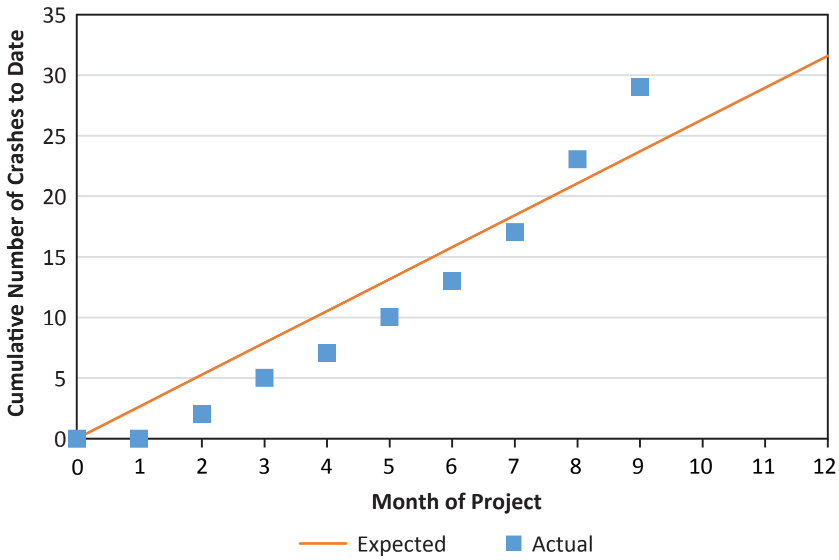

Figure 7. Expected versus actual crashes using the work zone SPF for this example.

actual crashes through 9 months of the project against this estimate (as shown in Figure 7) may or may not have led the engineer to conclude that crashes were becoming excessive relative to what was expected. The difference in results by the two methods is another reminder of the importance of engineering judgment when interpreting and using planning-level estimates such as these.

Estimating the Effect of Accelerated Construction on the Expected Number of Work Zone Crashes

An agency is contemplating including contract incentives in a bid package to reduce the overall duration of the project and is trying to come up with a rational, defensible value for the incentive. The work zone design team believes that by using traditional methods, the project would take 2 years to complete. If the winning contractor could reduce the duration of the project by 6 months, the agency would like to estimate how much that acceleration of the project could reduce crashes. The roadway has the following characteristics:

- Project is 4 miles long.
- It is an urban six-lane freeway facility.
- The traffic volume on the facility is expected to be approximately 120,000 vpd for year 1 of the project and 130,000 vpd for year 2 of the project.
- The freeway has 12-ft lanes, 6-ft inside shoulders, and 10-ft outside shoulders.
- The total crash density on this section of freeway is 32.6 crashes per mile per year before construction based on 3 years of historical data. Traffic volumes during those years averaged 110,000 vpd (similar to what is expected for year 1 of the project).

In this example, the agency is interested in the difference in crashes that would be expected to occur under the original 2-year project duration to the number that would be expected if the project were reduced to 18 months followed by 6 months of normal (non-work-zone) crash frequency. Unlike the previous example, the agency does not have a normal non-work-zone expected crash frequency for the roadway for each year of the project. Consequently, it will be necessary to estimate the normal pre-work-zone crash frequency for each of the 2 years of the project based on the data available. Since the only data available for use is the historical crash rate for the roadway segment associated with a lower AADT than that anticipated during the project, the agency would first factor the crash rate for the 2 years of the project using the following ratio of AADT numbers:

$$Year\ 1\ non\text{-}work\text{-}zone\ crash\ rate = \left(\frac{32.6\ crashes}{mile/year}\right)\left(\frac{120{,}000}{110{,}000}\right) = \frac{35.6\ crashes}{mile/year}$$

$$Year\ 2\ non\text{-}work\text{-}zone\ crash\ rate = \left(\frac{32.6\ crashes}{mile/year}\right)\left(\frac{130{,}000}{110{,}000}\right) = \frac{38.5\ crashes}{mile/year}$$

This factoring process assumed a linear relationship between crashes and AADT, which is typically not true. However, in the absence of local safety performance functions, it is considered to be a plausible planning-level assumption. Once the agency has a predicted non-work-zone crash rate for each year, work zone CMFs are then computed for each of the 2 years of the project based on the following expected traffic volumes:

$$WZCMF_{6\text{-}lanes,\,year\ 1} = \frac{e^{-9.987+1.164\ln(120{,}000)}}{e^{-12.318+1.344\ln(120{,}000)}} = 1.253$$

$$WZCMF_{6\text{-}lanes,\,year\ 2} = \frac{e^{-9.987+1.164\ln(130{,}000)}}{e^{-12.318+1.344\ln(130{,}000)}} = 1.235$$

The total number of crashes expected for each alternative can then be calculated. For Alternative 1:

$$Year\ 1\ expected\ WZ\ crashes_{Alt\ 1} = \left(\frac{35.6\ crashes}{mile/year}\right)(4\ miles)(1\ year)(1.253) = 178.4\ crashes$$

$$Year\ 2\ expected\ WZ\ crashes_{Alt\ 1} = \left(\frac{38.5\ crashes}{mile/year}\right)(4\ miles)(1\ year)(1.235) = 190.2\ crashes$$

$$Total\ expected\ WZ\ crashes_{Alt\ 1} = 178.4 + 190.2 = 368.6\ crashes$$

For Alternative 2, the expected number of crashes for year 1 of the project would remain the same. For the second year, the first 6 months would be at the expected work zone crash rate, and the second 6 months would be at the non-work-zone crash rate:

$$Year\ 2\ expected\ WZ\ crashes_{Alt\ 2} = \left(\begin{array}{c}\left(\frac{38.5\ crashes}{mi/yr}\right)\left(\frac{6\ mo}{12\ mo/yr}\right)(1.235)\\ +\left(\frac{38.5\ crashes}{mi/yr}\right)\left(\frac{6\ mo}{12\ mo/yr}\right)\end{array}\right)(4\ miles) = 172.1\ crashes$$

$$Total\ expected\ WZ\ crashes_{Alt\ 2} = 178.4 + 172.1 = 350.5\ crashes$$

$$Expected\ WZ\ crashes\ difference_{Alt\ 1-Alt\ 2} = 368.6 - 350.5 = 18.1\ crashes$$

Reducing the duration of the project by 6 months would be expected to result in 18.1 fewer crashes over the non-accelerated project schedule. If desired, the agency could apply

Table 1. Estimated crash cost savings if project duration can be reduced for this example.

Crash Severity Level	Proportional Distribution of Crash Severities	Proportion of the 18.1 Crashes Reduced	Average Crash Cost[1]	Crash Costs Saved If Project Is Accelerated
Fatality (K)	0.005	0.0905	$4.509,991	$408,154
Disabling injury (A)	0.018	0.3258	$242,999	$79,169
Evident injury (B)	0.088	1.5928	$88,875	$141,560
Possible injury (C)	0.136	2.4616	$50,512	$124,340
Property damage only (PDO)	0.753	13.6293	$8,325	$113,464
TOTAL	**1.000**	**18.1**		**$866,987**

[1]Crash Costs in the *Highway Safety Manual*, First Edition, updated to 2016 dollars.

comprehensive crash cost numbers to this value to estimate the road user safety cost savings that could be attributed to this reduction. For example, if the agency typically experiences a crash severity distribution on the facility similar to that shown in Table 1 and used typical crash cost values recommended in the HSM, reducing the project duration would be estimated to yield nearly $900,000 in crash cost savings. This would be in addition to any mobility-related savings that might also be achieved.

CHAPTER 3

Using CMFs to Evaluate Alternative Work Zone Design Features, Operating Strategies, and Safety Countermeasures

Rationale

Oftentimes, practitioners developing construction plans have options for accommodating traffic through the various phases or stages of the project. These alternatives can include factors such as whether or not to (a) close lanes or shoulders, (b) utilize narrower lanes on a temporary basis, (c) close ramps, and (d) reduce acceleration or deceleration lane lengths. Similarly, decisions are sometimes made whether or not to incorporate safety countermeasures such as targeted law enforcement or work zone intelligent transportation system (ITS) technology into the TMP for a project. When making decisions, it would be useful to know the differences in expected crashes among these alternatives.

Limitations

Computing the relative difference in crashes expected for two or more work zone alternatives is fairly straightforward if (1) appropriate CMFs of the particular features, strategies, or countermeasures are available and (2) an appropriate baseline estimate of crashes is available to which the CMFs can be applied. Some CMFs predict the effect of an incremental change in the value of a particular feature (e.g., change in crash likelihood per 1-ft decrease in lane or shoulder width), while other CMFs simply predict the change in crashes if a feature is added or removed. However, work-zone-specific CMFs are often lacking for many features of interest. In such instances, all that can be done is to apply CMFs developed for permanent roadway features to what is expected, understanding that the results obtained are only a rough approximation of how an alternative may affect crashes during the time that it is in place in the work zone. Still, such approximations can often provide useful insight into the potential value of the different alternatives being considered.

When comparing alternatives, it is important that practitioners remember to evaluate each one across the same time period. Often, one of the alternatives being considered will result in a work zone of shorter duration than the other. In these situations, it usually cannot be assumed that the alternative with the work zone of shorter duration will not experience any crashes during the saved time period relative to the other alternative. Rather, crashes will likely still occur at some normal (non-work-zone) frequency, as illustrated in the Estimating the Effect of Accelerated Construction on the Expected Number of Work Zone Crashes section in Chapter 2.

Method

The process of utilizing CMFs for trade-off analyses is fairly straightforward, as illustrated in Figure 8. The first step is to define the various work zone alternatives for which the expected

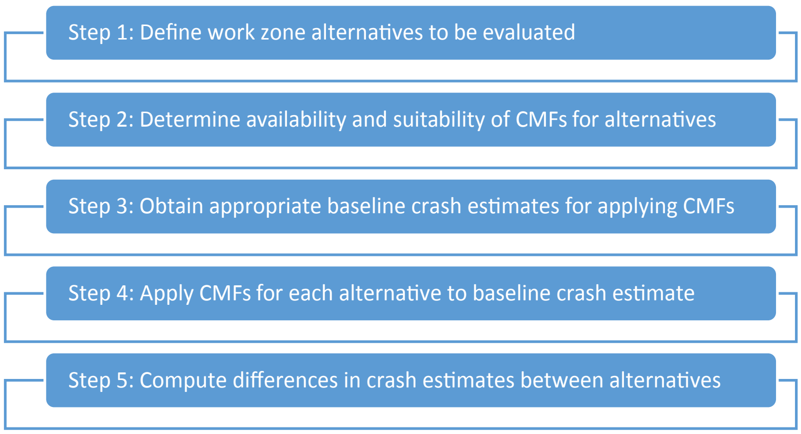

Figure 8. Use of CMFs for assessing trade-offs of various work zone features, strategies, and countermeasures.

safety effects are to be compared. Each feature, strategy, or countermeasure that differentiates between each alternative is defined. In addition, the expected length of the work zone or work zone segment affected by each alternative, expected duration of that alternative, and expected AADT are estimated.

The second step is to determine the availability and suitability of CMFs, describing how the differences in features, strategies, and countermeasures affect crash expectancies. The applicability of the CMF for work zone analyses is also assessed at this time to help gauge the level of confidence expected in the results obtained. Those CMFs developed using work-zone-specific data are likely to be more applicable and trustworthy estimates than those developed for permanent situations. However, CMFs developed for permanent situations may be the best available at the time for evaluating the effect of a particular feature. A catalog of available CMFs that could be used for work zone safety analyses is provided in Chapter 4. Also included in that chapter are a number of features and potential countermeasures for which no CMFs currently exist. The available information regarding the known operational or other effects of those features is provided to assist practitioners who must make decisions on whether or not to utilize them.

In the third step, baseline crash estimates are obtained or computed that will be used to evaluate each alternative. This is the baseline that the CMFs will be multiplied by to assess how the feature, strategy, or countermeasure will affect crashes. Some work zone CMFs have been developed relative to pre-work-zone conditions, whereas others were developed relative to a given set of baseline work zone conditions. It is important to determine what the baseline is for each CMF and to use that baseline estimate in the computations so that the best estimate of the incremental effect of the feature, strategy, or countermeasure can be computed.

As part of this step, it is important to recognize that there may be instances where a CMF developed with non-work-zone data might still be applied to a during-work-zone baseline crash estimate. For instance, even though a lane width CMF was developed using non-work-zone data, an analyst might choose to apply it to a work zone baseline estimate. While the incremental effect of the CMF would be based on non-work-zone conditions, applying it to a baseline estimate of crashes expected to occur in general in the work zone would yield a greater absolute change in crashes than if it were applied to the normal non-work-zone crash estimate for that segment, because crash frequencies in segments with work zones tend to be higher than when no work zone is present. Limitations do exist as to the accuracy of available data and methods for estimating baseline work zone crashes on most facilities. Consequently, the accuracy of the results obtained using this methodology will only be as accurate as the baseline crash estimates used.

The fourth and fifth steps of the procedure are multiplying the selected CMFs for each work zone alternative with its appropriate baseline crash estimate, and then computing crash estimate differences among the alternatives. The following section provides a few examples to illustrate this methodology.

Examples of Computing Crash Estimate Differences for Alternative Work Zone Design Features, Operating Strategies, and Safety Countermeasures

Estimating Benefits of an End-of-Queue Warning System

An agency is contemplating the use of a work zone ITS to warn traffic about queues developing during a 6-month bridge repair project on a roadway that crosses a four-lane Interstate facility. The contractor will perform nighttime lane closures (7 p.m. to 6 a.m.) on the Interstate to perform the work and will work 5 nights per week. The Interstate serves 70,000 vpd in this area, and queues are expected to develop each night of work. A traffic analysis indicates that traffic queues could grow to up to 5 miles on some nights. Normally, this section of Interstate experiences 14.8 crashes per mile per year, 50% of which occur during the hours when the work is scheduled to occur. The agency wishes to estimate how many crashes might be prevented if work zone ITS is incorporated into the project. The agency performs the following analysis.

Step 1. Define work zone alternatives to be compared

Alternative 1—perform the nighttime lane closures over the 6-month project without a work zone ITS.

Alternative 2—install a work zone ITS at the beginning of the project to warn of queued traffic conditions when they occur.

Step 2. Determine availability and suitability of CMFs for alternatives

For both alternatives, a CMF will be needed to quantify the effect of the nighttime lane closures on crashes. As given in Table 9, the CMF for working at night with one or more lanes closed is 1.61. For Alternative 2, a CMF describing the effect of the work zone ITS for queue warning is needed. From Table 16, the CMF for a work zone queue warning system installed when queues are expected is 0.56. Since the nighttime lane closures for this project are expected to result in queues, this CMF is appropriate for use in this analysis.

Step 3. Obtain appropriate baseline crash estimate for applying CMFs

The normal non-work-zone crash rate for this section of Interstate was determined to be 14.8 crashes per mile per year. The lane closures will be affecting 50% of these crashes over a 5-mile section of Interstate each night and will be occurring on 5 of the 7 nights each week. The queue warning CMF is measured relative to what would be expected to occur during the lane closure if the system were not used. Therefore, the baseline crash estimate for Alternative 2 would actually be the work zone crash estimate for Alternative 1. This is computed as follows:

$$\begin{aligned} \mathit{Baseline\ Crashes} &= \left(\frac{14.8\ \mathit{crashes}}{\mathit{mi}/\mathit{yr}}\right)(5.0\ \mathit{mi})\left(\frac{6\ \mathit{mo}}{12\ \mathit{mo}/\mathit{yr}}\right)\left(\frac{5\ \mathit{days}/\mathit{wk}}{7\ \mathit{days}/\mathit{wk}}\right)\left(\frac{0.5\ \mathit{night\ crashes}}{\mathit{all\ crashes}}\right)(1.61) \\ &= 21.28\ \mathit{crashes} \end{aligned}$$

For comparison purposes, the normal number of crashes expected to occur on this section of roadway on these nights if no work zone is present would be 21.28 crashes divided by the work zone CMF of 1.61, or 13.22 crashes. Thus, the nighttime lane closures are predicted to result in 8.06 additional crashes (i.e., 21.28 – 13.22 = 8.06) over the 6-month period of the project.

Step 4. Apply CMFs for each alternative to baseline crash estimate

As stated in the previous step, the CMF for nighttime lane closures was applied in the previous step. Consequently, the expected number of crashes under Alternative 1 is as follows:

$$Crashes_{Alt\,1} = 21.28\ crashes$$

For Alternative 2, the baseline crash estimate must be multiplied by the work zone queue warning CMF to compute the expected number of crashes:

$$Crashes_{Alt\,2} = (21.28)(0.56) = 11.92\ crashes$$

Step 5. Compute differences in crash estimates between alternatives

Subtracting the crashes expected under Alternative 2 from those computed for Alternative 1 yields the number of crashes that the installation of the work zone queue warning system is expected to avoid:

$$Expected\ Crash\ Difference_{Alt\,1-Alt\,2} = 21.28 - 11.92 = 9.36\ crashes$$

The use of a queue warning system at this location was computed to result in 9.36 fewer crashes. If desired, the agency could apply comprehensive crash cost numbers to estimate the societal benefit in comparison with the cost of the system. If, for example, the agency had found crash severities at past work zones to be distributed as shown in Table 2, the crash cost benefits of the queue warning system would be computed to be nearly $450,000.

The crash cost savings estimate in this analysis assumes that the severity of crashes remains the same in either alternative and is equivalent to the overall average crash severity distribution that the agency had experienced in work zones. There is some evidence that the severity of crashes

Table 2. Estimated crash cost savings if Alternative 2 is used in this example.

Crash Severity Level	Proportional Distribution of Crash Severities	Proportion of the 9.36 Crashes Reduced	Average Crash Cost[1]	Crash Costs Saved in Alternative 2
Fatality (K)	0.005	0.0468	$4.509,991	$211,140
Disabling injury (A)	0.018	0.1685	$242,999	$40,940
Evident injury (B)	0.088	0.8237	$88,875	$73,205
Possible injury (C)	0.136	1.2730	$50,512	$64,300
Property damage only (PDO)	0.753	7.048	$8,325	$58,675
TOTAL	**1.000**	**9.360**		**$448,260**

[1]Crash Costs in the *Highway Safety Manual*, First Edition, updated to 2016 dollars.

that occur when a queue warning system is implemented is also reduced relative to a no-system condition, which would further increase the crash cost savings that might be achieved (*6*).

Comparing Narrowed Lanes to Temporary Widening

An agency needs to do full-depth pavement repair in the right lane of a 0.5-mile section of a four-lane divided highway. The repairs create a pavement drop-off, so the agency plans to attach temporary concrete barriers to the rightmost 2 ft of the left lane through the project while repairs are made. The left lane is normally 12 ft wide. A 1-ft inside shoulder is normally present adjacent to the left lane. The agency is trying to decide whether to use the existing pavement width by reducing the lane width through the work zone to 11 ft and eliminating the inside shoulder, or to first add 2 ft of temporary pavement to the left edge of the shoulder so that a 12-ft lane and the 1-ft shoulder can be maintained during construction. The addition of the temporary pavement will add 2 weeks to the current 6-month project duration and an additional $300,000 to the project cost. The roadway normally accommodates 15,000 vpd, and the section of interest is estimated to experience 5.0 crashes per mile per year based on the agency's calibrated SPF for that roadway. The agency performs the following analysis.

Step 1. Define work zone alternatives to be evaluated

Alternative 1—long-term right lane closure, reduction of left lane width from 12 ft to 11 ft, reduction of inside shoulder from 1 ft to 0 ft over 6 months.

Alternative 2—2 weeks of daytime inside lane closures to construct temporary pavement (assume that approximately 33% of daily crashes occur during those work hours), followed by 6 months of the long-term right lane closure with the left lane width at 12 ft and a 1-ft inside shoulder.

For the sake of this example, the initial 2-week period of Alternative 2 where the temporary pavement is being constructed will be denoted as "Part 1" and the 6-month pavement repair will be termed "Part 2."

Step 2. Determine availability and suitability of CMFs for alternatives

Alternative 1—CMFs are needed for reducing a travel lane from 12 ft to 11 ft and for reducing the inside shoulder from 1 ft to 0 ft. In Chapter 4, lane width and shoulder width CMFs are listed in Table 32 and Table 17, respectively; however, these CMFs are of questionable applicability to work zones because they were developed for normal roadway segments. Note that for the shoulder width CMF, it is defined in the literature relative to adding width to the shoulder. Since the agency is considering reducing the shoulder width, the reciprocal of the CMF shown was used. The following CMFs were thus selected:

$$CMF_{Lane\ width\ 12\rightarrow 11\ ft} = 1.05$$

$$CMF_{Shoulder\ width\ 1\rightarrow 0\ ft} = \frac{1}{0.97} = 1.03$$

In both alternatives, the right lane will be closed. The agency again examines the CMF catalog and determines that CMFs for daytime lane closures with workers present (in Table 8) are equal to 1.66, measured against the normal (non-work-zone) condition. For nighttime periods, the CMF for a lane closure with workers present is determined to be 1.61 (from Table 9).

For Part 1 of Alternative 2, the CMF for daytime condition lane closures with workers present can be used, but only for the times during which the lane closures will be in place. The agency examines the time-of-day distribution of crashes that normally occur on that section of roadway and determines that 30% of crashes typically occur during the daytime lane closure hours planned.

It is also assumed that work will occur Monday through Friday but not on weekends. Therefore, the lane closure CMF for Part 1 is computed as follows:

$$WZCMF_{Lane\ closures,Part\ 1} = \left(\frac{5\ days}{7\ days/wk}\right)(1.66(0.30)+1.0(0.7)) + \left(\frac{2\ days}{7\ days/wk}\right)1.0 = 1.14$$

During Part 2 of Alternative 2, workers will not be present during all hours when the lane is closed. Given that the description of the daytime and nighttime lane closure CMFs indicate that workers were present, the agency decides that the 1.66 and 1.61 values are too high to apply during periods when work is not occurring. For comparison purposes, the agency decides to compute what the general work zone CMF (no lane closure) would be for this facility, using the CMF equation for four-lane facilities with worker presence unknown (shown in Table 7):

$$WZCMF_{4-lanes} = \frac{e^{-10.036+1.164\ln(15{,}000)}}{e^{-11.231+1.248\ln(15{,}000)}} = 1.47$$

Considering this value and the daytime and nighttime lane closure with workers present CMFs, the agency chooses to assume that a CMF of 1.60 for both daytime and nighttime hours throughout that portion of the project would be a reasonable value to use in the analysis.

$$WZCMF_{Lane\ closures,Part\ 2} = 1.60$$

Step 3. Obtain appropriate baseline crash estimates for applying CMFs

To properly apply the CMFs determined in Step 2, separate baseline crash estimates are needed for Part 1 and Part 2. The value of Part 1 is as follows:

$$Baseline\ Crashes_{\text{Part 1}} = \left(\frac{5.0\ crashes}{mi/yr}\right)(0.5\ mi)\left(\frac{2\ wks}{52\ wks/yr}\right) = 0.11\ crashes$$

For Part 2, the baseline crash estimate is as follows:

$$Baseline\ Crashes_{Part\ 2} = \left(\frac{5.0\ crashes}{mi/yr}\right)(0.5\ mi)\left(\frac{6\ mo}{12\ mo/yr}\right) = 1.25\ crashes$$

Step 4. Apply CMFs for each alternative to baseline crash estimate

For Alternative 1, no CMF need be applied to the baseline crash estimate for Part 1. For Part 2, the baseline crash estimate is multiplied by the appropriate work zone CMF and the lane width and shoulder width CMFs, as shown below:

$$Crashes_{Alt\ 1,Part\ 2} = (1.25\ crashes)(1.60)(1.05)(1.03) = 2.17\ crashes$$

Therefore, the total estimate of crashes for Alternative 1 would be as follows:

$$Crashes_{Alt\ 1} = 2.17 + 0.11 = 2.28\ crashes$$

For Alternative 2, the work zone CMF computed for Part 1 is multiplied by its baseline crash estimate, and the CMF computed for Part 2 is multiplied by its appropriate baseline crash estimate. Note that the lane width and shoulder width CMFs are not applied for this alternative.

$$Crashes_{Alt\ 2,Part\ 1} = (0.11\ crashes)(1.141) = 0.12\ crashes$$

$$Crashes_{Alt\ 2,Part\ 2} = (1.25\ crashes)(1.60) = 2.00\ crashes$$

Table 3. Estimated crash cost savings if Alternative 2 is used in this example.

Crash Severity Level	Proportional Distribution of Crash Severities	Proportion of the 0.16 Crashes Reduced	Average Crash Cost[1]	Crash Costs Saved in Alternative 2
Fatality (K)	0.005	0.00075	$4.509,991	$3,382
Disabling injury (A)	0.018	0.0027	$242,999	$656
Evident injury (B)	0.088	0.0132	$88,875	$1,173
Possible injury (C)	0.136	0.0204	$50,512	$1,030
Property damage only (PDO)	0.753	0.1205	$8,325	$1,003
TOTAL	**1.000**	**0.160**		**$7,244**

[1] Crash Costs in the *Highway Safety Manual*, First Edition, updated to 2016 dollars.

Therefore, the total estimate of crashes for Alternative 2 would be as follows:

$$Crashes_{Alt\ 2} = 2.00 + 0.12 = 2.12\ crashes$$

Step 5. Compute differences in crash estimates between alternatives

The final step in the process is to subtract the crash estimates from each alternative to determine the expected differences in crashes:

$$Expected\ Crash\ Difference_{Alt\ 1-Alt\ 2} = 2.28 - 2.12 = 0.16\ crashes$$

Thus, Alternative 1 is expected to result in an additional 0.16 crashes during the project, despite being of slightly shorter duration. If desired, the agency could compute a comprehensive economic cost of this estimate. For example, if the same distribution of crashes and crash costs as shown in Table 1 was assumed to be applicable here, the resulting crash cost savings would be computed as shown in Table 3. Based on the analysis shown, even though Alternative 2 has a slightly lower estimated crash frequency and associated crash cost savings, the amount of the savings is minor relative to the added $300,000 cost of providing the temporary pavement, and so would not be justifiable based on crash cost savings alone. Ideally, an analysis of the effect of the two alternatives on work zone capacity and traffic delays would also be performed (such as shown in Table 3), monetized, and added to this cost estimate.

CHAPTER 4

Catalog of Available Work Zone CMFs

Overview

This chapter describes CMFs available in existing research that may be applicable to work zone safety analyses. The CMFs were first evaluated with respect to their potential reliability for work zone safety analyses. The overall reliability of each CMF for work zone analyses was determined using a combination of the applicability and quality ratings for each CMF. For example, highly reliable CMFs were developed using work zone data, and they had good study designs with low standard errors. Unreliable CMFs either had a low quality score or there was reason to doubt their applicability to a work zone. Reliability was categorized as follows:

Highly Reliable—The CMF was developed with work zone data and had a high quality score (is included in HSM or has a 4- or 5-star rating from the Clearinghouse).

Possibly Reliable—CMFs must meet one of two conditions:

1. The CMF was developed from work zone data with a medium quality score, or
2. The CMF was not developed with work zone data, but there is no obvious reason why it could not be applied to a work zone condition. CMFs developed from non-work-zone data should have a quality score of medium or higher.

Unreliable—CMFs meet one of two conditions:

1. CMF has a low quality score, regardless of data source, or
2. CMF was developed using non-work-zone data, but there is reason to doubt its applicability to a work zone. This category applies regardless of quality rating.

Treatments and factors with no CMF available are discussed in the final section of this chapter. In those cases, available safety research is reviewed, but no quantitative crash reduction effects are provided.

Once the reliability of the available CMFs was established, they were aggregated and cataloged. Tables 4, 5, and 6 summarize the work zone CMFs included in this guidebook, organized by reliability rating. A summary of each treatment or factor is then presented using the elements described below.

Description: The treatment for the CMF being computed is briefly described.

Applicability to Work Zones: The CMF's level of applicability to work zones is defined using three categories:

Directly Applicable—The CMF was developed using work zone data.
Possibly Applicable—The CMF was not developed using work zone data but may be appropriate for work zone applications. In this case, the base condition, study design, and limitations

Table 4. Highly reliable work zone CMFs.

Feature	Applicability to Work Zones	Quality	Facility Type	Table Number
Work zone with no lane closure	Directly applicable	High	Freeways and expressways	Table 7
Work zone with one or more lanes closed (workers present)	Directly applicable	High	Freeways and expressways	Table 8
Work at night (workers present)	Directly applicable	Medium-High	Freeways and expressways	Table 9
Increase duration of work zone Increase length of work zone	Directly applicable	High	Urban Interstate	Table 10 Table 11

Table 5. Possibly reliable work zone CMFs.

Feature	Applicability to Work Zones	Quality	Facility Type	Table Number
Use stationary enforcement	Directly applicable	Medium	Not specified	Table 12
Use automated speed enforcement	Possible	High	Rural two-lane highways	Table 13
Use speed feedback display	Possible	High	Not specified	Table 14
Use transverse rumble strips	Directly applicable, Questionable	High	Rural freeways, urban/suburban local roads	Table 15
Use queue warning system	Directly applicable	Medium	Rural freeways	Table 16
Increase inside or outside shoulder width by 1 ft	Directly applicable	Medium	Freeways	Table 17 Table 18
Change median width	Possible	High	Stop-controlled intersections, urban and rural freeways	Table 19
Change roadside side slope	Possible	High	Rural two-lane and multilane highways	Table 21
Change horizontal curve radius	Possible	Low-Medium	Rural two-lane and multilane highways	Table 23
Change superelevation variance	Possible	High	Rural two-lane highways	Table 24
Remove left turn lane	Possible	High	Rural and urban intersections	Table 25 Table 26
Remove right turn lane	Possible	High	Rural and urban intersections	Table 27 Table 28
Remove crosswalk	Possible	Medium	Four-leg stop-controlled intersections	Table 29
Remove bicycle lane	Possible	Medium	Urban multilane roadways and intersections	Table 30
Remove two-way left-turn lane (TWLTL)	Possible	High	Rural two-lane highways and urban intersections	Table 31
Reduce lane width	Possible	High	Freeways, rural two-lane and multilane highways	Table 32 Table 33 Table 34 Table 35
Reduce shoulder width	Possible	High	Freeway, rural two-lane and multilane highways	Table 36 Table 37 Table 38 Table 39
Change vertical alignment (grade and curve)	Possible	Low-High	Rural two-lane highways	Table 40

Table 6. Potentially unreliable work zone CMFs.

Feature	Applicability to Work Zones	Quality	Facility Type	Table Number
Use work zone variable speed limit	Possible	High	Urban freeway	Table 41
Reduce acceleration/deceleration lane length	Questionable	High	Rural and urban freeways	Table 42
Reduce intersection sight distance	Possible	Medium	Intersection	Table 43
Use crossover work zone	Directly applicable	Medium	Rural multilane	Table 44
Use Safety Edge on temporary roadways	Possible	High	Rural two-lane and multilane	Table 45
Increase retroreflectivity of markings (above agency standards)	Possible	Low-Medium	Rural two-lane and multilane	Table 46
Use left hand merge and downstream shift (Iowa Weave)	Directly applicable	Low	Rural freeway	Table 47
Reduce speed limit	Questionable	Medium-High	Principal arterial freeways and expressways	Table 48
Install median barrier	Questionable	High	Freeways	Table 49 Table 50

should be checked before using these CMFs. There are no obvious reasons why these CMFs could not be applied in work zones; however, it is possible that some factors present in the work zone may not have been taken into account.

Questionable—A CMF was available for a particular treatment, but there are reasons to believe that the CMF was developed for conditions that may not be directly transferable to a work zone environment. As a result, these CMFs should be used with caution, and limitations should be clearly noted by the analyst.

Quality: The quality of a CMF depends on the standard error, number of samples, and study design, irrespective of its applicability to work zones. Hence, a directly applicable CMF can be of low quality and vice versa. The CMFs included in the HSM are considered as high quality CMFs because they underwent extensive review prior to inclusion in the HSM. The CMF Clearinghouse (http://cmfclearinghouse.org) also rates the quality of CMFs. The Clearinghouse rates each CMF with a star rating format. The star quality rating indicates the quality or confidence in the results of the study producing the CMF. The star rating is based on a scale of 1 through 5, with a 5-star rating indicating the most reliable CMFs. Reviewers considered five aspects of each study—study design, sample size, standard error, potential bias, and data source—and judged each CMF according to its performance in each category. More details on the rating system used by the Clearinghouse can be found on its website. For this guidebook, CMFs with 4 or 5 stars were considered to be of *high quality*, 3 stars were considered to be of *medium quality,* and 1 or 2 stars were considered to be of *low quality*. The quality of those CMFs that have not been evaluated by the Clearinghouse was designated as not available (N/A).

Facility Type: The type of road to which the CMF is applied. Application to facility types not listed may or may not be appropriate.

Work Zone with No Lane Closure

Description

This CMF applies to a work zone where no lane closure is active. It is considered to be highly reliable. CMFs for conditions when workers are present, and conditions when the presence of workers is unknown, are shown. To develop the worker-present CMFs, daily project inspector diaries from 64 freeway construction projects in four states (California, North Carolina, Ohio, and Washington) were analyzed (*7*). This CMF was calculated based on the sites where work activity was occurring somewhere within the project but temporary lane closures were not in place.

In a more recent effort involving projects from Ohio, Texas, Virginia, Utah, and Washington, a negative binomial regression model of crashes before and during work zones on Interstates and freeways was used to generate a planning-level work zone CMF that varies as a function of AADT (*5*).

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: No work zone.

Available CMFs

Table 7. Work zone with no lane closure.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Daytime (workers present)	All	Freeways and expressways	All	1.31	0.03	(*7*)
Daytime (workers present)	Injury*	Freeways and expressways	All	1.17	0.04	(*7*)
Overall (worker presence unknown)	All	Four-lane freeways and expressways	5,000–70,000 AADT	$\frac{e^{-10.036+1.164\ln(AADT)}}{e^{-11.231+1.248\ln(AADT)}}$	NA	(*5*)
Overall (worker presence unknown)	All	Six-lane freeways and expressways	50,000–150,000 AADT	$\frac{e^{-9.987+1.164\ln(AADT)}}{e^{-12.318+1.344\ln(AADT)}}$	NA	(*5*)

*Injury category includes both serious and minor injuries.
NA = not applicable

CMF Application Notes

1. The studies listed in Table 7 did not consider the effect of traffic diversion as the result of the presence of a work zone, so the CMFs only apply to the route that was under construction.
2. The Ullman et al. 2008 study did not control for other changes in roadway cross section, such as lane or shoulder width, so it is possible that these results also include some impact from changes in other characteristics (*7*).
3. Since the CMF for the Ullman et al. 2008 study was calculated for periods when workers were present, it may overestimate crashes if applied to all periods when the work zone is in place (*7*). It is possible that the presence of workers may induce rubbernecking and additional distractions that would increase crashes relative to times when the work zone is in place but no construction or maintenance activities are under way.
4. The CMFs for the Ullman et al. 2018 study may have experienced occasional short-term or short-duration lane closures (*5*). No attempt was made to quantify the frequency of these lane closures in the analysis.

Work Zone with One or More Lanes Closed (Workers Present)

Description

This CMF applies to work zones where at least one travel lane is closed and workers are present. The CMFs developed did not distinguish between the number of base lanes and the number of lanes closed at a site, so it may not fully account for specific geometric effects. To develop these CMFs, daily project inspector diaries from 64 freeway construction projects in four states (California, North Carolina, Ohio, Washington) were analyzed to determine hours of work, hours and locations of temporary lane closures, and number of travel lanes closed during each work period (*7*).

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: No work zone.

Available CMFs

Table 8. Work zone with one or more lanes closed (workers present).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Daytime	All	Freeways and expressways	All	1.66	0.07	(*7*)
Daytime	Injury*	Freeways and expressways	All	1.46	0.11	(*7*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The information presented in Table 8 is from an evaluation that did not examine the difference in safety effects between the closure of a single lane and the closure of multiple lanes. Also, initial lane configuration of the roadway was not considered.
2. This study did not consider the effect of traffic diversion as the result of the presence of a work zone, so the CMF only applies to the route that was under construction.
3. Since the CMF was calculated for periods when workers were present, it may overestimate crashes if applied to all periods when the work zone is in place. The presence of workers may induce rubbernecking and additional distractions that would increase crashes relative to times when the work zone is in place but no construction or maintenance activities are underway.
4. There were 64 project sites used to develop these CMFs. The majority of projects where temporary lane closures were performed during the day occurred at locations where AADTs were relatively low, and at night at locations where AADTs were relatively high.

Work at Night (Workers Present)

Description

Performing work at night reduces operational impacts on traffic because volumes are lower; however, lower light levels at night may reduce visibility for drivers and construction workers and introduce glare issues. These factors can affect construction zone crash risk and crash severity.

Separate CMFs were developed for sites with lane closures and sites without lane closures. Again, the CMFs for night work at lane closures did not differentiate between the base number of lanes and the number of lanes closed. CMFs were also developed for periods when workers were present, so these may overestimate crashes if applied to periods when work was not under way.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: No work zone present.

Available CMFs

Table 9. Work at night (workers present).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Work zone with one or more lanes closed (workers present)						
Nighttime	All	Freeways and expressways	All	1.61	0.06	(*7*)
Nighttime	Injury*	Freeways and expressways	All	1.42	0.09	(*7*)
Work zone with no lane closure (workers present)						
Nighttime	All	Freeways and expressways	All	1.58	0.15	(*7*)
Nighttime	Injury*	Freeways and expressways	All	1.41	0.23	(*7*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. For the information presented in Table 9, nighttime crashes were defined as those occurring from 7:00 p.m. to 6:00 a.m.
2. This evaluation did not examine the difference in safety effects between the closure of a single lane and the closure of multiple lanes. Also, initial lane configuration of the roadway was not considered.
3. Nighttime work zones with no lane closure were a fairly infrequent event. Consequently, the CMFs had a large standard error associated with the estimates, and should be used with caution.
4. Because the CMFs were calculated for periods when workers were present, they may overestimate crashes if applied to all periods when the work zone is in place. It is possible that the presence of workers may induce rubbernecking and additional distractions that would increase crashes relative to times when the work zone is in place but no construction or maintenance activities are under way.

Increase Work Zone Duration or Length

Description

The HSM documents the result of a study that examined how changing the duration or length of a work zone would impact expected crashes (*8*). The CMFs developed were created relative to a base case of a work zone with a duration of 16 days and a length of 0.51 miles.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones. CMFs are applicable to work zones with durations of between 16 and 714 days and lengths between 0.5 and 12.2 miles.

Base Condition: Work zone with a duration of 16 days and a work zone length of 0.51 miles. Note that the percent increases in the CMF formulas in Table 10 and Table 11 are calculated relative to these base conditions (e.g., a work zone with a length of 1.02 miles would be a 100% increase in length over the 0.51-mile base condition).

Available CMFs

Table 10. Increase duration of work zone.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Freeway	4,000 to 237,000 AADT	$1 + \frac{(\%\ Increase\ in\ Duration\ \times 1.11)}{100}$	0.959	(*8*)

Table 11. Increase length of work zone.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Freeway	4,000 to 237,000 AADT	$1 + \frac{(\%\ Increase\ in\ Length\ \times 0.67)}{100}$	0.530	(*8*)

CMF Application Notes

1. CMFs in Tables 10 and 11 were developed using a negative binomial regression cross-sectional study design using work zone data from California.
2. The study design did not isolate other changes in roadway cross section, so these CMFs may also include effects related to other work zone design elements.
3. Please see notes under base condition to ensure that formulae are applied correctly.

Use Stationary Police Enforcement

Description

Stationary police enforcement involves an officer in a patrol car being deployed adjacent to the travel lanes within or upstream of a work zone. Two main types of stationary police enforcement can be used. If the emphasis is on active identification and citation of traffic law violators, the enforcement officer may choose either an overt strategy (positioning a marked vehicle in full view of approaching traffic) or a covert strategy (using an unmarked vehicle or positioning his or her vehicle out of view of oncoming traffic) (*9*). On the other hand, if the goal is to alert approaching drivers and calm traffic rather than issue citations, the officer and marked vehicle can be positioned in full view close to the travel lanes with emergency lights flashing.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: No enforcement used.

Available CMFs

Table 12. Use stationary police enforcement.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Not specified	696 to 124,907 AADT	.585*	Not calculated	(*10*)

* Use with caution. Authors stated that the CMF value "…seemed to be quite large and difficult to justify solely from the expected speed reduction caused by police enforcement" (*10*).

CMF Application Notes

1. The CMF in Table 12 was obtained using data from Indiana work zones and a random-effect negative binomial crash frequency model, where each observation represented 1 month of data. Detailed hourly data with enforcement efforts was not available at enough sites to be used in the model. The authors noted that about 90% of the enforcement observations referred to conspicuous and ticketing enforcement (i.e., overt and active).
2. Other studies have shown speed reductions associated with stationary enforcement in the order of 5 to 13 mph for rural freeways, 3 to 8 mph for urban freeways, and 9 mph in a study conducted along an urban arterial (*11*, *12*, *13*). Although speed reductions of as much as 13 mph have been recorded with stationary enforcement, 5 to 7 mph reductions are more common, especially on high-volume, high-speed roadways (*9*).
3. Stationary enforcement will typically result in a greater speed reduction than circulating patrols and automated speed enforcement, but its spatial effects will be more localized. Spatial effects may be found from just before the officer location to approximately 1 mile downstream (*14*). Therefore, where speed reductions at a spot location are desired, the officer and vehicle should be positioned at a short distance (e.g., 1,000 ft is suggested). In addition, studies suggest that the temporary effect of stationary enforcement may not be significant after the departure of police (*12*).

Use Automated Speed Enforcement

Description

Automated speed enforcement programs are promising safety countermeasures that have been tried in many countries and in a few states. Photo speed enforcement systems can consistently cite more drivers than traditional police enforcement, which can increase compliance with posted speed limits. Another benefit is that they do not require officers to risk injury by exposing themselves to vehicles moving at high speeds through the work zone (*15*). Previous studies have shown that safety effects from speed enforcement diminish with time as travelers become more aware of the cameras. Also crash reductions seem to be higher in corridors that had a higher density of automated speed enforcement devices (*16*). Caution should be taken before selecting automatic speed enforcement as a safety countermeasure because it is not always welcomed by the general public or policy makers due to privacy concerns. Likewise, legislation permitting automatic speed enforcement usage must be present, which is not the case in many jurisdictions.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: No automated enforcement demonstration program.

Available CMFs

Table 13. Use automated speed enforcement (relative to no enforcement).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	Fatal, injury*	All	Not specified	0.83	0.01 (unadjusted)	(*4*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. There were no studies available that specifically examined the safety effects of using automated speed enforcement in work zones. The CMF listed in Table 13 was derived from past studies on non-work-zone roads.

Use Speed Feedback Displays

Description

Speed feedback displays consist of a digital display that shows the speed of approaching traffic. Figure 9 shows an example of a speed feedback display. Speeds are typically detected using radar, and the posted speed limit is often shown somewhere on the display so that drivers can determine if they are exceeding the posted speed limit. Speed feedback displays may be either (a) portable, trailer-mounted units or (b) permanent installations. In work zones, typical applications are trailer-mounted units placed in the advance warning area. Past studies have shown that speed feedback displays can be more effective at reducing speeds within the work zone than static speed limit signs (*17*, *18*, *19*).

CMFs

Applicability to Work Zones: Possibly applicable, although CMFs were not developed with work zone data, so caution should be used for work zone applications. Available CMFs may have been collected under conditions that were not similar to work zones.

Base Condition: Absence of speed feedback displays.

Figure 9. Trailer-mounted work zone speed feedback display.

Available CMFs

Table 14. Use speed feedback displays.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Not specified	Not specified	0.54	0.2	(*4*)

CMF Application Notes

1. While speed feedback displays may be used to manage work zone speeds, there were no studies available that examined safety effects in work zones specifically. The CMF listed in Table 14 was derived from a meta-analysis of past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. Likewise, the types of roads included in the meta-analysis were not specified, so this CMF may be influenced by data collected on lower volume residential streets. These values should be used with caution.

Use Transverse Rumble Strips

Description

Transverse rumble strips can be raised bars or grooves placed perpendicular to the direction of travel. They may be used in work zones to provide advance warning to drivers approaching work zones and to manage speeds. Although rumble strips are sometimes used in work zones (see Figure 10), most prior studies that developed CMFs have focused on traffic calming or intersection applications (as shown in Figure 11) that may not be transferable to a work zone. One evaluation performed as part of this research project focused on portable transverse rumble strips that are put down prior to closing a lane for a single work shift and then picked up when the lane closure is removed.

CMFs

Applicability to Work Zones: Likely applicable for short-term application to Interstate lane closures. Possibly applicable for long-term applications; however, those CMFs were not

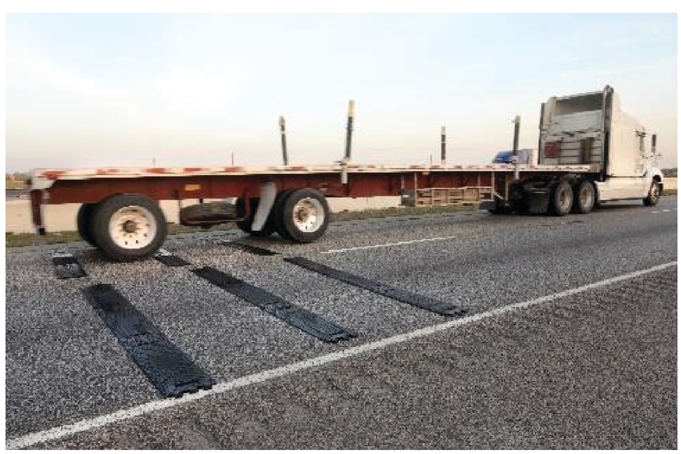

Figure 10. Portable transverse rumble strips on Interstate work zone application.

Figure 11. Transverse rumble strips for permanent applications (20).

developed with work zone data. The CMFs were developed using conditions that are likely to vary significantly from a work zone.

Base Condition: No transverse rumble strips present.

Available CMFs

Table 15. Use transverse rumble strips.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Install portable transverse rumble strips at short-term nighttime Interstate lane closures						
Nighttime	All	Rural Interstate when queues **were not** present	55,000–110,000 AADT	0.890 (not significant)	0.377	(*5*)
Nighttime	All	Rural Interstate when queues **were** present	55,000–110,000 AADT	0.397	0.265	(*5*)
Install transverse rumble strips on stop-controlled approaches of an intersection						
All	All	Rural three- and four-leg stop-controlled intersection	Not specified	1.118	0.086 (unadjusted)	(*21*)
All	Fatal, serious injury	Rural three- and four-leg stop-controlled intersection	Not specified	0.785	0.107 (unadjusted)	(*21*)
Install transverse rumble strips on roadway segment as traffic-calming devices						
All	Injury*	Urban and suburban local roads	Not specified	0.64	0.12	(*22*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMFs for the short-term nighttime Interstate lane closures found that the portable transverse rumble strips did not have a significant effect on crashes when traffic queues were not present at the lane closures. However, if traffic queues did form, the rumble strips reduced crashes that were expected to have occurred by 60%.
2. The CMFs listed in Table 15 for intersections and as traffic-calming devices on local roads were derived from past studies on non-work-zone situations, so their potential applicability to

a work zone situation is unclear. These values should be used with caution. Applications were primarily to alert drivers to stop signs or traffic calming on local roads, so it is unclear if these safety effects could be translated to a work zone.

3. For the long-term intersection application, the CMF for total crashes was not statistically significant, but there was a statistically significant reduction in fatal and serious injury crashes.

Use Queue Warning Systems

Description

Queue warning systems use real-time data to dynamically alert traffic to stopped or slowed traffic downstream. For work zone applications, messages are typically displayed on portable changeable message signs. Large speed differentials between traffic approaching the end of a slow-moving traffic queue formed by a lane closure have sometimes been identified as a significant contributor to work zone rear-end collisions. Countermeasures that can reduce this rear-end collision potential at work zones where queues develop is of high interest to agencies and contractors nationally.

During the widening effort on Interstate 35 through central Texas, Texas Department of Transportation (TxDOT) officials wanted to examine and implement technologies to help mitigate the impacts of end-of-queue crashes. An end-of-queue warning system was established, consisting of a highly portable work zone ITS of easily deployable radar speed sensors linked to one or more portable changeable message signs (PCMS). The end-of-queue warning system was deployed upstream of nighttime lane closures where queues are expected to develop. The system was deployed in conjunction with portable transverse rumble strips.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: No queue warning system present.

Available CMFs

Table 16. Use queue warning systems.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Nighttime	All	Rural Interstate where queues were expected	55,000 to 110,000 AADT	0.559	0.255	(*6*)
Nighttime	All	Rural Interstate when queues **were actually** present	55,000 to 110,000 AADT	0.468	0.301	(*5*)
Nighttime	All	Rural Interstate when queues **were not actually** present	55,000 to 110,000 AADT	0.717 (not significant)	0.353	(*5*)

CMF Application Notes

1. The CMFs listed in Table 16 were developed through an empirical Bayes analysis using 234 control and 216 treatment nights of lane closures. The sample sizes were very small in terms of both expected and actual crashes because less than 1 year's worth of nighttime lane closures from each condition was available for analysis.

2. For the Ullman et al. 2016 study, queues were assumed to have occurred for some period of time at all nights examined in this study (*6*). However, this was not verified. Also, the duration of any queues that occurred was not measured.
3. For the Ullman et al. 2018 study, Bluetooth data was used to identify actual periods when queues were present and periods when queues were not present (*5*).
4. Because all data was collected along a single corridor with multiple work zones, results may or may not be transferable to other locations.
5. In the Ullman et al. 2018 study, the CMFs for the queue warning system plus portable rumble strips were found to be similar to the CMFs for portable rumble strips only (*5*) (see Table 15). The effect of the queue warning system without the use of portable rumble strips could not be ascertained.

Increase Inside or Outside Shoulder Width in Work Zone by 1 Ft

Description

The safety effect of increasing the inside and outside shoulder width in a work zone was examined using cross-sectional data on I-70 in Indianapolis, Indiana (*23*). A cross-sectional study design was used because a number of countermeasures were in place, but the researchers were able to estimate the isolated impact of increasing the shoulder width by 1 ft on both the inside and the outside shoulder. While CMF standard errors were low, results are based on a single corridor, so transferability to other sites remains uncertain.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: Shoulder width prior to work zone installation.

Available CMFs

Table 17. Increase inside shoulder width by 1 ft.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Urban Interstate	Not specified	0.97	0.01	(*23*)

Table 18. Increase outside shoulder width by 1 ft.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Urban Interstate	Not specified	0.948	0.01	(*23*)
Single vehicle	All	Urban Interstate	Not specified	1.043	0.02	(*23*)

CMF Application Notes

1. CMFs listed in Tables 17 and 18 were developed using a regression cross-sectional study design using work zone data. Although standard error values produced were low, the CMF developed was produced from data from a single Interstate route. Transferability of the CMF to other locations remains uncertain.

Change Median Width

Description

Medians serve to provide physical separation between opposing directions of traffic. Numerous studies have reported crash reductions due to the presence of medians (*22*, *24*, *25*, *26*). The type of crash most affected by the presence of a median or width of median is cross-median crashes. A cross-median crash is defined as a scenario where a vehicle departs its traveled way to the left, traverses the separation between the highway's directional lanes, and collides with a vehicle traveling in the opposite direction.

During construction, there may be a temporary reduction in median width as lanes are shifted to accommodate the work zone. Currently, no CMF is available for decreasing median width; however, the HSM includes CMFs for increasing median width. For work zones, it is assumed that the effect of decreasing median width is the inverse of increasing median width.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs for increasing median width were not developed with work zone data, so caution should be used for work zone applications. Table 19 provides a few CMFs for increasing the median width, whereas Table 20 presents CMFs for reducing the median width.

Base Condition: Base conditions vary depending on whether the CMF is for a segment or intersection. The original base conditions were set for widening medians, so the inverse of those CMFs are presented here. The original base conditions for widening the medians are as follows:

- Four-lane highways with full access control: 10-ft-wide traversable median for a four-lane highway with full access control (*25*)
- Stop-controlled intersections: Median wider than 80 ft (maximum median width of 300 ft) (*26*)

Available CMFs

Table 19. Increase median width in 3-ft increments (intersections).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Multivehicle	All	Rural four-leg approach	Not specified	1.04	0.02	(*26*)
Multivehicle	All	Urban and suburban four-leg approach	Not specified	0.94	0.01	
Multivehicle	All	Urban and suburban three-leg approach	Not specified	0.98	0.01	

Table 20. Reduce median width (segments).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
20 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	1.16	0.02 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.12	0.04 (unadjusted)	

Table 20. (Continued).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
30 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	1.35	0.04 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.25	0.07 (unadjusted)	
40 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	1.59	0.05 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.41	0.09 (unadjusted)	
50 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	1.85	0.06 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.56	0.1 (unadjusted)	
60 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	2.17	0.07 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.75	0.1 (unadjusted)	
70 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	2.5	0.07 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	1.96	0.1 (unadjusted)	
80 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	2.94	0.07 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	2.17	0.1 (unadjusted)	
90 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	3.45	0.07 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	2.44	0.1 (unadjusted)	
100 ft to 10 ft conversion						
Cross median	Not specified	Rural freeway	2,400 to 119,000 AADT	4.00	0.06 (unadjusted)	(*25*)
Cross median	Not specified	Urban freeway	4,400 to 131,000 AADT	2.78	0.1 (unadjusted)	

CMF Application Notes

1. The CMF values in Tables 19 and 20 were calculated by finding the inverse of CMF values for providing left turn lanes. The standard error is from the original study (CMF for increasing median width). Caution should be taken before using these values.
2. Segment CMFs are presented here for only fully access-controlled facilities for the sake of brevity. Please refer to the HSM for additional CMFs for divided highways with partial or no access control (*4*).
3. The CMFs were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
4. Roads with full access control experience relatively fewer cross-median crashes probably because these roads generally have larger median widths. In the sample for this research, the average median width for roads with full access control ranged from 55 to 60 ft,

whereas the average median width for roads with partial or no access control ranged from 29 to 40 ft.

5. For rural intersections, the confidence interval may contain 1. The HSM recommends using the rural intersection CMF with caution.

Change Roadside Side Slope

Description

The steepness of the roadside slope (or side slope) is a cross-sectional feature that affects the likelihood of an off-road vehicle rolling over or recovering back into the travel lane. As part of their 1987 study, Zegeer et al. developed relationships between single-vehicle crashes and field-measured side slopes from 1:1 to 7:1 or steeper for 1,776 miles of roadway in three states: Alabama, Michigan, and Washington (*27*).

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Prior condition varied depending on CMF type.

Available CMFs

Table 21. Increase roadside side slope.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
1V:7H to 1V:2H or steeper						
All	Not specified	Rural	Not specified	1.18	Not specified	(*4*)
1V:7H to 1V:4H						
All	Not specified	Rural	Not specified	1.12	Not specified	(*4*)
1V:7H to 1V:5H						
All	Not specified	Rural	Not specified	1.09	Not specified	(*4*)
1V:7H to 1V:6H						
All	Not specified	Rural	Not specified	1.05	Not specified	(*4*)

Table 22. Reduce roadside side slope.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
1V:2H to 1V:4H						
All	Not specified	Rural	Not specified	0.94	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.9	Not specified	(*4*)
1V:2H to 1V:5H						
All	Not specified	Rural	Not specified	0.91	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.85	Not specified	(*4*)
1V:2H to 1V:6H						
All	Not specified	Rural	Not specified	0.88	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.79	Not specified	(*4*)
1V:2H to 1V:7H						
All	Not specified	Rural	Not specified	0.85	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.73	Not specified	
1V:3H to 1V:4H						
All	Not specified	Rural	Not specified	0.95	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.92	Not specified	(*4*)

Table 22. (Continued).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
1V:3H to 1V:5H						
All	Not specified	Rural	Not specified	0.92	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.86	Not specified	(*4*)
1V:3H to 1V:6H						
All	Not specified	Rural	Not specified	0.89	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.81	Not specified	(*4*)
1V:3H to 1V:7H						
All	Not specified	Rural	Not specified	0.85	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.74	Not specified	(*4*)
1V:4H to 1V:5H						
All	Not specified	Rural	Not specified	0.97	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.94	Not specified	(*4*)
1V:4H to 1V:6H						
All	Not specified	Rural	Not specified	0.93	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.88	Not specified	(*4*)
1V:4H to 1V:7H						
All	Not specified	Rural	Not specified	0.89	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.81	Not specified	(*4*)
1V:5H to 1V:6H						
All	Not specified	Rural	Not specified	0.97	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.94	Not specified	(*4*)
1V:5H to 1V:7H						
All	Not specified	Rural	Not specified	0.92	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.86	Not specified	(*4*)
1V:6H to 1V:7H						
All	Not specified	Rural	Not specified	0.95	Not specified	(*4*)
Single vehicle	Not specified	Rural	Not specified	0.92	Not specified	(*4*)

CMF Application Notes

1. The CMFs listed in Tables 21 and 22 were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution. The CMFs may not account for other objects that might be present on the roadside during construction, such as construction equipment or material.
2. Through NCHRP Projects 17-25 and 17-29, an expert panel on rural multilane highways was convened. This panel concluded that the CMFs derived were valid and the best available for both rural two-lane roads and rural multilane highways (*25*). These CMFs are included in the HSM.

Change Horizontal Curve Radius

Description

Past research has shown that horizontal curves experience crash rates of up to four times the rates on tangent sections, all else being equal (*27*, *28*). A number of researchers have found that milder curves are associated with lower crash rates compared with sharper curves (*29*, *30*). Work zone activities may alter horizontal curvature during construction.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications, especially in cases where there may be interactions with barriers or other work zone features.

Base Condition: For the first CMF, the base condition is a tangent section. For rural four-lane highways, the base condition is roadways with a maximum speed limit of 55 mph (*31*).

Available CMFs

Table 23. Change horizontal curve radius.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Modify horizontal curve radius and length and provide spiral transitions						
All	All	Rural two-lane minor arterial	Not specified	$\frac{(1.55L_c) + \left({}^{80.2}/_{R}\right) - (0.012 * S)}{1.55 * L_c}$ L_c = Length of curve including length of spiral (if present) (mi) *R* = Radius of curvature (ft) *S* = 1 if spiral transition is present, otherwise 0	Not specified	(*4*)
Increase in horizontal curvature from X to Y degrees						
All	Fatal and injury*	Rural four-lane highways	Not specified	$e^{0.0831*(Y-X)}$	Not specified	(*31*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMFs listed in Table 23 were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
2. Fitzpatrick et al. (2009) used datasets from Texas freeways that included 561 curve/tangent pairs for a total of 324.3 miles and 1,122 segments (*31*). When separate models were estimated for each area type/number of lane category, the result was significant for the rural, four-lane freeways at the 5% significance level, was significant for the urban, four-lane freeways at the 10% level, and was not significant for urban, six- or eight-or-more-lane freeways.
3. In addition to the freeway CMF listed, the HSM 2014 Supplement includes CMFs for horizontal curvature broken down by single/multiple vehicle crashes and PDO/fatal-injury crashes (*32*). They are not presented here for the sake of brevity but can be found in Chapter 18 of the HSM Supplement.

Change Superelevation Variance

Description

The CMF for superelevation is based on the superelevation deficiency of a horizontal curve (i.e., the difference between the actual superelevation and the superelevation required by AASHTO policy). When the actual superelevation meets or exceeds that required by AASHTO policy, the value of the superelevation CMF is 1.00. An expert panel made a judgment that there would be no effect of superelevation deficiency on safety until the superelevation deficiency exceeds 0.01.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Based on a horizontal curve radius of 842.5 ft.

Available CMFs

Table 24. Change superelevation variance (SV).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
0.01 ≤ SV ≤ 0.02						
All	All	Rural two-lane arterial	Not specified	1+6*(SV−0.01)	Not specified	(*33*)
SV > 0.02						
All	All	Rural two-lane arterial	Not specified	1+3*(SV−0.02)	Not specified	(*33*)

CMF Application Notes

1. The CMFs in Table 24 are included in the HSM. However, they were derived from non-work-zone data, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
2. These CMFs were developed based on a horizontal curve radius of 842.5 ft. To determine the CMF for changing that condition, the "new" condition CMF should be divided by the "existing" condition CMF.

Remove Left Turn Lane

Description

Removing turn lanes from an intersection affects the safety and capacity of that facility. Currently, no CMF is available for removing left turn lanes; however, the HSM includes a CMF for providing left turn lanes. For work zones, it is assumed that the effect of removing left turn lanes is the inverse of providing left turn lanes.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs for adding left turn lanes were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Intersection where the left turn lane has been temporarily closed by a work zone.

Available CMFs

Table 25. Remove left turn lanes from one major approach.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Rural, three-leg stop-controlled intersection	1,600 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	1.79	0.07	(*4*)
All	All	Rural, three-leg stop-controlled intersection	1,600 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	1.39	0.03	(*4*)
All	All	Urban, four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 200 to 8,000 (minor road AADT)	1.37	0.04	(*4*)
All	All	Urban, four-leg signalized intersection	4,600 to 40,300 (major road AADT) 100 to 13,700 (minor road AADT)	1.32	0.03	(*4*)

(continued on next page)

Table 25. (Continued).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Urban, four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 2,600 (minor road AADT)	1.11	0.1	(*4*)
All	Fatal, injury*	Rural, three-leg stop-controlled intersection	1,600 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	2.22	0.1	(*4*)
All	Fatal, injury*	Rural, four-leg stop-controlled intersection	1,600 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	1.54	0.04	(*4*)
All	Fatal, injury*	Urban, four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 200 to 8,000 (minor road AADT)	1.41	0.05	(*4*)
All	Fatal, injury*	Urban, four-leg signalized intersection	4,600 to 40,300 (major road AADT) 100 to 13,700 (minor road AADT)	1.39	0.06	(*4*)
All	Fatal, injury*	Urban, four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 2,600 (minor road AADT)	1.10	0.02	(*4*)

*Injury category includes both serious and minor injuries.

Table 26. Remove left turn lanes from both major approaches.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Rural, four-leg stop-controlled intersection	1,500 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	1.92	0.04	(*4*)
All	All	Urban, four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 200 to 8,000 (minor road AADT)	1.89	0.04	(*4*)
All	All	Urban, four-leg signalized intersection	4,600 to 40,300 (major road AADT) 100 to 13,700 (minor road AADT)	1.72	0.04	(*4*)
All	Fatal, injury*	Rural, four-leg stop-controlled intersection	1,500 to 32,400 (major road AADT) 50 to 11,800 (minor road AADT)	2.38	0.04	(*4*)
All	Fatal, injury*	Urban, four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 200 to 8,000 (minor road AADT)	2.00	0.06	(*4*)
All	Fatal, injury*	Urban, four-leg signalized intersection	4,600 to 40,300 (major road AADT) 100 to 13,700 (minor road AADT)	1.92	0.07	(*4*)
All	Fatal, injury*	Urban, four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 2,600 (minor road AADT)	1.20	0.02	(*4*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. Tables 25 and 26 list the CMF values calculated by finding the inverse of CMF values for providing left turn lanes. The standard error is from the original study (CMF for providing left turn lanes). Caution should be taken before using these values.
2. These CMFs are included in the HSM. However, they were derived from non-work-zone data, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
3. The study was limited to projects at three- and four-leg intersections. The database assembled for the 580 study intersections included a total of 26,056 intersection-related accidents in the District of Columbia, Illinois, Iowa, Louisiana, Minnesota, Montana, Nebraska, New Jersey, North Carolina, Oregon, and Virginia.

Remove Right Turn Lane

Description

Removing right turn lanes from an intersection affects the safety and capacity of that facility. Currently, no CMF is available for removing right turn lanes; however, the HSM includes a CMF for providing right turn lanes. For work zones, it is assumed that the effect of removing right turn lanes is the inverse of providing them.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs for adding right turn lanes were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Intersection where the right turn lane has been temporarily closed by a work zone.

Available CMFs

Table 27. Remove right turn lanes from one major approach.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Three-leg and four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 25 to 26,000 (minor road AADT)	1.16	0.06	(*4*)
All	All	Three-leg and four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 8,400 (minor road AADT)	1.04	0.02	(*4*)
All	Fatal, injury*	Three-leg and four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 25 to 26,000 (minor road AADT)	1.30	0.08	(*4*)
All	Fatal, injury*	Three-leg and four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 8,400 (minor road AADT)	1.10	0.04	(*4*)

*Injury category includes both serious and minor injuries.

Table 28. Remove right turn lanes from both major approaches.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Three-leg and four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 25 to 26,000 (minor road AADT)	1.35	0.08	(*4*)
All	All	Three-leg and four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 8,400 (minor road AADT)	1.09	0.03	(*4*)
All	Fatal, injury*	Three-leg and four-leg stop-controlled intersection	1,500 to 40,600 (major road AADT) 25 to 26,000 (minor road AADT)	1.69	Not specified	(*4*)
All	Fatal, injury*	Three-leg and four-leg signalized intersection	7,200 to 55,100 (major road AADT) 550 to 8,400 (minor road AADT)	1.20	Not specified	(*4*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMF values listed in Tables 27 and 28 were calculated by taking the inverse of the CMF values for providing right turn lanes. The standard error in the table is from the original study (CMF for providing right turn lanes). Caution should be taken before using these values.
2. These CMFs are included in the HSM, but they were derived from non-work-zone data, so their applicability to a work zone situation is unclear. These values should be used with caution.
3. The study was limited to projects at three- and four-leg intersections. The database assembled for the 580 study intersections included a total of 26,056 intersection-related accidents in the District of Columbia, Illinois, Iowa, Louisiana, Minnesota, Montana, Nebraska, New Jersey, North Carolina, Oregon, and Virginia.

Remove Crosswalk from Minor Approaches

Description

Removing crosswalks from an intersection affects the pedestrian safety of that facility. While CMFs do exist for crosswalk installation, they do not exist for removal of a crosswalk. It is assumed that the effect of removing a crosswalk is the inverse of providing a crosswalk at an intersection.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs are assumed to be the inverse of providing a crosswalk on the minor approach of an intersection.

Base Condition: A four-leg stop-controlled intersection where a crosswalk has been removed from the minor approach.

Available CMFs

Table 29. Remove crosswalk from a minor approach.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Four-leg stop-controlled intersection	Not specified	2.66	Not specified	(*34*)

CMF Application Notes

1. The CMF value listed in Table 29 was calculated by taking the inverse of the CMF values for providing a crosswalk. Caution should be taken before using this value.
2. The analysis conducted by Haleem et al. (2011) was performed on 2,475 unsignalized intersections collected from six counties in Florida (*34*).

Remove Bicycle Lane

Description

Bicycle lanes enable bicyclists to travel at their preferred speed and facilitate predictable behavior and interactions between bicyclists and motorists. If these lanes are removed as part of a work zone, there could be negative safety consequences. Because no CMFs exist for removing bicycle lanes, it is assumed that the effect of removing a bicycle lane is the inverse of providing one.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs are assumed to be the inverse of providing a bicycle lane facility. CMFs for adding a bicycle lane were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Roadway segments and intersections where a bicycle lane has been removed.

Available CMFs

Table 30. Remove bicycle lanes.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Urban multilane road segment	Not specified	1.06	0.101 (unadjusted)	(*35*)
All	Fatal, injury*	Urban multilane road segment	Not specified	1.06	0.114 (unadjusted)	(*35*)
All	All	Urban three-leg and four-leg intersections	Not specified	0.95	0.053 (unadjusted)	(*35*)
All	Fatal, injury*	Urban three-leg and four-leg intersections	Not specified	0.93	0.059 (unadjusted)	(*35*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMF values listed in Table 30 were calculated using the inverse of the CMF values for providing bicycle lanes. The standard error in the table is from the original study (CMF for providing bicycle lane). Caution should be taken before using these values.
2. The data was collected on the intersections and roadway segments of New York City from 1999 to 2008. A before–after study was performed on the data.

Remove TWLTL from Major Approach

Description

A TWLTL can provide lateral separation between opposing traffic, yet allow the full complement of turning movements (e.g., left turns into and out of access points). If these lanes are removed as part of a work zone setup, safety may be affected. No CMFs for removal of TWLTLs were found, so it is assumed that the effect of removing a TWLTL is the inverse of providing it.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs are assumed to be the inverse of providing TWLTLs. The CMF for adding TWLTLs was not developed with work zone data, so caution should be used for work zone applications.

Base Condition: TWLTL removed from a road with a driveway density ≥5 driveways per mile.

Available CMFs

Table 31. Remove TWLTL.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Rural two-lane arterial	Not specified	$1 - 0.7 * p_{dwy} * p_{LT/D}$ p_{dwy} = proportion of driveway-related crashes $p_{LT/D}$ = TWLTL-involved left turn crashes as a proportion of driveway-related crashes	Not calculated	(*4*)
All	All	Urban and rural two-lane road	Not specified	1.25	0.03 (unadjusted)	(*36*)
All	Fatal, injury*	Urban and rural two-lane road	Not specified	1.35	0.07 (unadjusted)	(*36*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMF values listed in Table 31 were calculated using the inverse of the CMF values for providing a TWLTL. The standard error in the table is from the original study (CMF for providing TWLTL). Caution should be taken before using these values.
2. Geometric, traffic, and crash data were obtained for 78 sites in North Carolina, 10 sites in Illinois, 31 sites in California, and 25 sites in Arkansas. The Empirical Bayes method was used to determine the safety effectiveness of installing the TWLTLs.

Reduce Lane Width

Description

Work zone activities may require that lane widths be reduced to accommodate construction or maintenance activities (see Table 32). The HSM considers a 12-ft-wide lane as the standard, but narrower lane widths are also possible. The HSM provides CMFs for reduced lane widths, but these CMFs do not consider interactions with shoulder widths or barriers that may be present in work zones. As a result, it is unclear if these CMFs can be directly applied because the impact of interactions with other work zone features is not considered.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed using work zone data and do not consider interactions with work zone features.

Base Condition: A 12-ft-wide lane.

Available CMFs

Table 32. Reduce lane width from 12 ft to 11 ft (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane, divided and undivided multilane	<400 AADT	1.01	Not calculated	(*4*)

Table 32. (Continued).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	400 to 2,000 AADT	$1.01 + 2.5 * 10^{-5} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	>2,000 AADT	1.05	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	400 to 2,000 AADT	$1.01 + 1.88 * 10^{-5} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	>2,000 AADT	1.04	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	400 to 2,000 AADT	$1.01 + 1.25 * 10^{-5} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	>2,000 AADT	1.03	Not calculated	(*4*)

Table 33. Reduce lane width from 12 ft to 10 ft (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane, undivided multilane roadway	<400 AADT	1.02	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	400 to 2,000 AADT	$1.02 + 1.75 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	>2,000 AADT	1.30	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	400 to 2,000 AADT	$1.02 + 1.31 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	>2,000 AADT	1.23	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	<400 AADT	1.01	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	400 to 2,000 AADT	$1.01 + 8.75 * 10^{-5} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	>2,000 AADT	1.15	Not calculated	(*4*)

Table 34. Reduce lane width from 12 ft to 9 ft or less (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	<400 AADT	1.05	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	400 to 2,000 AADT	$1.05 + 2.81 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway	>2,000 AADT	1.50	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	<400 AADT	1.04	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	400 to 2,000 AADT	$1.04 + 2.13 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Undivided rural multilane roadway	>2,000 AADT	1.38	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	<400 AADT	1.03	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	400 to 2,000 AADT	$1.03 + 1.38 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Divided rural multilane roadway	>2,000 AADT	1.25	Not calculated	(*4*)

Table 35. Reduce lane width (freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	Fatal, injury*	Freeway	Not specified	$\begin{cases} e^{-0.0376(W_1-12)}, W_1 < 13\,ft \\ 0.963, \quad W_1 \geq 13\,ft \end{cases}$ $W_1 = lane\ width$	N/A	(*4*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMFs listed in Tables 33, 34, and 35 are included in the HSM, but they were derived from non-work-zone data so their potential applicability to a work zone situation is unclear. These values should be used with caution because they do not account for interactions with other work zone elements.
2. The freeway CMFs are applicable to lane widths in the range of 10.5 ft to 14 ft.

Reduce Shoulder Width

Description

Shoulder widths may also be reduced during work zone activities. The HSM considers a 6-ft-wide lane as the baseline value for two-lane and multilane roadways. The HSM provides CMFs for reduced shoulder widths, but these CMFs do not consider interactions with lane widths, clear zone objects, or barriers that may occur in work zones. As a result, it is unclear if these CMFs can be directly applied because the impact of interactions with other work zone features has been not considered. Analysts need to weigh the values provided by this CMF with those presented in Tables 17 and 18 (that utilized limited work zone data) to assess which values would provide more reasonable results.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed using work zone data.

Base Condition: A 6-ft-wide shoulder.

Available CMFs

Table 36. Reduce shoulder width from 6 ft to 4 ft (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	<400 AADT	1.02	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	400 to 2,000 AADT	$1.02 + 8.13 * 10^{-5} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	>2,000 AADT	1.15	Not calculated	(*4*)

Table 37. Reduce shoulder width from 6 ft to 2 ft (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	<400 AADT	1.07	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	400 to 2,000 AADT	$1.07 + 1.43 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	>2,000 AADT	1.30	Not calculated	(*4*)

Table 38. Reduce shoulder width from 6 ft to 0 ft (non-freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	<400 AADT	1.10	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	400 to 2,000 AADT	$1.10 + 2.5 * 10^{-4} * (AADT - 400)$	Not calculated	(*4*)
Single vehicle run off road, multiple vehicle head-on, side swipe	All	Rural two-lane roadway, undivided multilane roadway	>2,000 AADT	1.50	Not calculated	(*4*)

Table 39. Reduce shoulder width (freeway).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	Fatal, injury*	Freeway	Not specified	$e^{-0.0172\,(W_{is}-6)}$ W_{is} = paved inside shoulder width	Not calculated	(*4*)

*Injury category includes both serious and minor injuries

CMF Application Notes

1. The CMFs in Tables 36, 37, 38, and 39 are included in the HSM. However, they were derived from non-work-zone data, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
2. The freeway CMFs are applicable to shoulder widths in the range of 2 to 12 ft.

Change Vertical Grade

Description

Vertical curves provide gradual changes between tangents of different grades. Grades or straight vertical sections are designed to be steep enough to allow for longitudinal drainage, but not so steep as to pose a danger to vehicles either through inadvertent increased speed downhill or through the difficulty of climbing uphill and posing safety risks where there are inadequate passing opportunities.

CMFs

Applicability to Work Zones: Likely applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Roadway with no vertical grade.

Available CMFs

Table 40. Increase vertical grade by 1%.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Rural two-lane road	Not specified	1.04	Not specified	(*4*)

CMF Application Notes

1. The CMF listed in Table 40 was derived from past studies on non-work-zone roads, so the potential applicability to a work zone situation is unclear. These values should be used with caution.
2. The CMF included in the HSM can be applied to each individual section on the roadway, without respect to the sign (upgrade/downgrade). This CMF is included in the HSM in bold letters indicating a standard error of 0.1 or less. This value is based on roads with a 55 mph speed limit and a 12-ft lane width.

Install Variable Speed Limit System

Description

Variable speed limit (VSL) systems dynamically change the posted speed limit in response to traffic conditions. The operation of VSL systems vary but frequently are configured to adjust speed limits in response to observed congestion, weather conditions, or work zone presence. While no work-zone-specific CMFs were located, a CMF is available for a permanent freeway deployment where the VSL was implemented primarily to provide speed harmonization and address congestion (*37*).

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications. Safety impacts for permanent locations with recurring congestion may not translate to a work zone where congestion may be more unpredictable.

Base Condition: No VSL system present.

Available CMFs

Table 41. Install VSLs.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Urban Interstate	Not specified	0.92	0.04	(*37*)

CMF Application Notes

1. While VSL systems may be used to manage work zone speeds, there were no studies available that examined safety effects in work zones specifically.

2. The CMF in Table 41 was developed using data from a single permanent site in Missouri using an empirical Bayes analysis. While the CMF is reliable for the corridor that was studied, analysts should consider whether the results from a permanent installation would be transferable to a particular work zone application.

Reduce Ramp Acceleration/Deceleration Lane Length

Description

Work zone activities may decrease the length of freeway ramp acceleration or deceleration lanes. The HSM Supplement refers to acceleration and deceleration lanes as speed-change lanes (*32*). They are defined as the section of roadway area located between the marked gore and taper points of a ramp merge or diverge area, and on the same side of the freeway as the merge or diverge area (see Figure 12).

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications. If the change in acceleration/deceleration

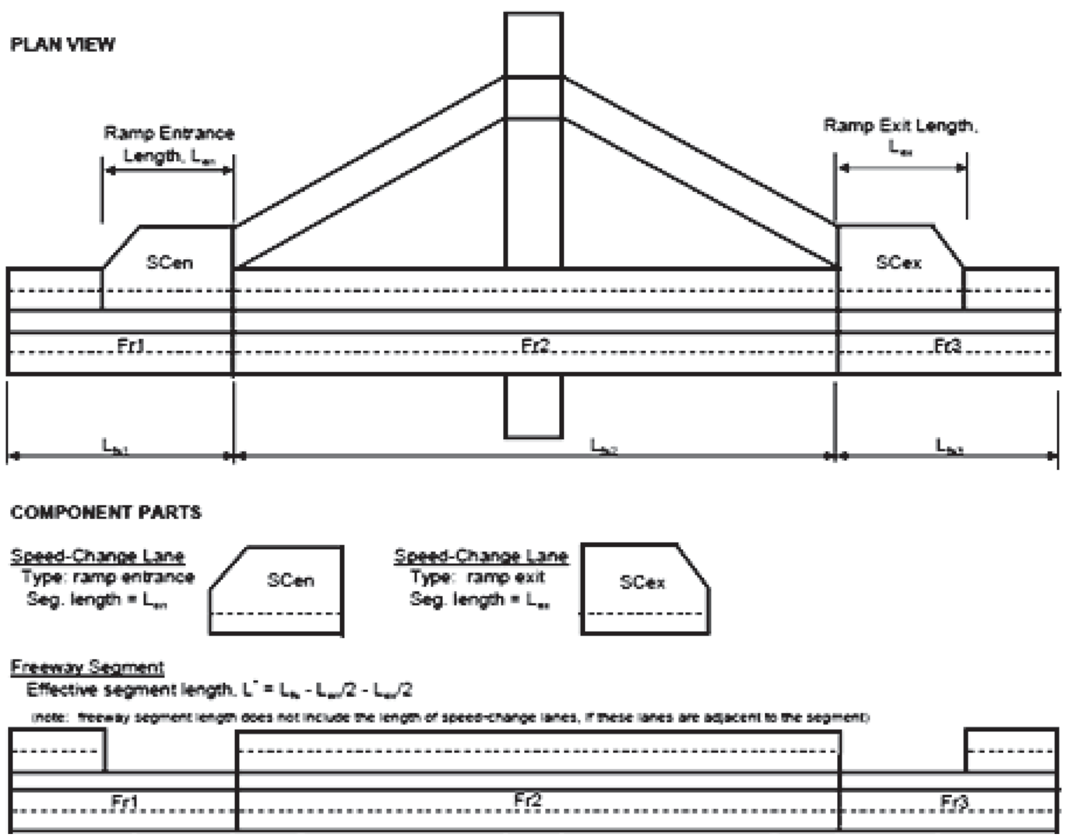

Figure 12. Illustrative freeway segments and speed-change lanes (32).

lane length was accompanied by installation of barriers or other changes that might interact with the speed-change lane length, these CMFs should be used with extra caution.

Base Condition: Freeways with ramp entrances/exits located on the right side of the road.

Available CMFs

Table 42. Change acceleration/deceleration lane length.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Crash modification factors for entrance ramp acceleration lanes						
All	Fatal, injury*	Rural; one through lane	0 to 7,000 vpd	$exp(0.594 * I_{left} + \frac{0.0318}{Len} + 0.198 + ln[0.001 * AADT_r]$ I_{left} = ramp side indicator variable (1.0 if entrance/exit is on the left, otherwise 0) Len = Length of ramp entrance $AADT_r$ = AADT volume of ramp	Not calculated	(*32*)
		Urban; one through lane	0 to 18,000 vpd			
		Urban; two through lanes	0 to 32,000 vpd			
Crash modification factors for exit ramp deceleration lanes						
All	Fatal, injury*	Rural; one through lane	0 to 7,000 vpd	$\exp(0.594 * I_{left} + \frac{0.0116}{Lex})$ I_{left} = ramp side indicator variable (1.0 if entrance/exit is on the left, otherwise 0) Lex = Length of ramp exit	Not calculated	(*32*)
		Urban; one through lane	0 to 18,000 vpd			
		Urban; two through lanes	0 to 32,000 vpd			

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMF for entrance ramps is applicable for deceleration lane lengths of between 0.04 and 0.30 miles (210 to 1,600 ft). The CMF for exit ramps is applicable for acceleration lane lengths of between 0.02 and 0.30 miles (106 to 1,600 ft) (see Table 42).
2. The CMF volume ranges indicate the conditions for which the CMF is considered valid. It is not known whether the CMF would produce reasonable results outside of these ranges.
3. The indicator variable for ramp side I_{left} is associated with a positive regression coefficient. This sign indicates that a ramp entrance/exit on the left side of the through lanes is associated with an increase in crash frequency, relative to one on the right side.
4. CMFs for PDO crashes are also included in the HSM for these factors.

Reduce Intersection Sight Distance

Description

Drivers acquire most of the information they use to control and navigate their vehicles visually. Appropriate sight distance approaching and within work zones is desirable from an operations and safety perspective. Likewise, work activities may reduce pre-existing sight triangles due to the presence of barriers and work vehicles. Reductions in sight distance could create negative safety impacts. While CMFs for increasing intersection sight distance are available, they do not

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specify the magnitude of the sight distance change that occurred to generate the CMFs. The CMFs for reducing intersection sight distance were assumed to be the inverse of the CMFs for increasing the sight distance.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs are assumed to be the inverse of increasing sight distance. CMFs were not developed with work zone data and do not include the magnitude of the sight distance reduction, so extreme caution should be used for work zone applications.

Base Condition: Unclear. Studies did not quantify how much intersection sight distance was available before/after improvement, so the base condition is uncertain. Use of these CMFs is thus more problematic because severe sight distance reductions are treated the same as smaller ones.

Available CMFs

Table 43. Reduce intersection sight distance.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	Property damage only	Four-leg intersection	Not specified	1.12	0.15	(*22*)
All	Injury*	Four-leg intersection	Not specified	1.89	0.29	(*22*)
All	Fatal	Signalized intersection	Not specified	2.27	Not calculated	(*38*)
All	Injury*	Signalized intersection	Not specified	1.59	Not calculated	(*38*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. The CMFs listed in Table 43 were developed by Elvik et al. (2004) and did not differentiate between signalized and unsignalized intersections (*22*). No other geometric information of the intersections was provided.
2. There was no information available on the degree of change to the intersection sight distance. The sight distances before and after the modification were not mentioned in any of these reports.
3. The standard errors listed are those for the original study, which examined increases in intersection sight distance.

Use Crossover Work Zone (Two-Lane, Two-Way Operation)

Description

This countermeasure applies to multilane divided facilities where one direction of travel is closed due to work activities. Traffic in both directions is merged into a single lane, and traffic in one direction is transitioned to the opposite side of the roadway. Figure 13 shows a typical application for a freeway crossover work zone from the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*39*).

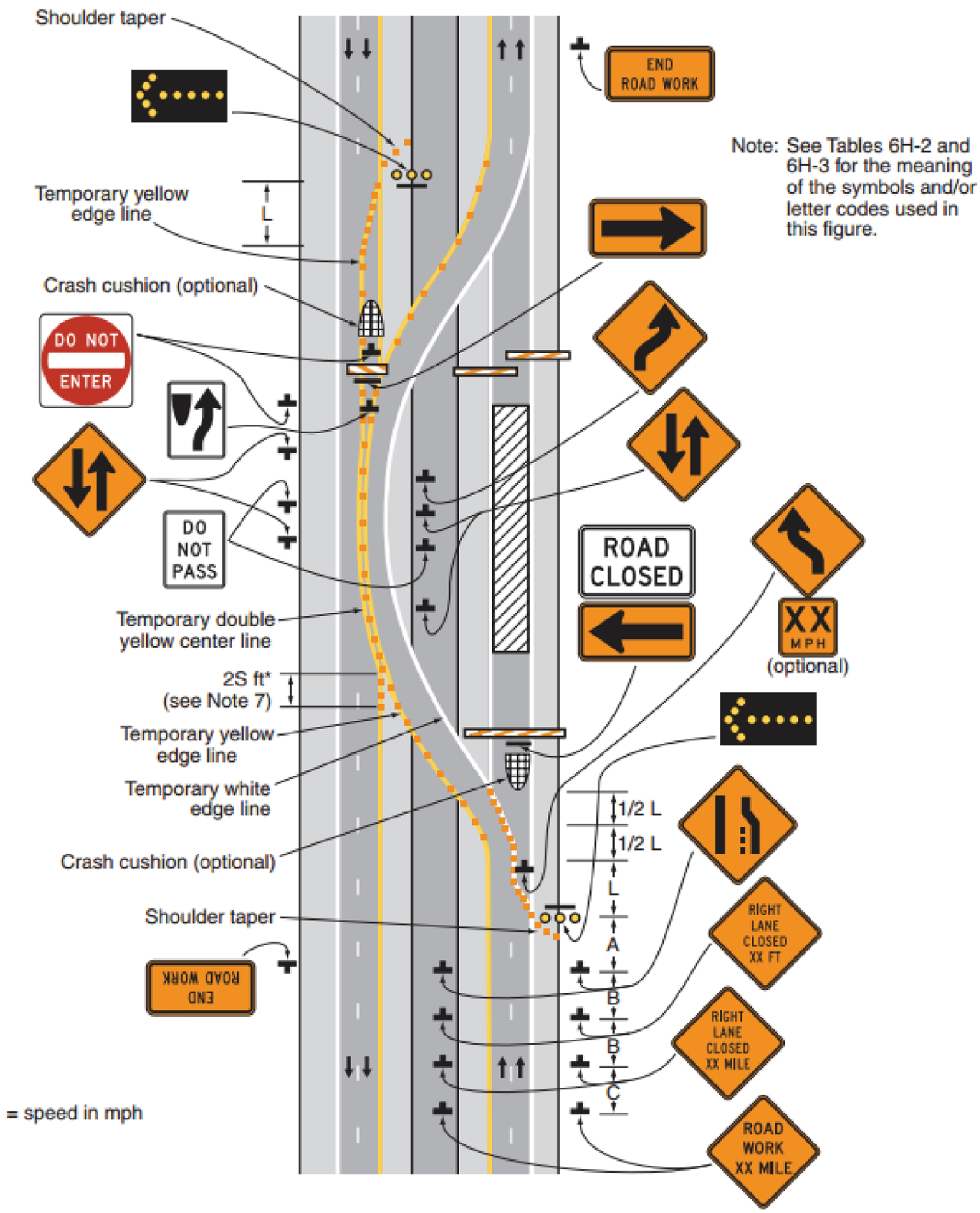

Figure 13. Typical freeway work zone crossover application from MUTCD (39).

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: Single lane closure in one direction.

Available CMFs

Table 44. Use crossover work zone.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Four-lane divided highway	Not specified	1.00	0.35	(*40*)

CMF Application Notes

1. The CMF in Table 44 was developed using a simple before-and-after study. Even though the CMF indicates no safety impact, the standard error is extremely large, so the impacts of the crossover design are unclear at this time.

Install Safety Edge on Temporary Roadway

Description

Pavement edge drop-offs on highways have been linked to many serious crashes, including fatal collisions. To mitigate vertical drop-offs, FHWA advocates installing Safety Edge on pavements during paving or resurfacing projects. Safety Edge provides a beveled edge to the pavement, which allows drivers who drift off the roadway to return to the pavement safely (see Figure 14). Even though this treatment showed a positive safety impact on regular roadways, its impact on temporary roadways has yet to be explored.

Figure 14. Safety Edge on roadways.

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: Rural highways prior to resurfacing and installation of Safety Edge (unpaved and paved shoulders).

Available CMFs

Table 45. Use Safety Edge on temporary roadway.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Rural two-lane principal arterial	310 to 18,697 AADT	0.943	0.057 (unadjusted)	(*41*)
Run off road	All	Rural two-lane principal arterial	310 to 18,697 AADT	0.937	0.057 (unadjusted)	(*41*)

CMF Application Notes

1. The CMFs listed in Table 45 were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution.
2. While none of these results is statistically significant, they do show a small, consistent benefit of the provision of Safety Edge on rural two-lane highways.
3. There were some observed differences between treatment and comparison sites for the period before resurfacing, which could confound the analysis results. Also, the sites with unpaved shoulders, where Safety Edge was expected to be most effective, had the lowest crash frequencies. This increased the variability in the data and made the statistical tests less powerful. These CMFs should be used with caution.

Increase Retroreflectivity of Pavement Markings

Description

Pavement markings provide useful visual and navigational information to motorists. Previous research has shown that greater longitudinal pavement marking retroreflectivity levels increase drivers' detection distance of this marking. However, increased visibility may also cause drivers to feel too comfortable during nighttime conditions, and drivers may then pay less attention or operate at unsafe speeds (*42*).

CMFs

Applicability to Work Zones: Possibly applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications.

Base Condition: For rural roadways, the base condition is a retroreflectivity value less than or equal to 200 millicandela/square meter/lux (mcd/m^2/lux) (*43*). For principal arterials, base condition is thermoplastic markings (ranging from 250 to 512 mcd/m^2/lux for white edgeline, 252 to 401 mcd/m^2/lux for white skiplines, 204 to 348 mcd/m^2/lux for yellow edgeline, and 202 to 328 mcd/m^2/lux for yellow centerlines) (*42*).

Available CMFs

Table 46. Increase retroreflectivity of markings from X to Y mcd/m²/lux.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Increase retroreflectivity of white edgeline, yellow edgeline, and yellow centerline						
Several*	All	Rural; multilane arterials and freeways	Not specified	$e^{-0.0021\,(Y-X)}$	Not specified	(*43*)
Increase pavement marking retroreflectivity of white edge lines from X to Y mcd/m²/lux						
All	All	Three-lane principal arterial	2,752 to 47,572	$e^{-0.004\,(Y-X)}$	Not specified	(*42*)
All	All	Two-lane principal arterial	2,752 to 47,572	$e^{-0.001\,(Y-X)}$	Not specified	(*42*)
Increase pavement marking retroreflectivity of white skiplines from X to Y mcd/m²/lux						
All	All	Three-lane principal arterial	2,752 to 47,572	$e^{-0.002\,(Y-X)}$	Not specified	(*42*)
Increase pavement marking retroreflectivity of yellow edge lines from X to Y mcd/m²/lux						
All	All	Three-lane principal arterial	2,752 to 47,572	$e^{0.007\,(Y-X)}$	Not specified	(*42*)
Increase pavement marking retroreflectivity of yellow centerlines from X to Y mcd/m²/lux						
All	All	Two-lane principal arterial	2,752 to 47,572	$e^{-0.007\,(Y-X)}$	Not specified	(*42*)

*Several = cross median, fixed object, frontal and opposing direction side swipe, head on, nighttime, run off road, side swipe, single vehicle.

CMF Application Notes

1. There were no studies available that examined the safety effects of increasing retroreflectivity in work zones specifically. The CMFs listed in Table 46 were derived from non-work-zone roads, so their potential applicability to a work zone situation is unclear.
2. No standard errors for the CMFs were determined, so it is unclear how reliable these CMFs are.
3. It is important to check the base condition before using these CMFs to ensure that formulae are applied correctly.
4. The expected effect of letting the pavement markings degrade below the base level over the duration of the work zone can also be estimated using the formulae. In these cases, the Y (ending) value will be less than the X (beginning) value.
5. Cross-sectional regression equations were used to estimate the monthly target crash frequency. For multilane highways, the yellow pavement marking retroreflectivity parameter estimate was counterintuitive (*42*). Further research is needed to verify this relationship.

Use Left-Hand Merge and Downstream Lane Shift (Iowa Weave)

Description

Some states will implement right lane closures followed by a lane shift when the activity area requires a left lane closure. This configuration is sometimes termed the “Iowa Weave.” Thus, every work zone would initially require that drivers merge from the right lane to the left lane, regardless of which lane is actually closed. Past studies have shown that this configuration is effective at

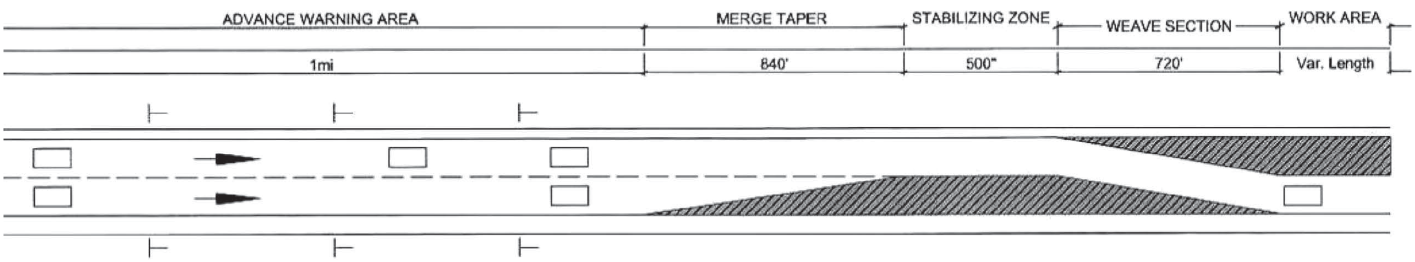

Figure 15. Example traffic control plan for Iowa Weave (44).

slowing approach speeds, and it may improve driver expectations when approaching a work zone lane closure (*44*). Figure 15 shows an example conceptual traffic control plan of this strategy.

CMFs

Applicability to Work Zones: Directly applicable, data collected in work zones.

Base Condition: CMFs are calculated relative to expected crashes with a conventional MUTCD right lane closure. No CMFs are available relative to a left lane closure.

Available CMFs

Table 47. Use Iowa Weave.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	All	Four-lane rural freeway	20,120 to 35,864 vpd	0.54	Not calculated	(*45*)
All	Fatal, injury*	Four-lane rural freeway	20,120 to 35,864 vpd	2.24	Not calculated	(*45*)

*Injury category includes both serious and minor injuries.

CMF Application Notes

1. CMFs for the treatment listed in Table 47 were developed in a single study using data from 10 Arkansas Interstate work zones. A non-regression cross-sectional study design was used. Therefore, there were likely several uncontrolled sources of variation in the data. For example, no assessment of before-work-zone crash frequency was performed, so it is unknown whether the differences are due to the treatment or other site characteristics among the 10 sites.
2. No standard errors for the CMFs were determined, so it is unclear how reliable these CMFs are. Although the CMFs were computed using work zone data, they are based on limited information and should be used cautiously.

Lower Posted Speed Limit

Description

Work zones may alter the geometric design and capacity of the roadway, so speed limits may be lowered in response to these changes. While no CMFs were identified that relate specifically to work zone speed limit reductions, several CMFs do exist that estimate safety effects of reduced speed limits in non-work-zone situations. Given that work zone speed limit reductions are often in response to changes in geometry at the site, it is uncertain whether these CMFs are transferable to work zones.

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CMFs

Applicability to Work Zones: Questionably applicable. CMFs were not developed with work zone data, so caution should be used for work zone applications. Work zone speed reduction decisions may be driven by very different factors than non-work-zone speed reductions, so it is unclear if these may be used for work zones.

Base Condition: Divided roadway with posted speed limit of 100 kph (62 mph) (*46*), freeways with the highest speed limit of 55 mph (*47*).

Available CMFs

Table 48. Lower posted speed limit.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Lower speed limit from 100 kph to 80 kph						
All	All	Principal arterials, freeways, and expressways	3,100 to 50,300	0.86	0.079 (unadjusted)	(*46*)
Lower posted speed by 5 mph						
All	All	Urban and rural freeways	Not specified	1.17	Not specified	(*47*)
Lower posted speed by 10 mph						
All	All	Urban and rural freeways	Not specified	0.96	Not specified	(*47*)
Lower posted speed by 15 to 20 mph						
All	All	Urban and rural freeways	Not specified	0.94	Not specified	(*47*)

CMF Application Notes

1. The CMFs listed in Table 48 were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution for work zones because reduced work zone speed limits are often connected to other changes in the roadway cross section.
2. Park et al. (2010) used 33 treatment sites and 44 comparison sites from Korean expressways to carry out the analysis (*46*). The results were statistically significant.
3. The study by Parker et al. (1997) was conducted from October 1985 to September 1992, when the maximum speed limit was 55 mph (89 kph) on freeways (*47*). The general types of sites included in the study were short sections, that is, 0.5-mile (0.8-km) segments in rural communities and 1-mile (1.6-km) sections in urban and rural communities. Because random selection and assignment of roadway sections to (a) experimental groups and (b) control groups for posted speed limit changes were not possible, these findings apply only to the study locations and cannot be generalized.

Install Barriers

Description

Work zones often use barriers to provide protection for workers. While barrier use is a common work zone design attribute, there have been no prior studies that have developed CMFs for work zone barrier use. The HSM includes CMFs for barriers on freeways for non-work-zone situations, but there are questions about whether those CMFs would translate into a work zone environment. For example, the HSM CMFs assume a base case of no barrier being present. The roadside is likely to have many more potentially hazardous objects in close proximity to the travel lanes during work zone activities than when the road is under construction. As a result, these barrier CMFs likely underestimate the benefits of installing barriers versus not having barriers for work zone cases. Caution should be used in applying these CMFs.

CMFs

Applicability to Work Zones: Questionably applicable. The CMFs documented here were developed for non-work-zone conditions. The roadside environment is likely more hazardous during work activities, so potential safety benefits of barrier use are likely underestimated. Furthermore, the HSM defines a barrier as cable barrier, concrete barrier, guardrail, and bridge rail, and so the CMF values are influenced by non-work-zone barrier types.

Base Condition: No barrier present in the median for median barrier CMF. No barrier present in the clear zone for outside lane barrier CMF.

Available CMFs

Table 49. Install median barrier.

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
All	Fatal and injury	Freeways	Not specified	$(1 - P_{ib}) + P_{ib} exp\left(\frac{0.131}{W_{icb}}\right)$	Not specified	(*32*)
All	PDO	Freeways	Not specified	$(1 - P_{ib}) + P_{ib} exp\left(\frac{0.169}{W_{icb}}\right)$	Not specified	(*32*)

P_{ib} = Proportion of effective segment length with median barrier, W_{icb} = Distance from edge of inside shoulder to barrier face (ft).

Table 50. Install outside barrier (outside of rightmost travel lane).

Crash Type	Crash Severity	Facility Type	Volume Range	CMF	Standard Error	Source
Single vehicle	Fatal and injury	Freeways	Not specified	$(1 - P_{ob}) + P_{ob} exp\left(\frac{0.131}{W_{ocb}}\right)$	Not specified	(*32*)
Single vehicle	PDO	Freeways	Not specified	$(1 - P_{ob}) + P_{ob} exp\left(\frac{0.169}{W_{ocb}}\right)$	Not specified	(*32*)

P_{ob} = Proportion of effective segment length with barrier on the outside, W_{ocb} = Distance from edge of outside shoulder to barrier face (ft).

CMF Application Notes

1. The CMFs listed in Tables 49 and 50 were derived from past studies on non-work-zone roads, so their potential applicability to a work zone situation is unclear. These values should be used with caution for work zones since the base case (without barrier) may be more hazardous than for non-work-zones. These CMFs are best used to assess the relative trade-offs of positioning the barriers at different lateral distances from the travel lanes, once the decision to use barriers has been made on the basis of other factors (pavement edge drop-offs, proximity of workers, equipment to travel lanes, etc.).

2. The barrier CMFs shown here also reflect results for cable barrier, guardrail, and bridge rail. As a result, they may not correctly estimate the safety impact of concrete barriers used in work zones.
3. For the median barrier CMF, the CMF is valid for W_{icb} values of between 0.75 and 17 ft.
4. For the outside barrier CMF, the CMF is valid for W_{ocb} values of between 0.75 and 17 ft.

Work Zone Features for Which No CMFs Exist

Although this catalog of available CMFs is extensive, it does not encompass the entirety of work zone feature alternatives that practitioners can consider when designing and operating work zones. Through the conduct of this research, specific questions arose about the crash modification effect of a number of additional features for which no CMF data could be identified. However, in some cases, studies of the operational effects of these features were identified. These operational measures can provide useful insights into the potential safety benefits of the features. Summaries of key non-CMF research findings are provided for the following:

- Circulating or mobile police enforcement
- Pack enforcement
- Legislation and signage for increased work zone fines
- Programmatic public education and outreach campaigns for work zone safety
- Project-specific public education and outreach campaigns for work zone safety
- Enhancements to work space ingress and egress points

Circulating or Mobile Police Enforcement

Description

Circulating patrols involve officers circulating through a work zone in marked or unmarked vehicles and are intended to extend the coverage of stationary enforcement in both time and space. Officers can identify a violator through measurements from a radar unit or by physically following the vehicle and noting the speed required to maintain a consistent following distance. Circulating patrols prevent drivers from reducing their speed only at locations where they "know" the officer is located, but these patrols' ability to reduce speed and increase driver awareness at a particular spot is limited. Circulating patrols can also serve roles in conjunction with speed enforcement in work zones, such as roadway monitoring, incident detection, and emergency response (*9*). It is likely that site-specific factors such as the length of the circulation route will influence the effectiveness of this feature and so would likely have less of an effect on safety than was previously reported for stationary police enforcement.

Other Reported Safety Impacts

Some studies have reported the effects of circulating enforcement in terms of speed reduction. When compared with freeway scenarios without enforcement, studies from 1985 showed reductions in the order of 2 to 3 mph with circulating enforcement (*48*), and separate efforts from 1992 found 4.3 to 4.4 mph lower average speeds for cars and 4.3 to 5.0 mph lower average speeds for trucks (*49*). More recent data suggests that average speed reductions with circulating enforcement tend to be somewhat smaller (in the order of 2 to 4 mph) than those achieved with stationary techniques (*9*).

Studies also show that the spatial effects of circulating patrols are limited. Halo (or lasting) effects for trucks were found that lasted for at least 1 hour after patrols departed from the work zone (*49*). However, cars traveled 2.4 to 3.0 mph faster and the percentage of fast-moving cars in the work zone increased after the police left the area. In addition, results from a 28-mile freeway segment in Michigan without a work zone showed that drivers had a tendency to reduce their speed by as much as 5 mph as they approached the patrol car, but accelerated back to their original speed or higher (up to 3 mph) after passing it. The study also concluded that the halo effect of police presence had negligible influence on speed selection by the motorists (*50*).

Pack Enforcement

Description

In situations where active enforcement (i.e., identification and citation of traffic law violators) is desired, some agencies utilize a pack enforcement strategy. In this case, an officer in an enforcement vehicle (marked or unmarked) is positioned to identify traffic law violators and immediately communicates the description and license plate number of the violator to one or more officers at a downstream location for apprehension and citation. In this way, the speed reduction and traffic-calming effect of the upstream enforcement vehicle is maintained while the active enforcement efforts downstream contribute to a lasting change in driving behavior (*9*).

In some cases the officer identifying violators provides an upstream overt presence to encourage slowing at the back of the queue or work zone approach, but the officer can also be positioned at the work zone approach, within the work zone, or on an overpass (*51*).

Other Reported Safety Impacts

No studies evaluating speed reductions or safety effects associated with pack enforcement were found. However, some of the general advantages of pack enforcement have been summarized in previous publications (*9, 51*), including the following:

- It is perceived to be “safer” than other enforcement strategies as it eliminates the pursuit of violators through work zones.
- Violators can be identified at locations with concrete barriers, and then pulled over downstream where shoulders are available.
- Speed reduction effects achieved at an upstream location remain downstream.
- Downstream citation ensures that credibility of enforcement is not lost.
- Multiple officers are available to respond in case of work zone incidents.

Conversely, some of the disadvantages of this strategy include increased costs, greater requirement of law enforcement resources, and known violators traveling through the work zone until they reach the location of officers positioned downstream.

Legislation and Signage for Increased Work Zone Fines

Description

As of June 2016, every state except Wyoming has implemented increased fines for certain violations occurring in work zones (*52*). Increased fines may apply to speeding, all moving violations, or all violations, depending on the state (see Figure 16). In 25 states, workers must be present for the increased fines to be in effect. The rationale for these increased fines is that the higher penalties would influence driver behavior, thereby improving safety.

Other Reported Safety Impacts

A 1997 Texas Transportation Institute (TTI) study attempted to assess the impact of increased fine legislation on the number of fatal crashes in long-term freeway work zones in the United States (*53*). Data from the Fatality Analysis Reporting System (FARS), a national database of all fatal crashes, was analyzed to determine if trends in fatal crashes in work zones

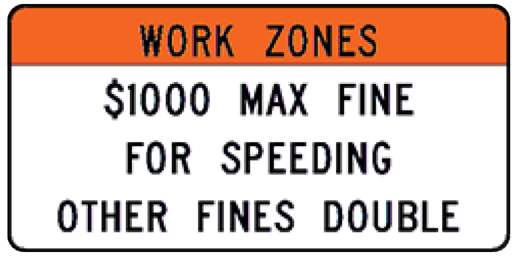

Figure 16. Sample work zone sign showing increased fines.

were significantly different between states with and without increased fines in work zones (*3*). At the time, only 14 states had at least 1 year of crash data following the implementation of the increased fine legislation. The data from these states was compared with data from the remaining 36 states that had not enacted legislation. The researchers found no significant difference between the trends in the number of fatal work zone crashes. Evaluations in Maryland, Minnesota, Pennsylvania, and Washington showed inconclusive impacts on total crashes, but those efforts were hampered by limited exposure data (*53*). Speed impacts were also generally not found to be significant.

Although safety impacts remain inconclusive, an Oregon study found that increased fines can be an effective strategy for increasing driver awareness of work zone safety hazards, with 79% of drivers surveyed indicating that they reduced speed either "a lot" or "some" in response to signs (*54*). While violations were not found to be significantly reduced, increased awareness of work zone hazards was seen as a significant benefit.

Programmatic Public Education and Outreach Campaigns for Work Zone Safety

Description

State DOTs and other agencies engage in public education and outreach aimed at improving work zone safety. Programmatic campaigns are typically intended to encourage drivers to reduce speeds, respect workers, drive attentively, and practice other good driving habits in work zones (*55*). These campaigns can be directed toward the general population or designed to target specific groups, for example young drivers. Examples of nationwide programmatic campaigns include the annual "National Work Zone Awareness Week," a recurrent event aimed at motorist and worker safety and mobility issues in work zones, and "Turning Point: Roadway Work Zone Safety for New Drivers," an effort that promoted safety messages to the general public, especially to new teen drivers. At the state level, efforts led by DOTs in coordination with other agencies are common practice, and almost every state has launched work-zone-related campaigns in recent years.

Other Reported Safety Impacts

Despite the wide use of programmatic campaigns for work zone safety throughout the United States, evaluations to measure their effects are not common. Evaluations tend to rely on qualitative opinions of drivers, and it is difficult to translate these results into crash reductions. A survey on state DOT work zone public outreach efforts indicated that only 2 of 42 agencies have conducted an evaluation of campaign effectiveness (*55*). The majority of survey respondents indicated that they believe work zone safety is one of the most important safety-related public outreach messages, but also expressed doubt about the adequacy of the scope of these efforts, citing difficulties to change driver behavior in the absence of additional funding for advertising purchases. In 2013, a study in Saskatchewan conducted an advertisement effectiveness study to evaluate awareness of paid construction zone advertising, finding that 70% of the questionnaire respondents agreed that advertising messages have changed their behavior (*56*).

Some general purpose campaigns have had significant impact. For example, an analysis of themed campaigns across the world indicated that drinking-and-driving campaigns reduced crashes by 13 to 14%, speeding campaigns reduced crashes by 8%, and other single campaigns reduced crashes by 10% (*57*). In general, media and public traffic safety education campaigns tend to have high benefit-cost ratios compared with other outreach efforts (*58, 59*). It should be noted, however, that the results are likely to be very site- and campaign-specific and thus cannot be directly translated into CMFs.

Project-Specific Public Education and Outreach Campaigns for Work Zone Safety

Description

Project-specific campaigns are typically aimed at notifying the public about an individual highway project or phase of a project and can result not only in monetary savings by reduced road user delay costs but also in enhanced public support and agency credibility (*55*). Moreover, the Final Rule on Work Zone Safety and Mobility requires that TMPs for significant projects include a public information plan to inform those affected by the project of the expected work zone impacts and changing conditions (*60*). Public information plans include both public awareness and motorist information strategies that range from press releases and media alerts to education campaigns and 511 traveler information systems (*61*). Public information plans may include, but are not limited to, information on the project characteristics, expected impacts, closure details, and commuter alternatives.

Other Reported Safety Impacts

Given that a public information component is required for the Final Rule on Work Zone Safety and Mobility, examples of a wide variety of project-specific campaigns can be found in the literature across the United States. However, the rule does not require a follow-up evaluation of public information efforts, and project-specific campaigns are difficult to evaluate from a safety standpoint due to several reasons, including the uniqueness of projects (making comparisons with other projects difficult), relatively short periods for safety analysis, and the difficulty to isolate the public campaign effects from other factors (*60*). Examples of campaigns with significant results in terms of traffic diversion and delay savings include the I-405 project in Los Angeles related to the "Carmageddon" work zone (*62*), the I-15 Devore project also in California (*63*), and the "Hyperfix" project on I-65/70 in Indianapolis (*64*).

Enhancements to Work Zone Ingress and Egress Points

Description

Work zone access and egress are critical to work zone safety, and data shows that vehicles entering and exiting the work zone can be a significant safety concern (*65, 66*). As part of federal rules to promote safety for workers and motorists in work zones, agencies should also address safe means for work vehicles and equipment to enter and exit traffic lanes and for the delivery of constructions materials to the work zone (*67*). Recommended practices to enhance safety at work zone access and egress locations are available, including incorporating construction access and egress locations into project plans, using ITS, and providing median access from cross-street overpasses (*68*).

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Other Reported Safety Impacts

Strategies to enhance safety at work zone access and egress locations have been implemented by several agencies, but only a few studies have been conducted to quantify or qualify the results of those implementations. Regarding the use of enhanced temporary traffic control devices and ITS, an access and egress survey indicated that DOTs and contractors believed that improper use of traffic control equipment can be a major contributor to confusion for truck drivers, equipment operators, and the traveling public (*69*). The survey identified "Upgrade/additional equipment, markings" as the best practice related to access and egress in closed (positive barrier between workers and traffic) and open work zones (no positive barrier and mostly used for short-term work zones). In the survey, additional equipment and upgrading equipment referred to signage, arrow boards, message boards, and any other additional equipment that a contractor can provide to either protect its jobsite or to communicate with the traveling public. Participants from the same studies also suggested improving construction trucks' access and egress by extending acceleration and deceleration distances and by providing alternate routes.

In addition, a survey of state DOTs that included responses from 20 officials from 14 states ranked the following as the most effective measures to improve safety of access and egress locations in freeway and expressway work zones (*70*) (in descending order):

- Incorporate access and egress locations into internal traffic control plans.
- Build temporary ramps to provide median access from street overpass.
- Improve lighting and visibility of access and egress points during nighttime work zones.
- Use ITS technology to improve access and egress safety.

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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