



## PURPOSE

This policy outlines the selection and application of crash modification factors (CMF) for estimating the change in crashes associated with a specific safety treatment / countermeasure. Thousands of CMFs are available in the 1<sup>st</sup> Edition of the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM), CMF Clearinghouse, and other sources. In many cases, several CMFs exist for a given treatment, making it difficult to determine the most appropriate CMF to apply on a project. The WisDOT CMF Table was developed to provide a list of acceptable CMFs for use in WisDOT safety analyses to ensure consistent application statewide and reduce the amount of time needed to find an applicable CMF. As additional research is completed, the WisDOT CMF Table will be updated accordingly.

## BACKGROUND

### What is a CMF?

#### *Definition*

A CMF is an estimate of the change in crash frequency as a result of a particular safety treatment or design element. CMFs are used to quantify the effectiveness of a safety treatment.

$$CMF = \frac{\text{Crash Frequency WITH Treatment}}{\text{Crash Frequency WITHOUT Treatment}}$$

- A CMF < 1.0 indicates that a treatment has the potential to reduce crashes.
- A CMF > 1.0 indicates that a treatment has the potential to increase crashes.
- The percent crash reduction is  $(1 - CMF) * 100\%$

#### *Standard Error*

The CMF value is only an estimate of the expected average crash frequency based on a statistical analysis of crash data, safety performance functions (SPF), traffic volumes, etc. The true value of the CMF for any treatment is unknown. Most CMFs include a standard error which is the estimated standard deviation of the sampling distribution of the CMF. The standard error is critical to understanding the statistical significance of the CMF and is one factor related to the quality of the CMF. A lower standard error generally means a more reliable estimate. This standard error can be used to calculate a confidence interval which provides a range that the true value of the CMF *should* fall within. To calculate the confidence interval, use the following equation:

#### **Equation 1**

$$C.I. = CMF \pm (SE) * (SM)$$

C.I. = Confidence Interval for the desired level of significance

CMF = Crash Modification Factor

SE = Standard Error

SM = Statistical Multiplier, which is a variable based on the desired level of significance

**Table 1: Level of Significance for Confidence Intervals**

$\alpha$	Level of Significance	Statistical Multiplier
0.01	99%	2.576
0.05	95%	1.960
0.10	90%	1.645

If the confidence interval does not include the value of 1.0, then the CMF is significant at that level. Additional information about CMFs can be found in Chapter 3 and Part D of the HSM.

### How Are CMFs Used?

CMFs are used to estimate the change in crashes after a safety treatment is installed. There are two common applications for CMFs.

Application 1: Multiply the CMF(s) and the observed<sup>1</sup> crashes from an existing site to estimate the crash frequency after installation of a safety treatment. This is done when a safety performance function<sup>2</sup> (SPF) is not available for the treated site. This method is less reliable than Application 2. Application 1 is demonstrated in Example 1.

Application 2: Multiply the CMF(s) and the predicted<sup>3</sup> crashes obtained from a SPF. This is done to account for differences between the SPF's conditions and actual site conditions (e.g., proposed safety treatment). This should only be done after verifying that the CMF conditions are consistent with the conditions represented by the SPF. This type of CMF would supplement the adjustment factors associated with the SPFs found in Part C of the HSM. Application 2 is demonstrated in Example 2.

## **POLICY**

CMFs used in WisDOT safety analyses **shall** come from the WisDOT CMF Table unless a CMF is not available for the identified treatment or the CMF in the table does not match the site's crash and roadway characteristics.

### Applying Multiple CMFs for a Single Treatment

In some cases, there is more than one CMF associated with a single safety treatment. CMFs for different crash types and/or severities **shall** be applied to the respective crashes.

### Applying CMFs for Multiple Treatments

Implementing several safety treatments might be more effective than just one; however, there is limited research on the effects of combining many CMFs. The interactions between safety treatments are complicated and as a result, it is difficult to determine the effectiveness of multiple treatments when used together. Therefore, no more than two unique treatments **shall** be used and each treatment *may* have more than one CMF for different crash types and/or severities.

If two treatments are used at one location, the following methodology **shall** be used to estimate the combined effect of both treatments.

1. If both CMFs are less than 1.0, combine the CMFs using the *Dominant Common Residuals Method*
2. If one or both CMFs are greater than 1.0, use the *Dominant Effect Method*

#### *Dominant Common Residuals Method*

The dominant common residuals method provides a more conservative estimate of the combined effect of multiple treatments than simply multiplying the CMFs together. In this method, the CMFs (i.e., common residuals) are raised to the power of the most effective CMF (i.e., dominant common residual). The combined effect of multiple treatments is estimated as shown in Equation 2. The primary limitation is when either of the individual CMFs are greater than 1.0, particularly the most effective treatments. In these cases, the combined CMFs are raised to a power greater than 1.0, which intensifies the effect rather than dampening. As such, this method is not appropriate for CMFs greater than 1.0. Example 3 demonstrates the *Dominant Common Residuals Method*. Additional examples can be found in the [Highway Safety Benefit-Cost Analysis Guide](#).

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<sup>1</sup> Observed crash frequency is the number of crashes that have occurred within the investigated site limits over one or more years.

<sup>2</sup> A Safety Performance Function (SPF) is a statistically derived equation used to predict the expected average crash frequency of a site based on specific traffic volumes and roadway or intersection characteristics. Refer to Chapter 3.5.2 of the HSM for more information regarding SPFs and how they are used.

<sup>3</sup> Predicted crash frequency is the estimated number of crashes determined with a SPF.

**Equation 2**

$$CMF_{comb} = (CMF_1 * CMF_2)^{CMF_1}$$

CMF<sub>comb</sub> = the combined effectiveness of the two treatments selected

CMF<sub>1</sub> = the CMF with the lowest value (i.e., the most effective treatment selected)

CMF<sub>2</sub> = the CMF for the other treatment selected

***Dominant Effect Method***

The dominant effect method applies the CMF for only the most effective treatment (i.e., lowest CMF value). This method is a simplified and conservative approach to estimating the combined effect of multiple treatments. By only applying a single CMF, this method avoids the issue of independence. The primary limitation of this method is that it is likely to underestimate the combined treatment effect if subsequent treatments improve safety.

**Applying CMFs from Other Sources**

If a CMF is not available for the identified treatment or the CMF in the WisDOT CMF Table does not match the site's crash and roadway characteristics, a CMF *may* be used from another source. When a CMF is used from outside the WisDOT CMF Table, the following documentation **shall** be provided:

1. The CMF study citation, with links to the study when possible
2. CMF value and standard error
3. Roadway and crash characteristics associated with the CMF

Before selecting a CMF, confirm that the following attributes match those of the site being evaluated:

- Area Type
- Roadway Type
- Crash Type
- Crash Severity
- Other Site Conditions – such as number of intersection legs or location of application (e.g., shoulder, curve, etc.)

Also check the quality of the study by:

- Reviewing the number of crashes in the sample
- Identifying the number of sites in the sample and where those sites were located (i.e., in just one state or in many states)
- Considering the statistical methodology that was used and what biases may be present

**GUIDANCE****WisDOT CMF Table**

The WisDOT CMF Table can be found here:

<http://wisconsin.gov/dtsdManuals/traffic-ops/manuals-and-standards/teops/cmf-table.xlsm>

There are two types of CMFs in the HSM; Part C CMFs and Part D CMFs. Part C CMFs are often referred to as 'SPF adjustment factors' because they are used to adjust the base conditions of the SPFs used in conjunction with the HSM predictive methods. Most WisDOT safety analyses should utilize the predictive methods found in Part C of the HSM. The WisDOT CMF Table does not include those CMFs found in Part C. The WisDOT CMF Table includes CMFs that are used to account for differences between the geometric conditions within the SPF's and actual site conditions. (i.e., Application 2 described above).

***Selection Process***

CMFs in the table were chosen based on the following factors:

1. **Availability:** Included treatments commonly used in Wisconsin

2. **Quality:** Many factors influence the quality of a CMF including: study design and statistical methodology, sample size, standard error, potential bias, and data source.
3. **Applicability:** Location of the sites in the study and the crash types and severities for which the CMF was developed. Preference was given to studies with sites near Wisconsin or with similar climates, driver behavior, design standards, etc.

For each CMF in the table, multiple studies were reviewed and the factors described above were documented. A WisDOT committee reviews and approves which CMFs are included in the WisDOT CMF Table.

### Selecting a CMF from the WisDOT CMF Table

CMFs can be applied to total crashes or to target crash types and severities. It is often useful to estimate the change in crashes by type and severity but this should only be done when there are CMFs available for the specific crash types and severities in question. Crash severity is defined by the most severe outcome of those involved in the crash. It is not appropriate to apply a CMF for a specific crash type or severity to other crash types and severities because a treatment may reduce certain crash types or severities while increasing others.

The first step is to identify the treatment being evaluated. Each row in the WisDOT CMF Table corresponds to a specific treatment and has an associated CMF or group of CMFs. In a few cases, there is more than one row in the table that has the same treatment name with different CMF values due to the applicability of the CMF.

Next, select the most appropriate CMF(s) by matching the CMF characteristics to the roadway and crash characteristics of the site being evaluated. If the crash and roadway characteristics are different, it *may* be necessary to find a CMF from another source, which is described in the section “Applying CMFs from Other Resources”.

## APPLICATION EXAMPLES

### Example 1: Applying a CMF to Observed Crash History

#### *Problem:*

At a midblock crossing on a 4-lane, undivided urban road, there have been 4 pedestrian crashes in 5 years.

#### *Analysis:*

One potential treatment is to install a pedestrian hybrid beacon (PHB) to warn drivers when pedestrians are crossing the street.

#### Crash History

Type	Fatal	Injury A	Injury B	Injury C	PDO	TOTAL
Pedestrian		1	2	1		4
Rear End				1	1	2
Other						0
<b>TOTAL</b>		1	2	2	1	6

#### *Solution:*

The CMF value for “Install a Pedestrian Hybrid Beacon” in the WisDOT CMF Table is 0.309. This CMF is for “Pedestrian” crashes of “All” severities. To determine the potential benefit of installing a PHB, multiply the CMF and the observed pedestrian crashes together.

$$N_{\text{Ped}} = \text{Observed}_{\text{Ped}} * \text{CMF}_{\text{Ped}}$$

$$N_{\text{Ped}} = 4 * 0.309$$

$$N_{\text{Ped}} = 1.24 \text{ crashes in 5 years}$$

Using the point estimate of the CMF, the estimated number of crashes in a 5 year period is 1.24, compared to 4 pedestrian crashes in a 5 year period without the PHB.

If desired, a confidence interval (C.I.) can be calculated using the standard error (SE) as well as the point estimate. For example, to be 95% confident of the estimated crash value, a statistical multiplier (SM) of 1.96 (shown in Table 1) is used with the standard error.

$$\begin{aligned} \text{C.I.} &= \text{CMF} \pm (\text{SE} * \text{SM}) \\ 95\% \text{ C.I.} &= 0.309 \pm (0.156 * 1.96) \\ 95\% \text{ C.I.} &= 0.0 \text{ to } 0.615 \\ N_{\text{Ped}} &= (0.0 * 4) \text{ to } (0.615 * 4) \\ N_{\text{Ped}} &= 0 \text{ to } 2.46 \text{ crashes in 5 years} \end{aligned}$$

This means there is 95% confidence that the estimated number of crashes in a 5 year period ranges from 0 crashes to 2.46 crashes.

### Example 2: Applying a CMF to a SPF Prediction

#### *Problem:*

In a rural area, there is a 4-leg, two-way stop-controlled (TWSC) intersection on a multilane, divided highway with a history of right angle crashes (17 in 5 years).

#### *Analysis:*

The improvement being considered is to convert the two-way stop controlled intersection to a single lane roundabout (RAB). The analysis will use safety performance functions instead of the observed crash history.

#### Crash History

Type	Fatal	Injury A	Injury B	Injury C	PDO	TOTAL
Right Angle		2	3	5	7	17
Left Turn			1	1	3	5
Rear End			3	1	7	11
Other			1		1	2
<b>TOTAL</b>		2	8	7	18	35

#### Traffic Volumes

Road	Approach 1	Approach 2	TOTAL
Major	5,550	3,500	9,050
Minor	1,800	500	2,300

#### *Solution:*

1. Get CMF(s) from the WisDOT Table for "Convert Two-Way Stop Control (TWSC) to Roundabout (RAB)"
  - a. CMF = 0.5 for "All" crash types and "KABC" crash severities
  - b. CMF = 1.16 for "All" crash types and "PDO" crash severity.
2. Next, use the Rural, 4-Lane, Two-Way Stop Controlled SPFs for Total Crashes and Fatal & Injury Crashes to predict the crashes in the analysis period
  - a. Predicted Total Crashes before Treatment:

$$N_{\text{Total}} = e^{(-10.008 + (0.848 * \ln(\text{Major Total AADT})) + (0.448 * \ln(\text{Minor Total AADT})))}$$

$$N_{\text{Total}} = e^{(-10.008 + (0.848 * \ln(9050)) + (0.448 * \ln(2300)))}$$

$$N_{\text{Total}} = 3.27 \text{ crashes per year}$$

b. Predicted Fatal and Injury Crashes before Treatment:

$$N_{\text{F\&I}} = e^{(-11.554 + (0.888 * \ln(\text{Major Total AADT})) + (0.525 * \ln(\text{Minor Total AADT})))}$$

$$N_{\text{F\&I}} = e^{(-11.554 + (0.888 * \ln(9050)) + (0.525 * \ln(2300)))}$$

$$N_{\text{F\&I}} = 1.82 \text{ crashes per year}$$

c. Predicted Property Damage Only Crashes before Treatment:

$$N_{\text{PDO}} = N_{\text{Total}} - N_{\text{F\&I}}$$

$$N_{\text{PDO}} = 3.27 - 1.82$$

$$N_{\text{PDO}} = 1.45 \text{ crashes per year}$$

3. Next, multiply the CMFs with the corresponding predictions.

a. Predicted Fatal and Injury Crashes after Treatment:

$$N_{\text{F\&I}} = N_{\text{F\&I}} * \text{CMF}_{\text{KABC}}$$

$$N_{\text{F\&I}} = 1.82 * 0.5$$

$$N_{\text{F\&I}} = 0.91 \text{ crashes per year}$$

b. Predicted Property Damage Only Crashes after Treatment:

$$N_{\text{PDO}} = N_{\text{PDO}} * \text{CMF}_{\text{PDO}}$$

$$N_{\text{PDO}} = 1.45 * 1.16$$

$$N_{\text{PDO}} = 1.68 \text{ crashes per year}$$

c. Predicted Total Crashes after Treatment:

$$N_{\text{Total}} = N_{\text{F\&I}} + N_{\text{PDO}}$$

$$N_{\text{Total}} = 0.91 + 1.68$$

$$N_{\text{Total}} = 2.59 \text{ crashes per year}$$

The safety performance functions predict the intersection would have 3.27 crashes per year with two-way stop control. Of the 3.27 predicted crashes, 1.82 crashes would be a fatal or injury crash and the other 1.45 would be property damage only crashes.

With the improvement of a roundabout, the number of fatal and injury crashes per year would drop to 0.91 while the property damage only crashes would increase to 1.68 crashes per year. This is equal to a total of 2.59 crashes per year.

**Example 3: Dominant Common Residuals Method** for Combining CMFs for Multiple Treatments**Problem:**

An urban signalized intersection is experiencing left turn and rear end crash issues.

**Analysis:**

For this intersection, two safety improvements are being evaluated; changing the signal heads to include a flashing yellow arrow (FYA) and adding retroreflective backplates to the signal heads. Since the two treatments both apply to “All” crash types and “All” severities, they need to be combined using the *Dominant Common Residuals Method*.

**Solution:**

1. Get CMF from the WisDOT Table for “Install Flashing Yellow Arrow: Maintain Protected/Permissive Phasing”
  - a. CMF = 0.922 for “All” crash types and “All” crash severities
2. Get CMF from the WisDOT Table for “Install Retroreflective Signal Backplates”
  - a. CMF = 0.85 for “All” crash types and “All” crash severities

3. Combined CMFs using the *Dominant Common Residuals Method*

$$CMF_e = (CMF_1 * CMF_2)^{CMF_1}$$
$$CMF_{comb} = (0.85 * 0.922)^{0.85}$$
$$CMF_{comb} = 0.81$$

Therefore, the combined CMF = 0.81.

**HELPFUL LINKS**

- WisDOT CMF Table: (<http://wisconsin.dot.gov/dtsdManuals/traffic-ops/manuals-and-standards/teops/cmfs-table.xlsx>)
- CMF Clearinghouse: (<http://www.cmfclearinghouse.org/>)
  - CMF Clearinghouse User Guide: (<http://www.cmfclearinghouse.org/userguide.cfm>)
- CMF Clearinghouse FAQ's: (<http://www.cmfclearinghouse.org/faqs.cfm>)
- CMFs in Practice: (<http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/>)