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Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the Highway Safety Manual

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Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the Highway Safety Manual

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Introduction

This report is a companion document to the first edition (anticipated in 2010) of the Highway Safety Manual (HSM). This document provides background to content of the HSM, which will be relevant to the users of the HSM, to those involved in compiling its future editions, and to related safety research studies. The HSM consists of four parts:

- Part A—Introduction, Human Factors, and Fundamentals;
- Part B—Roadway Safety Management Process;
- Part C—Predictive Methods; and
- Part D—Crash Modification Factors.

The development of Part D of the HSM required a systematic procedure to review, document, and filter the large mass of safety information published in the past several decades. This systematic procedure comprises two key stages: literature review procedure and inclusion process. These are described in the following sections.

It is the first time in the field of highway safety research and guidance that such procedures and processes were compiled, documented, and applied. It is envisioned that the content of this report will, in the future,

- Provide a framework to review safety publications to determine the reliability of findings,
- Outline the characteristics of safety studies that lead to more reliable results,
- Promote higher quality methods for the evaluation of treatments in order to advance the knowledge of their safety effects, and
- Encourage improvements to the evaluation and predictive methods for future editions of the HSM.

Terminology

Some terms used in this document are defined below.

Accuracy is the proximity of estimates to the true value.

Confounding factors: A confounding factor in a study is a variable which is related to one or more of the variables defined in a study. A confounding factor may mask an actual association or falsely demonstrate an apparent association between the study variables where no real association between them exists. If confounding factors are not measured and considered, bias may result in the conclusion of the study.

Crash modification functions or factors (CMFs) are estimated by means of observational before–after evaluation studies, as described in the HSM, Part B: Roadway Safety Management Process. Crash modification functions and factors express the safety effect of the implementation of a countermeasure or treatment to a roadway or facility. CMF is the ratio between the number of crashes per unit of time expected after a modification or measure is implemented and the number of crashes per unit of time estimated if the change does not take place.

When the implementation of a treatment is considered, one of the main questions is the change in safety that will result. A treatment is said to have caused a change in safety if without it the change would not have occurred. CMFs are found in Part D of the HSM, and they are shown in tables (see, for example, Table 1).

CMFs are further described in the HSM Part A, Chapter 3: Fundamentals. CMFs are used as shown in the HSM Part B Chapter 6: Selection of Countermeasures, and are also incorporated in the safety performance functions (SPFs) found in the HSM Part C: Predictive Methods.

Precision is the degree to which repeated estimates are similar to each other.

Regression-to-mean (RTM) is the tendency for the occurrence of crashes at a particular site to fluctuate up or down, and to converge to a long-term average. This tendency introduces regression-to-mean bias into crash estimation and analysis, which can make treatments at sites with extremely high crash frequency appear to be more effective than they truly are.

Safety performance functions typically express the objective relationship between the predicted number of crashes by type and severity, and traffic volume for a group of similar facilities such as signalized intersections or two-lane rural roads. Safety predictive functions may also include other roadway parameters such as shoulder width and type, number of lanes, percentage of heavy vehicles, etc.

Standard error: In general, standard deviation indicates the precision of a set of repeated measurements; in other words, precision is the degree to which repeated measurements are close to each other. When calculating the mean of a set of measurements, then the mean itself has a standard deviation; the standard deviation of the mean is called the *standard error*. In Part D of the HSM, the standard error indicates the precision of an estimated CMF.

TABLE 1 Sample CMF Table: Potential Crash Effects of Converting Minor Road Stop-Control to All-Way Stop-Control

Exhibit 14-9: Potential Crash Effects of Converting Minor-Road Stop-Control to All-way Stop-Control *(8)*

Treatment	Setting (Intersection type)	Traffic Volume	Accident type (Severity)	AMF	Std. Error
Convert minor-road stop control to all-way stop control *(8)*	Urban (MUTCD warrants are met)	Unspecified	Right-angle (All severities)	**0.25**	**0.03**
			Rear-end (All severities)	**0.82**	**0.1**
			Pedestrian (All severities)	*0.57*	*0.2*
			All types (Injury)	**0.30**	**0.06**
Convert minor-road stop control to all-way stop control *(7)*	Rural (MUTCD warrants are met)		All types (All severities)	**0.52**	**0.04**
Base Condition: Intersection with minor-road stop control meeting MUTCD warrants for an all-way stop controlled intersection.					

NOTE: **Bold** text is used for the most reliable AMFs. These AMFs have a standard error of 0.1 or less.
Italic text is used for less reliable AMFs. These AMFs have standard errors between 0.2 to 0.3.
Conversions from two-way to all-way stop-control meet established MUTCD warrants.
AMF from reference (4) is based on reference (16).

Treatment: A treatment is an engineering modification or an intervention to a site (or to a highway network) that may or may not be implemented with the objective of improving safety (e.g., a temporary condition such as a work zone may be considered a treatment).

Literature Review Procedure

The Highway Safety Manual presents information for quantifying the safety effects of various engineering treatments. The knowledge presented in Part D of the HSM is based on an extensive literature review of published highway safety research studies for over five decades. Evidence-based and rigorous review, supported by statistical evidence of the accuracy and validity of studies, was applied and is described in the next sections.

The literature review procedure, developed for the purpose of documenting it systematically, included the following major steps:

Step 1. Determine estimate of safety effect of treatment as documented in respective evaluation study publication;

Step 2. Adjust estimate of safety effect to account for potential bias from RTM and changes in traffic volume;

Step 3. Determine ideal standard error of safety effect;

Step 4. Apply method correction factor (MCF) to ideal standard error, based on evaluation study characteristics;

Step 5. Adjust corrected standard error to account for bias from RTM and changes in traffic volume; and

Step 6. Combine CMFs when specific criteria are met. In a limited number of cases, multiple evaluation studies provided estimates of safety effects post-implementation of same treatment at different locations with similar conditions.

Step 1. Determine Estimate of Safety Effect [or Crash Modification Factor (CMF)] of Treatment as Documented in Respective Evaluation Study Publication

There are generally five types of evaluation studies that generate CMFs, as follows:

- Simple before–after evaluation study, which compares the crash experience of sites before the treatment is applied and after the treatment is applied;
- Before–after evaluation study with a comparison group, which is similar to a simple before–after study but adds a comparison group or control group that is not treated;
- Nonregression cross-section evaluation study, which compares the crash experience of sites with the treatment and sites without the treatment;
- Multivariable regression cross-section evaluation study, which produces statistical models for the crash experience of sites with the treatment; and
- Meta-analysis study, which combines the results of two or more evaluation studies, of any one of the types described above, of the safety effects of a treatment.

When reviewing a publication, there are three possible ways to determine the safety effect of a treatment; they are as follows:

- The safety effect is reported either as an CMF or percent crash reduction (e.g., 0.80 or 20% reduction);

- The safety effect is not explicitly reported but can be calculated using the crash information, found in the publication, to develop the ratio between expected crash frequencies after and before, or with and without, the treatment. That is

$$\text{CMF} = \frac{\text{expected crash frequency after or with treatment}}{\text{expected crash frequency before or without treatment}}$$

- The safety effect or the expected crash frequencies are not reported. However, the ratio of observed crashes or crash rates for the after and before the treatment, while less accurate, are reported; these were used as estimates of safety effects of the treatment.

Step 2. Adjust Estimate of Safety Effect (or CMF) to Account for Bias from Regression-to-Mean (RTM) and Changes in Traffic Volume

Two types of bias considered in the estimate of safety effects are the following:

1. RTM bias and
2. Traffic volume bias.

The CMF is adjusted if one or both types of bias are suspected to exist based on information found in the evaluation study publication. The adjustments reflect the assumptions described below.

RTM Bias

RTM bias makes a treatment seem more effective than it really is. RTM bias can occur when a treatment is implemented because the number of crashes reported in the last few years at the site, before treatment, was high and the safety method used in the evaluation study does not account for this latest random increase in crashes.

RTM bias may be present when all of the following three statements are true:

1. The evaluation method used is a simple before–after comparison and does not account for RTM,
2. Site selection bias is likely because sites were selected on the basis of poor safety record, and
3. Study data used in the before period includes the time period when the site had a poor safety record influencing the treatment decision.

Using specific data and procedures, it is possible to estimate and reduce RTM bias when conducting a before–after evaluation study. The researchers of many past safety studies did not consider the RTM bias and did not collect the necessary data or apply the specific procedures. The potential for RTM bias can be found even in evaluation studies that used empirical Bayes methodology. Although most empirical Bayes studies account for RTM due to the nature of the evaluation methodology, this may not be true if its use is not carried out correctly.

Thus, in developing CMFs for possible inclusion in the HSM, the NCHRP 17-27 research team created a procedure to retrospectively correct published CMFs when necessary. The retrospective correction was made to results found in published reports or papers used in the study and recorded in the Highway Safety Manual Knowledge Base hosted in the Crash Modification Factors Clearinghouse (http://www.cmfclearinghouse.org/).

The procedure for retrospective RTM correction of the CMF value is based on the fact that treated sites were selected on the basis of a poor safety record, thus resulting in an CMF that is smaller than its true value. This exaggerated CMF is named "CMF_{biased}." It can be said that

- If there is no site selection bias, and the before and after periods are of equal duration, the CMF is estimated by the ratio *A*/*B*, where *B* is the before-crash frequency and *A* is the after-crash frequency; or
- If there is site selection bias, then *B* is larger than it should be and the ratio *A*/*B* or CMF_{biased} will be smaller than it should be.

To correct for the larger value of *B*, the RTM bias *X* is subtracted from *B*. So the corrected or unbiased CMF is estimated by the ratio $A/(B–X)$. The amount of RTM bias is the difference between the observed before-crash frequency and the expected crash frequency in the long run. The difference between the biased and unbiased CMF is

$$CMF_{biased} - CMF_{unbiased} = A/B - A/(B - X)$$
$$= CMF_{biased} * [1 - 1/(1 - (X/B))]$$

Since the RTM value, *X*, is small compared with *B*, the ratio of *X*/*B* is much less than 1, and $[1/(1 - (X/B))]$ is approximately equal to $[1 + (X/B)]$, thus it is concluded that

$$CMF_{biased} - CMF_{unbiased} = CMF_{biased} * (X/B)$$

Equation 1 shows this relationship by rearranging it for $CMF_{unbiased}$ (calculation of CMF_{biased} to correct for RTM bias).

$$CMF_{unbiased} = CMF_{biased} + CMF_{biased} * (X/B) \quad (1)$$

where

$CMF_{unbiased}$ = unbiased CMF value,
CMF_{biased} = published CMF,
B = expected number of before crashes, and
X = RTM bias assumed by the NCHRP 17-27 research team.

Since CMF_{biased} is calculated from the data in the study publication, the missing information to estimate the $CMF_{unbiased}$ is the ratio *X*/*B*. Typically, evaluation studies that do not consider RTM bias also do not provide sufficient information in their documentation to estimate *X*. Therefore, the NCHRP 17-27 research team developed a RTM correction method based on our researchers' expertise and extensive experience in the area of safety analysis.

The values of *X*/*B* ratios are assumed to range between 0.5 and 0.25. For a small RTM bias, where a large proportion of the total population of sites was treated and many years of before-crash data were included in the evaluation study, the CMF was corrected using a ratio for *X*/*B* of 0.05. For a large RTM bias, where only a few sites with the highest crash frequency were treated out of the total population and few years of before-crash data were included in the evaluation study, the CMF was corrected using a ratio for *X*/*B* of up to 0.25.

For example, if an evaluation study leads to a treatment CMF of 0.83, but the three conditions above for RTM bias are not present (see page 5), and the researchers reviewing the publication considered the circumstances to have led to a small RTM bias of $X/B = 0.1$, the $\text{CMF}_{\text{biased}}$ would be changed to

$$\begin{aligned}\text{CMF}_{\text{unbiased}} &= (\text{CMF}_{\text{biased}} + \text{CMF}_{\text{biased}} * 0.1)\\ &= 0.83 + 0.083\\ &= 0.91\end{aligned}$$

This correction brings the CMF value closer to the correct value of the safety effect of implementing the treatment.

Traffic Volume Bias

There are five conditions where traffic volume bias may occur. These conditions are

1. A known traffic volume change that was not accounted for during the evaluation study. Generally, crash frequency increases with increasing traffic volume. If the traffic volume has increased from before to after study periods, but this increase was not accounted for during the evaluation analysis, the resulting CMF is biased. Typically, the relationship between expected crash frequency and traffic volume is not linear, however if the study publication does not provide the relationship for the study data, a linear relationship is assumed by the NCHRP 17-27 researchers.

Equation 2 shows how to account for the change in traffic (calculation of $\text{CMF}_{\text{unbiased}}$ to correct for traffic volume bias):

$$\text{CMF}_{\text{unbiased}} = \frac{A}{B * (\text{change in traffic volume})} \tag{2}$$

where

$\text{CMF}_{\text{unbiased}}$ = unbiased CMF value,
A = expected number of after crashes, and
B = expected number of before crashes.

$\text{CMF}_{\text{biased}}$ is corrected by multiplying the before-crash frequency (*B*) by the change in traffic volume. For example, if a 5% increase in traffic volume occurred, the before-crash frequency is multiplied by 1.05. If a 7% decrease in traffic volume occurred, the before-crash frequency is multiplied by 0.93.

$$\text{CMF}_{\text{unbiased}} = \frac{A}{B * 1.05} \quad \text{or} \quad \text{CMF}_{\text{unbiased}} = \frac{A}{B * 0.93}$$

2. An unknown change in traffic volume.
3. If the original evaluation study did not account for changes in traffic volume, and the publication does not provide the traffic volumes in the before or after periods or even indicate what change in traffic volumes might have occurred, then it is not possible to adjust the CMF for traffic volume bias. This analytical weakness will be taken into account in rating the study quality, as discussed in Step 4.
4. The evaluation study used before- and after-crash rates that were derived using some form of traffic volume as a denominator; for example, million entering vehicles (MEV). In this case, the change in traffic volume from the before to the after period was accounted for. However, the use of exposure such as MEV is an approximation of the nonlinear relationship between crashes and traffic volume. Although it is inaccurate to use crash rates in evaluation studies, the NCHRP 17-27 researchers could not modify to correct the CMF published. This implicit error will be accounted for in rating the study quality, as discussed in Step 4.
5. The evaluation study developed a CMF based on traffic volume. The function will be recorded in the Highway Safety Manual Knowledge Base hosted in the Crash Modification Factors Clearinghouse, and adjustments to the function will not be made.
6. Migration or spillover safety effects can result if a treatment affects conditions outside the treated location; for example, a shift in traffic patterns or alteration of operating speed. If an evaluation study publication describes only the change in safety of the treated locations, this may represent only a part of the overall safety effect. The potential for migration or spillover will be noted in the Highway Safety Manual Knowledge Base hosted in the Crash Modification Factors Clearinghouse, but the CMF cannot be corrected for this analytical weakness. Examples of treatments that may result in migration effects are

- Traffic calming: Traffic calming may lead to changes in travel patterns. As a result, crashes may decrease in the treated area, but crashes may migrate elsewhere, for example, to a local arterial road.
- Road resurfacing: A newly-resurfaced surface may lead to an increase in operating speeds. There may be a spillover effect if drivers maintain their increased speed on other sections of road, outside the resurfaced road.

Step 3. Determine Ideal Standard Error of CMF

Standard error is a statistical measure of accuracy. The accuracy of an CMF depends on several factors, such as the amount and quality of data and the evaluation method used.

After the CMF value is determined and corrected for RTM and traffic volume bias if necessary, the ideal standard error is estimated. An ideal standard error, s_{ideal}, reflects mainly the randomness of the crash counts used to generate the CMF value.

As noted in Step 1, there are five main types of studies that provide CMF values. For empirical Bayes and meta-analysis studies, the standard error or standard deviation values are often reported in their publications. These published standard error or standard deviation values were included in the Highway Safety Manual Knowledge Base hosted in the Crash Modification Factors Clearinghouse as s_{ideal}.

For other study types where the standard error or standard deviation was not provided in the study publication, the s_{ideal} was calculated from the published data when possible. This calculation is tailored to the evaluation methodology used and described below.

Simple Before–After and Nonregression Cross-Section Studies

The standard error for a CMF derived from a simple before–after or nonregression cross-section evaluation study can be calculated by Equation 3 (*1*, p. 83).

$$s_{\text{ideal}}^2 = \frac{\text{CMF}_{\text{unbiased}} / r + \text{CMF}_{\text{unbiased}}{}^2}{B} \tag{3}$$

where

s_{ideal} = ideal estimate of standard error of the CMF,
$\text{CMF}_{\text{unbiased}}$ = unbiased CMF value,
B = expected number of before crashes, and
r = ratio of after to before time periods in evaluation study.

Before–After Study with Comparison Group

The standard error for an CMF derived from a before–after study with a comparison group can be approximated using the methodology described on page 125 of *Observational Before–After Studies in Road Safety*.

Multivariable Regression Cross-Section Studies

The ideal standard error for a CMF derived from a regression study can be calculated using the statistical precision of the parameter estimates. The statistical precision is usually given in the study publication as *t*-statistics. The ideal standard error for each parameter can be calculated as follows:

$$s_{\text{ideal}} = \text{parameter estimate}/t\text{-statistic} \tag{4}$$

Step 4. Apply Method Correction Factor to Ideal Standard Error, Based on Evaluation Study Characteristics

The ideal standard error reflects the randomness of the crash counts used to generate the CMF value. The NCHRP 17-27 researchers reviewed each publication to determine the evaluation methodology used and the study quality in terms of its empirical and subjective criteria. Following the findings of this critical review, the ideal standard error was modified accordingly.

The NCHRP 17-27 researchers developed a set of MCFs for each evaluation method for a range of study characteristics. These are shown in Tables 1 to 3. The MCF values were applied to the ideal standard errors calculated in Step 3 by using Equation 5.

$$s_{MCF} = s_{ideal} \times MCF \tag{5}$$

where

s_{MCF} = standard error of the CMF after multiplied by MCF,
s_{ideal} = ideal estimate of standard error of the CMF, and
MCF = method correction factor.

It is noted that, in Tables 2 to 4, no observational evaluation study receives a MCF of 1.0; only a rigorous randomized trial evaluation would not require an adjustment of the ideal standard error value. For all observational evaluation methods, a study of the best quality receives an MCF of 1.2.

Step 5. Adjust Corrected Standard Error to Account for Bias from RTM and Changes in Traffic Volume

The final step in this process further refines the standard error to correct for two types of bias:

1. RTM bias and
2. Traffic volume bias.

If bias was known to exist based on the review of the evaluation study publication, then the standard error was corrected using the process below.

RTM Bias

As described before, RTM makes a treatment seem more effective than it really is. Whenever an RTM correction is applied to the CMF, the standard error is modified using Equation 6.

$$s = \sqrt{s_{MCF}^2 + RTM^2} \tag{6}$$

where

s = adjusted standard error of the $CMF_{unbiased}$,
s_{MCF} = standard error of the $CMF_{unbiased}$, and
RTM = RTM correction applied to the $CMF_{biased} = CMF_{biased} * X/B$ where X = the RTM bias assumed by the NCHRP 17-27 research team; and B is the before-crash frequency.

Thus, continuing the example shown on page 7, the CMF_{biased} of 0.83 was corrected for RTM by a ratio for X/B of 0.1:

$$RTM = CMF_{biased} * 0.1 = 0.83 * 0.1 = 0.083$$

If s_{MCF} was calculated to be 0.05, then the adjusted standard error is

$$s = \sqrt{(0.05^2 + 0.083^2}$$
$$s = 0.097$$

TABLE 2 Method Correction Factors for Before–After and Meta-Analysis Studies

Key Study Characteristic	Method Correction Factor
All potential sources of bias were properly accounted for Uses crash frequencies	1.2
Accounts for regression to the mean bias Uses crash frequencies	1.8
Regression to the mean may not be accounted for but considered to be minor, if any Uses crash frequencies or crash rates	2.2
Regression to the mean not accounted for and considered to be likely Uses crash rates	3
Severe lack of information published regarding study data and findings	5

NOTE: This table applies to empirical Bayes, simple before–after, before–after with likelihood functions, before–after with comparison group, expert panels, and meta-analysis.

TABLE 3 Method Correction Factors for Nonregression Cross-Section Studies

Key Study Characteristic	Method Correction Factor
All potential confounding factors have been accounted for by matching sites	1.2
Most potential confounding factors have been accounted for by matching sites	2
Traffic volume is the only confounding factor accounted for in the study	3
No confounding factors accounted for in the study	5
Severe lack of information published regarding study data and findings	7

TABLE 4 Method Correction Factors for Regression Cross-Section Studies

Key Study Characteristic	Method Correction Factor
All potential confounding factors have been accounted for by variables of the regression in an appropriate functional form	1.2
Most potential confounding factors have been accounted for by variables of the regression in an appropriate functional form	1.5
Several important confounding factors were accounted for, and functional form is conventional	2
Few variables used and functional form is questionable	3
Severe lack of information published regarding study data study and findings	5

Traffic Volume Bias

If a known traffic volume change occurred between the before and after evaluation time periods, the originally published CMF value was corrected using the process described above while the standard error was not corrected because the bias due to a known volume change would be small.

If the change in traffic volume between the before and after evaluation time periods is unknown, the CMF value and standard error cannot be explicitly corrected. This lack of information is taken into account in rating the study quality.

Step 6. Combine CMFs

For a limited number of instances, multiple studies provided results for safety effects of the same treatment implemented in similar conditions. After careful consideration of the treatment and conditions of each study, and confirmation that they took place at similar road and traffic volume characteristics, the results were combined. The goal of combining the results of several studies of one treatment is to provide a more accurate estimate of the safety effect of a treatment, based on a larger sample size of similar conditions.

Unbiased CMFs are combined using Equation 7, and the standard error of the combined CMF is calculated using Equation 8 (*1*, p. 193).

$$\mathrm{CMF} = \frac{\sum_{i=1}^{n} \mathrm{CMF}_{\mathrm{unbiasedi}} / s_i^2}{\sum_{i=1}^{n} 1 / s_i^2} \qquad (7)$$

where

CMF = combined unbiased CMF value,
$\mathrm{CMF}_{\mathrm{unbiasedi}}$ = unbiased CMF value from Study *i*,
s_i (or $s_{\mathrm{MCF}i}$) = adjusted (or corrected) standard error of the unbiased CMF from Study *i*, and
n = number of CMFs to be combined.

$$S = \sqrt{\frac{1}{\sum_{i=1}^{n} 1 / s_i^2}} \qquad (8)$$

where

S = the standard error of the combined unbiased CMF value,
s_i (or $s_{\mathrm{MCF}i}$) = adjusted (or corrected) standard error of the CMF from Study *i*, and
n = number of CMFs to be combined.

For example, three studies of a treatment applied on similar road types with similar volumes were reviewed, and the following three unbiased CMFs with adjusted standard errors were identified (see Table 5):

- Study 1: $CMF_1 = 0.90$, $s_1 = 0.1$
- Study 2: $CMF_2 = 0.45$, $s_2 = 0.3$
- Study 3: $CMF_3 = 0.62$, $s_3 = 0.4$

It is noted that the combined CMF has a standard error that is smaller than any of the individual studies used in the procedure. The goal of providing a more accurate estimate of the safety effect of a treatment is accomplished.

TABLE 5 Calculations to Combine Three CMFs

Study	CMF_i	s_i	CMF_i/s_i^2	$1/s_i^2$
1	0.90	0.1	90.00	100
2	0.45	0.3	5.00	11.1
3	0.62	0.4	3.87	6.25
		Sum	98.87	117.35
		Results	CMF = 98.87/117.35 =0.84	$S = \sqrt{1/117.35}$ =0.09

Inclusion Process

The CMFs found in Part D of the HSM will provide sound information when selecting the most cost-effective safety treatments because this knowledge was "filtered" to include only reliable information. This filter, or inclusion process, is described below.

For any decision-making process, it is generally accepted that a more accurate estimate is preferable to a less accurate one. The greater the accuracy of the information used to make a decision, the greater the chance that the decision is correct. In addition to the accuracy of information, it is also important to understand the precision of the information used to make decisions. Precision refers to the degree of similarity among several repeated measurements. Again, a higher degree of precision is preferable to improve the chance that the decision is correct.

Therefore, for safety-related decision making, more accurate and precise CMF values will lead to more cost-effective decisions.

Two key features of the inclusion process that indicate the need for quantification of CMF stability are

1. The concept of a hypothetical new CMF that is realistically accurate. In other words, that future evaluation studies will provide accurate CMFs with small standard errors, and
2. A maximum permissible change in the current CMF; that is, the maximum difference between the estimates of the current CMF included in the HSM and a revised CMF that is such that the current CMF is deemed sufficiently stable.

For unbiased CMFs, precision and accuracy are indicated by the *standard error* of the estimates. A small standard error indicates that an CMF is both precise and accurate. Since the literature review procedure accounted for known sources of bias (such as changes in traffic volume and RTM), only unbiased CMFs are documented in the Highway Safety Manual Knowledge Base hosted in the Crash Modification Factors Clearinghouse and considered for inclusion in the HSM.

Stability of CMFs

The stability of a CMF is defined as the extent to which new research results are likely to substantially change the CMF estimate. A small standard error indicates that the CMF value is stable; in other words, the CMF is not likely to change substantially with new research. Once the new and unbiased CMF estimate is obtained, a revised estimate of the CMF, RevCMF, can be computed by Equation 9:

$$\text{RevCMF} = \text{CMF}_{\text{unbiased}} \frac{\frac{1}{s_C^2}}{\frac{1}{s_C^2}+\frac{1}{s_N^2}} + N \frac{\frac{1}{s_N^2}}{\frac{1}{s_C^2}+\frac{1}{s_N^2}} = \text{CMF}_{\text{unbiased}} \times \text{Weight}_C + N \times \text{Weight}_N \quad (9)$$

where

$\text{CMF}_{\text{unbiased}}$ = current estimate of the unbiased CMF. This unbiased value is calculated using the literature review procedure;

s_C^2 = squared standard error or variance of the unbiased CMF. This unbiased value is calculated using the literature review procedure;
N = estimate of new and unbiased CMF obtained from a research study conducted after publication of the first edition of the HSM; and
s_N^2 = variance of the new and unbiased CMF.

The stability of CMFs is illustrated with the following numerical example: suppose that the current $CMF_{unbiased} = 0.9$, and its standard error $s_C = 0.02$. A new study estimates, for the same treatment in the same setting, road type, and traffic volume to be New CMF = 1.1 with a standard error $s_N = 0.1$.

Table 6 summarizes the current and new CMFs, standard errors, and weights calculated as defined by Equation 9.

The resulting RevCMF is calculated using Equation 9:

$$\begin{aligned} \text{RevCMF} &= 0.9 * 0.962 + 1.1 * 0.038 \\ &= 0.866 + 0.042 \\ &= 0.908 \end{aligned}$$

Note that the weights in Equation 9 are nonnegative numbers that always sum to 1. These weights determine the proportion of the current and new CMFs used to develop the RevCMF. When Weight_C is close to 1 (as in Table 6) the RevCMF will be closer to the current $CMF_{unbiased}$. Conversely, when Weight_C is close to 0 the RevCMF will resemble the new CMF (N).

Thus, in this example, the results of the new evaluation study causes only a minor shift to the current $CMF_{unbiased}$; i.e., this is an example of a stable CMF estimate.

As mentioned above, the magnitude of change from a current $CMF_{unbiased}$ to a RevCMF, is defined as the proportion of the difference between the new CMF or N and the current $CMF_{unbiased}$, and the difference between the current $CMF_{unbiased}$ and the RevCMF. This proportion is shown in Equation 10.

$$P \equiv \frac{\text{RevCMF} - \text{CMF}_{\text{unbiased}}}{N - \text{CMF}_{\text{unbiased}}} \qquad (10)$$

where

P = magnitude of change in CMF,
$CMF_{unbiased}$ = current estimate of the unbiased CMF ,
N = new estimate of the unbiased CMF of a new evaluation study, and
RevCMF = calculated by Equation 9.

TABLE 6 Example of Calculating a Revised CMF

	CMF	s	s^2	$1/s^2$	Weight
Current	0.9	0.02	0.0004	2,500	0.962
New	1.1	0.1	0.01	100	0.038

For example, when the current $CMF_{unbiased}$ was more accurate (0.9 ± 0.02, Table 5), the revised CMF estimate was 0.908. In this case, P = (0.908–0.9)/(1.1–0.9) = 0.04. In other words, the current CMF shifted 4% toward the new CMF. In comparison, if the current estimate was much less accurate (say 0.9 ± 0.6), the revised estimate would be 1.09. In this case, P = (1.090.9)/(1.1–0.9) = 0.95. The current $CMF_{unbiased}$ would have shifted 95% toward the new CMF.

The magnitude of change in CMF is modified to reflect the standard error. Equation 11 shows Equation 10 rewritten by substituting RevCMF from Equation 9.

$$P \equiv \frac{1}{1 + s_N^2 / s_C^2} \qquad (11)$$

where

P = magnitude of change in CMF,
S_N = standard error of new and unbiased CMF, and
S_C = standard error of unbiased CMF.

Equation 11 can be rearranged to solve for s_C:

$$s_C = s_N \sqrt{\frac{P}{1 - P}} \qquad (12)$$

where

P = magnitude of change in CMF,
S_N = standard error of new and unbiased CMF, and
S_C = standard error of unbiased CMF.

The threshold values for P and S_N must be set in order to use the inclusion process. The NCHRP 17-27 research team in conjunction with its panel members and the TRB Task Force for the Development of the HSM studied this question carefully and adopted values for these key parameters. They are described in the next section.

Filtering CMF for Inclusion in the HSM

For the first edition of the HSM, a limiting value for the proportion of the difference between new and current CMFs was set at a 50% shift. In other words, CMFs included in the HSM are sufficiently stable, such that the value will not shift by more than 50% due to future evaluation studies, or $P < 0.5$. This condition requires that new CMFs to be considered for future editions of the HSM will be at *least as stable as* the CMFs found in the first edition.

For the first edition of the HSM, a limiting value for the standard error of a new CMF was set at 0.10. In other words, CMFs produced by future evaluation studies would be relatively stable with a low standard error that is not easy to obtain without a rigorous methodology.

By applying these two threshold values to Equation 12, the inclusion process filters CMFs so that only those with standard errors of 0.1 or less are considered sufficiently accurate, precise, and stable to be included in the first edition of the HSM.

It is noted that other CMFs, in addition to those CMFs that pass the inclusion thresholds, were included in Part D of the HSM. For treatments that have an CMF with a standard error of 0.1 or less, other CMFs with standard errors of equal or less than 0.3 were included, expanding the knowledge of safety effects of the same treatment on other facilities, or other crash types or severities.

Information on how to use the safety effects of treatments included in the HSM is found in the HSM Part D, "Introduction and Application Guidance."

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