# NCHRP

# 17-27

## Inclusion Process and Literature Review Procedure for Part D

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# Preface

The Knowledge Base forms the foundation for the contents of each chapter of Part D of the First Edition of the Highway Safety Manual. This document is a companion to the Knowledge Base of the Highway Safety Manual developed during NCHRP Project 17-27. The chapters in Part D are:

- Chapter 3: Roadway Segments
- Chapter 4: Intersections
- Chapter 5: Interchanges
- Chapter 6: Special Facilities and Geometric Situations
- Chapter 7: Road Networks

It is expected that this Knowledge Base, which documents the extensive literature review completed, will be of interest to highway safety professionals, and will be of use for the development of future editions of the HSM. It is envisioned that this Knowledge Base will be expanded and updated as new safety research becomes available.

In the Knowledge Base, safety effects are presented as Accident Modification Factors or Functions (AMFs). AMFs are typically estimated for three accident severities: fatal, injury, and non-injury. Fatal and injury are generally combined and noted as injury. Where distinct AMFs are available for fatal and injury severities, they are presented separately. Non-injury severity is also known as property-damage-only severity.

Each AMF is accompanied by a measure of accuracy, the standard error. A small standard error indicates that an AMF is accurate.

The development of the Knowledge Base of the Highway Safety Manual (HSM) required a formalized process and procedure to review, document, and filter the multitude of safety information published in the last 50 years.

The procedures that were applied in the development of the Knowledge Base are provided in this companion document.

# Highway Safety Manual, First Edition: Inclusion Process and Literature Review Procedure for Part D

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## EXHIBITS



## EQUATIONS

# Inclusion Process and Literature Review Procedure for Part D

The Inclusion Process and Literature Review Procedure followed during the development of Part D are detailed in this companion to the Knowledge Base. Examples of the Literature Review Procedure are provided at the end of this document.

## Inclusion Process

The AMFs in Part D provide sound support for selecting the most cost-effective road safety treatments because the knowledge has been filtered to include the most reliable information available. This filter, or Inclusion Process, is described here.

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.

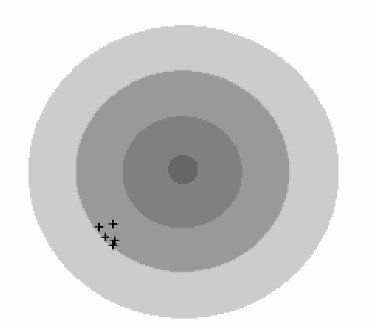
In addition to the accuracy of information, it is also important to understand the precision of the information used to make decisions. Precision refers to the degree of similarity among several repeated measurements. Again, a higher degree of precision is preferable to improve the chance that the decision is correct.

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

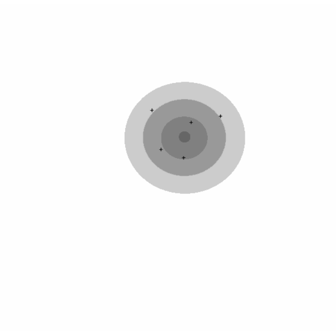
### Accuracy and Precision of AMFs

To illustrate accuracy and precision, consider a bull's-eye target where the center of the target is considered to be the most accurate information (Exhibit 1). If the estimates (the + signs) form a tight cluster, the estimates are precise. However, if the center of that cluster is not the bull's-eye, then the estimates are precise but not accurate. If the estimates are scattered and do not form a tight cluster they are neither precise nor accurate.

*Exhibit 1: Illustration of precision and accuracy*



Precise but not Accurate



Neither Precise nor Accurate

In summary:

- *Accuracy:* The proximity of estimates to the true value.
- *Precision:* The degree to which repeated estimates are similar to each other.

For unbiased estimates, precision and accuracy are indicated by the *standard error* of the estimates. Since the literature review procedure accounted for known sources of bias (such as changes in traffic volume and regression-to-mean), only unbiased AMFs are documented in the Knowledge Base and used in the HSM.

As outlined in the literature review procedure, each unbiased AMF is accompanied by a measure of precision and accuracy, the standard error. A small standard error indicates that an AMF is both *precise and accurate*.

## Stability of AMFs

The stability of an AMF is defined as the extent to which new research results are likely to substantially change the AMF estimate. A small standard error indicates that the AMF value is *stable*; in other words, the AMF is not likely to change substantially with new research. The stability of AMFs is illustrated with the following numerical example, where:

- C = the current estimate of the unbiased AMF. This unbiased value is calculated using the literature review procedure
- $s_C^2$ = the squared standard error or variance of the current AMF. This unbiased value is calculated using the literature review procedure
- N = the estimate of the unbiased AMF obtained from a new study, i.e., research conducted after publication of the first edition of the HSM
- $s_N^2$ = variance of the new AMF

Once N is obtained, a revised estimate of the AMF, R, can be computed by Equation 1.

*Equation 1: Revised estimate of the AMF based on new research*

$$R = C\frac{\frac{1}{s_C^2}}{\frac{1}{s_C^2}+\frac{1}{s_N^2}} + N\frac{\frac{1}{s_N^2}}{\frac{1}{s_C^2}+\frac{1}{s_N^2}} = C \times \text{Weight}_C + N \times \text{Weight}_N$$

### Example 1

Suppose that the current unbiased estimate of an AMF, C=0.9, and its standard error $s_C$ =0.02. A new study estimates the AMF for the same treatment in the same setting, road type, and traffic volume to be N=1.1 with a standard error $s_N$ =0.1.

Exhibit 2 summarizes the current and new AMFs and standard errors, and the Weights calculated as defined in Equation 1.

*Exhibit 2: Example of calculating a revised AMF*

| | AMF | s | $s^2$ | $1/s^2$ | Weight |
|---|---|---|---|---|---|
| Current | 0.9 | 0.02 | 0.0004 | 2500 | 0.962 |
| New | 1.1 | 0.1 | 0.01 | 100 | 0.038 |

The resulting Revised AMF is calculated using Equation 1:

R = 0.9 * 0.962 + 1.1 * 0.038

= 0.866 + 0.042

= 0.908

Note that the weights in Equation 1 are non-negative numbers that always sum to 1. These weights determine the proportion of the Current and New AMFs used to develop the Revised AMF. When $Weight_C$ is close to 1 (as in Exhibit 2) the Revised AMF will be closer to the Current AMF. Conversely, when $Weight_C$ is close to 0 the Revised AMF will resemble the New AMF.

In this example, the standard error of the Current AMF is small in comparison to the standard error of the New AMF, therefore the weight of the Current AMF is closer to 1 and the results of the new study causes only a minor shift to the Current AMF. In this example, the Current AMF is an example of a *stable* AMF estimate.

To illustrate an unstable AMF, suppose that the current AMF has a standard error of 0.6 instead of 0.02. Exhibit 3 summarizes the current and new AMFs and standard errors, and the Weights calculated as defined in Equation 1.

*Exhibit 3:Example of an unstable AMF*

| | **AMF** | **s** | **$s^2$** | **$1/s^2$** | **Weight** |
|---|---|---|---|---|---|
| Current | 0.9 | 0.6 | 0.36 | 2.78 | 0.027 |
| New | 1.1 | 0.1 | 0.01 | 100 | 0.973 |

The resulting Revised AMF is calculated using Equation 1:

R = 0.9 * 0.027 + 1.1 * 0.973

= 0.024 + 1.070

= 1.09

In this case, the Current AMF is much less accurate than the New AMF. As a result, the current expectation that the treatment reduces accidents by 10% is replaced by the new expectation that the treatment will increase accidents by 9%. This is an example of a situation in which the Current AMF lacks stability ($s_C$=0.6) and new studies of reasonable accuracy contradict current evidence-based research.

## Key features of the Inclusion Process

Two key features of the Inclusion Process that allow a quantification of AMF stability are:

1. The concept of a hypothetical new AMF that is realistically accurate. In other words, that new studies will provide accurate AMFs with small standard errors, such as in the previous example where $s_N = 0.1$.
2. A 'maximum permissible change' in the Current AMF. That is, the maximum difference between the estimates of the Current AMF and the Revised AMF that is acceptable, such that the current estimate is deemed sufficiently stable.

The first key feature, the concept of hypothetical new studies, was explored in the previous example.

The second key feature, the magnitude of change from a Current AMF to a Revised AMF, can be defined as the proportion of the difference between the New AMF and the Current AMF, and the difference between the Current AMF and the Revised AMF. This proportion is shown in Equation 2.

*Equation 2: Magnitude of change in the AMF*

$$P \equiv \frac{R - C}{N - C}$$

Where:

C = Current estimate of the unbiased AMF

N = New estimate of the unbiased AMF of a new study

R = Revised AMF based on the current and new AMFs

<u>Example 1 Continued</u>

When the current AMF was more accurate (0.9±0.02, Exhibit 2), the revised AMF estimate was 0.908. In this case, P = (0.908-0.9) / (1.1-0.9) = 0.04. In other words, the current AMF shifted 4% towards the new AMF.

In comparison, when the current estimate was much less accurate (0.9±0.6, Exhibit 3), the revised estimate was 1.09. In this case, P = (1.09-0.9) / (1.1-0.9) = 0.95. The current AMF shifted 95% towards the new AMF.

### *Filtering AMFs based on standard error*

To apply the definition of P in terms of standard error, Equation 2 is rewritten by substituting R from Equation 1:

*Equation 3: Magnitude of change in the AMF based on standard error*

$$P \equiv \frac{1}{1 + s_N^2 / s_C^2}$$

Equation 3 can be rearranged to solve for $s_C$:

*Equation 4: Equation 3 rearranged*

$$s_C = s_N \sqrt{\frac{P}{1-P}}$$

To apply the inclusion process, threshold values for P and $s_N$ must be set. To determine appropriate values for P and $s_N$, consider the following examples.

## Example 2

If a shift of 10% is acceptable (P=0.1) toward whatever unbiased AMF a new study would produce, then the standard error of the current AMF must be less than √(0.1/0.9)=0.33 of the standard error of the new AMF.

Then if a new study aims to estimate the AMF with a standard error of 0.05, the HSM would include current AMFs with a standard error less than 0.05×0.33=0.016.

## Example 3

If a shift of 50% is acceptable (P=0.5) toward the new AMF, then the standard error of the current AMF must be less than the standard error of the new AMF, since √(0.5/0.5)=1.0.

Then if a new study aims to estimate the AMF with a standard error of 0.05, the HSM would include current AMFs with a standard error less than 0.05×1=0.05.

For the First Edition of the Highway Safety Manual, a limiting value for the proportion of the difference between New and Current AMFs was set at a 50% shift. In other words, AMFs included in the HSM are ‘sufficiently stable’, such that the value will not shift by more than 50% due to future studies, or $P < 0.5$. This provides for the new AMFs considered for the HSM to be at least as stable as current AMFs.

For the First Edition of the Highway Safety Manual, a limiting value for the standard error of some future study was set at 0.10. In other words, AMFs produced by some future research would be relatively stable with a low standard error that is not easy to obtain without a rigorous study.

By applying these two threshold values to Equation 4, the Inclusion Process filters AMFs 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.

In addition to those AMFs that pass the inclusion thresholds, additional knowledge has been included in Part D. For treatments that have an AMF with a standard error of 0.1 or less, other AMFs with standard errors of 0.2 to 0.3 are also included expanding the knowledge of potential safety effects of the same treatment on other facilities, or other crash types or severities. These AMFs are presented in italic font and are accompanied by a number sign "#". This is important to note, as a treatment with a larger standard error is less reliable. These AMFs should be used with caution.

## Filtering AMFs based on value

After filtering AMFs based on standard error, the final step in the inclusion process is the consideration of the AMF value. AMFs that are within the range 0.90 to 1.10 may be shifted by future research to cross the value 1.0. In other words, it is possible that, although the AMF is considered sufficiently stable for inclusion in the First Edition of the HSM, future research may shift the AMF value from a decrease in accidents to an increase in accidents, or vice versa. This is illustrated in the following example.

Example 4

If the current AMF is 0.95 with a standard error of 0.05, the AMF passes the inclusion threshold of $s_C$<0.10 and would be included in the HSM.

If a new AMF is 1.30 with a standard error of 0.05, then the revised AMF is calculated using Equation 1:

| | **AMF** | **s** | **$s^2$** | **$1/s^2$** | **Weight** |
|---|---|---|---|---|---|
| Current | 0.95 | 0.05 | 0.0025 | 400 | 0.5 |
| New | 1.3 | 0.05 | 0.0025 | 400 | 0.5 |

R = 0.95*0.5 + 1.3*0.5

= 0.475 + 0.65

= 1.13

The new AMF has resulted in a change in the expected direction of the safety effect, from a decrease in accidents (C=0.95) to an increase in accidents (R=1.13).

AMFs with a value within the range 0.90 to 1.10 are most likely to be shifted across the value 1.0. These AMFs are accompanied by an asterisk "*". This is important to note, as a treatment with an AMF that crosses the value 1.0 may result in a reduction in crashes (safety benefit) or an increase in crashes (safety disbenefit). These AMFs should be used with caution.

## Conclusion

The Inclusion Process uses the standard error values to determine if an AMF is reliable enough to be included in the HSM. A standard error of 0.1 or less indicates an AMF value that is sufficiently accurate, precise, and stable. For treatments that have an AMF with a standard error of 0.1 or less, other AMFs with standard errors of 0.2 to 0.3 are also included expanding the knowledge of potential safety effects of the same treatment on other facilities, or other crash types or severities.

The examination of evidence-based reviews in the medical discipline has confirmed that the process to develop the Knowledge Base for Part D of the HSM share very similar aspects. A rigorous review, supported by statistical evidence of the accuracy and validity of studies, is advocated and applied in the medical field.

## Literature Review Procedure

The objective of Part D of the Highway Safety Manual is to provide knowledge of the safety effects of various treatments. Therefore, the objective of the literature review is to estimate the safety effect or Accident Modification Factor or Function (AMF) of a treatment accompanied by the estimate of its standard error, based on one or more evaluation studies. By definition, a treatment is some change to a site 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).

A literature review procedure was developed to document available knowledge using a consistent approach. During the critical review of publications, reviewers considered various aspects of each study to determine the quality of the study, including both empirical and subjective criteria.

The literature review procedure includes methods to: calculate Accident Modification Factors (AMFs) based on published data, estimate the standard error of published or calculated AMFs, and adjust the AMFs and standard errors to account for study quality and method. The steps of the literature review procedure are:

1. Determine the estimate of the safety effect or Accident Modification Factor or Function (AMF) of a treatment based on one published study
2. Adjust the AMF to account for bias from regression-to-mean and/or changes in traffic volume
3. Determine the ideal standard error of the AMF
4. Apply a Method Correction Factor to ideal standard error, based on the study characteristics
5. Adjust the corrected standard error to account for bias from regression-to-mean and/or changes in traffic volume
6. Combine AMFs when specific criteria are met

These steps are discussed in the following sections. Examples of the application of the procedure are provided at the end of the Appendix.

The literature review procedure resulted in the development of a Knowledge Base, which is a synthesis of the extensive literature review conducted for the development of this manual.

More information on Accident Modification Functions and standard errors is provided in Chapter 2 (Sections 2.3.3 and 2.3.4), including examples of their application.

## Step 1. Determine the estimate of the safety effect or Accident Modification Factor or Function (AMF) of a treatment based on one published study

There are generally five types of studies that generate AMFs:

- Simple before-after study, which compares the accident experience of sites before the treatment is applied and after the treatment is applied
- Before-after study with a comparison group, which is similar to a before-after study but adds a comparison group or control group that is not treated
- Non-regression cross-section study, which compares the accident experience of sites with the treatment and sites without the treatment
- Multivariable regression cross-section study, which produces statistical models for the accident experience of sites with the treatment
- Meta-analysis study, which combines the results many other studies of a treatment which could be of any type described above

Ideally, the original authors of a study published an AMF for the treatment, either as an AMF ratio or percent accident reduction (e.g., 0.80 or 20% reduction). If an AMF was not published, then an AMF can be calculated as the ratio of expected accident frequencies after and before, or with and without, the treatment, if published. That is:

$$AMF = \frac{\text{expected accident frequency after/with treatment}}{\text{expected accident frequency before/without treatment}}$$

When the ratio of expected accident frequencies was not published, the ratio of observed accidents or accident rates, while less accurate, was deemed acceptable.

## Step 2. Adjust the AMF to account for bias from regression-to-mean and/or changes in traffic volume

Two types of bias for the AMF were considered:

1. Regression-to-mean (RTM) bias
2. Traffic volume bias

If either or both types of bias are known to exist based on information published in the original study, then the AMF value is corrected using the following process.

### Regression-to-mean (RTM) bias

'Regression-to-mean bias' makes a treatment seem more effective than it really is. Regression-to-mean bias can occur when a treatment is implemented because the number of accidents recently reported at the treated site was high, and the safety evaluation does not account for this recent random increase in crashes. Regression-to-mean is discussed further in Chapter 2.

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

1. The study is a simple before-after comparison and does not explicitly or correctly account for RTM; and
2. Site selection bias is likely, that is, sites were selected on the basis of poor safety record; and

3. Data used in the before period includes the time period when the site had a poor safety record influencing the treatment decision.

The potential for RTM bias was also considered for empirical Bayes studies. Although most empirical Bayes studies account for RTM due to the nature of the methodology, this may not be true if the methodology is not applied correctly.

Using specific data and procedures, it is possible to estimate and reduce RTM bias when conducting a before-after study. However, a correction method had to be developed to retrospectively correct AMFs from studies where the data were not collected and the specific procedures were not applied by the original authors. The retrospective correction was made to the published information.

The method for retrospective RTM correction of the AMF value is based on the fact that sites selected on the basis of a poor safety record result in an AMF that is larger than it should be. In other words:

- If there is no site selection bias, and the before and after periods are of equal duration, the AMF is estimated by the ratio A/B, where B is the 'before' accident frequency and A is the 'after' accident frequency
- If there is site selection bias, then B is larger than it should be and the ratio A/B or AMFbiased 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 AMF is estimated by the ratio A/(B-X). The amount of RTM bias is the difference between the observed 'before' accident frequency and the expected accident frequency in the long run. The difference between the biased and unbiased AMF is:

$$\begin{aligned} AMFbiased - AMFunbiased &= A/B - A/(B-X) \\ &= A/B * [1 - (A/(B-X)) * (B/A)] \\ &= A/B * [1 - AB/A(B-X)] \\ &= A/B * [1 - B/(B-X)] \\ &= AMFbiased * [1 - 1/(1-(X/B))] \end{aligned}$$

Since the RTM value, X, is small compared to B, the ratio of X/B is much less than 1, and [1/(1-(X/B))] is approximately equal to [1+(X/B)]. As a result:

$$\begin{aligned} AMFbiased - AMFunbiased &= AMFbiased * [1 - 1 - X/B] \\ &= - AMFunbiased * (X/B) \end{aligned}$$

Rearranging for AMFunbiased:

$$AMFunbiased = AMFbiased + AMFbiased * (X/B)$$

Since AMFbiased is calculated from the published data, the missing information to estimate the AMFunbiased is the ratio X/B. However, published studies that do not consider RTM typically do not provide sufficient information to calculate X. Therefore, the RTM correction method is based on researchers' expertise and experience.

For a small RTM bias, where a large proportion of the total population of sites was treated and many years of before period data were included in the study, the AMF was corrected using a ratio for X/B of 0.05. For a large RTM bias, where only a few sites with the highest accident frequency were treated out of the total population and few before period years of data were included in the study, the AMF was corrected using a ratio for X/B of up to 0.25.

For example, if a study leads to an AMF of 0.83, but the three conditions above for RTM bias were present, and these factors were considered to lead to a small RTM bias of about X/B=0.1, the AMF would be changed to:

$$AMFunbiased = (AMFbias + AMFbias * 0.1)$$
$$= 0.83 + 0.083$$
$$= 0.91$$

This correction is applied since the direction of the bias can be anticipated, and doing so will bring the AMF value closer to the correct value.

### Traffic volume bias

There are two possible scenarios where traffic volume bias may occur. These two scenarios are:

1. A known traffic volume change that was not taken into account by the original authors

   It is generally accepted that accident frequency increases as traffic volume increases. If the traffic volume has changed from the before to the after period, but is not taken into account, the AMF is biased.

   If the study does not give a relationship between expected accident frequency and traffic volume, a linear relationship is assumed.

   To account for the change in traffic, AMFbiased is corrected by multiplying the before accident frequency by the change in traffic volume. For example, if a 5% increase in traffic volume occurred, the before accident frequency is multiplied by 1.05. If a 7% decrease in traffic volume occurred, the before accident frequency is multiplied by 0.93.

$$AMFunbiased = \frac{A}{B * 1.05}$$

2. An unknown change in traffic

   If the original study did not take into account changes in traffic volume, and does not provide the traffic volumes in the before and/or after periods or indicate what change in traffic volumes might have occurred, then it is not possible to adjust the AMF for traffic volume. However, this lack of information will be taken into account in rating the study quality, as discussed later in this section.

There are three other possible scenarios where traffic volume bias may occur. However, the traffic volume correction method does not correct for these scenarios:

1. The original study used before and after crash rates derived using some form of traffic volume as a denominator, e.g., million entering vehicles (MEV). In this case, the change in traffic volume from the before to the after period was taken into account. However, the use of exposure such as MEV is an approximation of the relationship between crashes and traffic volume. If the before and after volumes were known and if resources were available, it is preferable to retrieve the original data sets and consider reanalysis of the safety effect using more advanced methods. For this edition of the HSM, the inaccurate linear relationship, i.e., crash rate, used by the original authors was accepted and the AMF was not corrected. This implicit error will be taken into account in rating the study quality, as discussed later in this section.
2. The original study provides an Accident Modification Function based on traffic volume. The function will be included in Part D and adjustments to the function will not be made.
3. Migration or spillover safety effects can result if a treatment affects conditions outside the treated location, e.g., a shift in traffic or alteration of speed. If the AMF provided by the original study only describes the change in safety of the treated location, this may only be a part of the safety effect. The potential for migration or spillover will be noted, but it cannot be corrected for. Examples of treatments that may result in migration effects are:
    - Traffic calming: Traffic calming may lead to changes in travel patterns. As a result, accidents may decrease in the treated area, but accidents may migrate elsewhere, for example, to a local arterial road.
    - Road resurfacing: A new 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 the ideal standard error of the AMF

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

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

As noted in Step 1, there are four main types of studies that provide AMF values. For empirical Bayes and other study types, such as meta-analysis, standard error or standard deviation values are often provided in the original study. Published standard error or standard deviation values were adopted as $s_{ideal}$.

For other study types where the standard error or standard deviation was not provided in the original study, the $s_{ideal}$ was calculated from the published data, when possible. This calculation is tailored to the study type.

### Before-after and Non-regression Cross-section Studies

The standard error for an AMF derived from a before-after or non-regression cross-section study can be calculated by Equation 5.[1]

*Equation 5: Calculate ideal standard error for Before-after and Non-regression Cross-section Studies*

$$s_{ideal}^2 = \frac{AMF_{unbiased} / r + AMF_{unbiased}^2}{B}$$

Where:

$s_{ideal}$ = ideal estimate of standard error of the AMF

AMFunbiased = the unbiased AMF value

B = the expected number of before or without accidents

r = ratio of the time periods studied, such as after to before periods or with to without periods

### Before-after Study with Comparison Group

The standard error for an AMF 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".[(1)]

This methodology is illustrated in the examples at the end of the Appendix.

### Multivariable Regression Cross-section Studies

The ideal standard error for an AMF derived from a regression study can be calculated using the statistical precision of the parameter estimates. The statistical precision is usually given as "t-statistics" by the original study. The ideal standard error for each parameter can be calculated by Equation 6.

*Equation 6: Calculate the ideal standard error for Multivariable Regression Cross-section Studies*

$s_{ideal}$ = Parameter Estimate / t-statistic

[1] Based on Equation 7.3 of Hauer, E., "Observational Before-After Studies in Road Safety", Pergamon, 1997, p. 83.

## Step 4. Apply a Method Correction Factor to the ideal standard error, based on the study characteristics

The ideal standard error, which mainly reflects the randomness of the accident counts used to generate the AMF value, must be modified to account for study quality and method. Each study was critically reviewed to determine the quality of the study, including both empirical and subjective criteria.

Method Correction Factors (MCF) were developed by study type for a range of study qualities. Key study characteristics which were used to classify the study quality, as shown in Exhibit 4 to Exhibit 6. The MCFs values were developed by the NCHRP Project 17-27 Team and applied to the ideal standard errors calculated in the previous step using Equation 7.

*Equation 7: Apply Method Correction Factor to ideal standard error*

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

Where:

$s_{MCF}$ = standard error of the AMF after multiplied by MCF

$s_{ideal}$ = ideal estimate of standard error of the AMF

MCF = Method Correction Factor related to the study type and quality

Note that no observational study receives a MCF of 1.0, as only a rigorous randomized trial evaluation would not require an adjustment of the ideal standard error value. For all study types, a study of the best quality receives an MCF of 1.2.

*Exhibit 4: Method Correction Factors for Before/After and Meta-analysis studies*

| Key Study Characteristics | Method Correction Factor |
|---|---|
| • All potential sources of bias were properly accounted for<br>• Uses accident frequencies | 1.2 |
| • Accounts for regression to the mean<br>• Uses accident frequencies | 1.8 |
| • Regression to the mean may not be accounted for but considered to be minor if any<br>• Uses accident frequencies or accident rates | 2.2 |
| • Regression to the mean not accounted for and considered to be likely<br>• Uses accident rates | 3 |
| • Severe lack of information published regarding study set-up and results | 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

*Exhibit 5: Method Correction Factors for Non-regression Cross-Section studies*

| Key Study Characteristics | Method Correction Factor |
|---|---|
| • All potential confounding factors have been accounted for by matching | 1.2 |
| • Most potential confounding factors have been accounted for by matching | 2 |
| • Volume is only confounding factor accounted for | 3 |
| • No confounding factors accounted for (incl. volume, etc.) | 5 |
| • Severe lack of information published regarding study set-up and results | 7 |

*Exhibit 6: Method Correction Factors for Regression Cross-Section studies*

| Key Study Characteristics | 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; Functional form is conventional | 2 |
| • Few variables used; Functional form is questionable | 3 |
| • Severe lack of information published regarding study set-up and results | 5 |

## Step 5. Adjust the corrected standard error to account for bias from regression-to-mean and/or changes in traffic volume

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

1. Regression-to-mean (RTM) bias
2. Traffic volume bias

If bias was known to exist based on information published in the study, then the standard error was corrected using the following process.

## Regression-to-mean (RTM) bias

As described previously, 'regression-to-mean bias' makes a treatment seem more effective than it really is. Regression-to-mean (RTM) is discussed further in Chapter 2. Whenever an RTM correction is applied to the AMF, the standard error is modified using Equation 8.

*Equation 8: Correct standard error for regression-to-mean*

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

Where:

s = adjusted standard error of the AMFunbiased

$s_{MCF}$ = standard error of the AMFunbiased after multiplied by MCF

RTM = RTM correction applied to the AMFbiased

For example, in the example on page 12, the AMFbiased of 0.83 was corrected for RTM by a ratio for X/B of 0.1, that is:

RTM = AMFbias * 0.1 = 0.83 *0.1 = 0.083

If $s_{MCF}$ was calculated to be 0.05, then the adjusted standard error is calculated using the same RTM correction of 0.083:

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

s = 0.097

## Traffic volume bias

As described previously, there are two possible scenarios where traffic volume bias may occur:

1. A known traffic volume change that was not taken into account by the original authors:
2. An unknown change in traffic

If a known traffic volume change occurred and the AMF value was corrected using the process described previously, the standard error is not corrected as the bias due to a known volume change would be small.

If the change in traffic volume is unknown, the AMF value and standard error cannot be explicitly corrected. However, this lack of information will be taken into account in rating the study quality, as discussed later in this section.

## Step 6. Combine AMFs

In a limited number of cases, multiple studies provided results for the same treatment in similar conditions. After careful consideration of the treatment and conditions of the studies, the results may be combined. The goal of combining the results of several studies of one treatment is to:

- Provide a more accurate and reliable estimate the safety effect of a treatment, based on multiple and similar studies involving similar road and traffic volume characteristics

A limited number of AMFs were combined in Part D. The AMFunbiased and the standard error from each study are used in the combination of AMFs. The following example illustrates the procedure applied.

Unbiased AMFs can be combined using Equation 9, and the standard error of the combined AMF is calculated using Equation 10.[2]

*Equation 9: Combine AMFs from different studies*

$$AMF = \frac{\sum_{i=1}^{n} AMF_{unbiasedi} / s_i^2}{\sum_{i=1}^{n} 1 / s_i^2}$$

Where:

AMF = the combined unbiased AMF value

$AMFunbiased_i$ = the unbiased AMF value from Study "i"

$s_i$ (or $s_{MCFi}$) = adjusted (or corrected) standard error of the unbiased AMF from Study "i"

n = number of AMFs to be combined

*Equation 10: Standard error of a combined AMF*

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

Where:

S = the standard error of the combined unbiased AMF value

$s_i$ (or $s_{MCFi}$) = adjusted (or corrected) standard error of the AMF from Study "i"

n = number of AMFs to be combined

[2] Hauer, E., "Observational Before-After Studies in Road Safety", Pergamon, 1997, p. 193.

For example, three studies of a treatment applied on similar road types with similar volumes were reviewed, and the following three unbiased AMFs with adjusted standard errors were identified:

- Study 1: $AMF_1 = 0.90$, $s_1 = 0.1$
- Study 2: $AMF_2 = 0.45$, $s_2 = 0.3$
- Study 3: $AMF_3 = 0.62$, $s_3 = 0.4$

The following table summarizes the calculations to combine these three AMFs.

| i | $AMF_i$ | $s_i$ | $AMF_i/s_i^2$ | $1/s_i^2$ |
|---|---|---|---|---|
| 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** | **AMF=98.87/117.35 =0.84** | **S=√1/117.35 =0.09** |

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

## Examples of the Literature Review Procedure

The following sections provide examples for four types of studies that may require the estimation and refinement of AMF and s values:

1. Simple before-after study
2. Before-after study with comparison group
3. Non-regression cross-section study
4. Regression cross-section study

These four examples do not cover all possible study types or possible study outcomes. They are intended to illustrate the procedure developed and applied in the development of Part D of the First Edition of this Manual.

### Simple before-after study

Suppose that you have a before-after study with the following features:

- Before period duration: 3 years
- After period duration: 1 year
- Before accidents: 67
- After accidents: 18

*Step 1.* *Determine the AMF*

AMF = (after accidents/ after period) / (before accidents/before period)

= (18/1)/(67/3)

= 0.81

*Step 2.* *Adjust the AMF*

In this case, assume the reviewer did not identify evidence of the potential for RTM, and that volumes were not reported. Therefore, bias cannot be corrected for (which is most often the case).

*Step 3.* *Determine the ideal standard error*

After to Before duration ratio, r = 1/3

Using AMF=0.81, r =1/3, B = 67, and Equation 5:

$$s_{ideal}^2 = \frac{AMF / r + AMF^2}{B}$$

$s_{ideal} = 0.215$

*Step 4.* *Apply MCF*

For this example, assume the reviewer identified the Method Correction Factor of 2.2 (Exhibit 4):

$s_{MCF}=s_{ideal} \times$ (Method Correction Factor) = 0.215×2.2=0.473

*Step 5.* *Adjust the corrected standard error*

As noted in Step 2, bias could not be identified, therefore t was not corrected for bias, and s is not corrected for bias.

*Conclusion*

AMF = 0.81, s = 0.473

## Before-after study with comparison group (C-G study)

Suppose that you have a C-G study with the following features:

- Accident count before: Treatment = 173; Comparison = 897
- Accident count after: Treatment = 144; Comparison = 870
- Variance of the odds ratio = 0.055 (if no information on the variance of the odds ratio is available in the study, examine sensitivity using values between 0.001 and 0.01)

*Step 1.* *Determine the AMF*

Use Hauer's calculations to determine AMF and $s_{ideal}$ (Exhibit 7). For further details on the methodology used to compute AMF and $s_{ideal}$, refer to Chapter 9 of Hauer (1997).

In this case, AMF=0.85

*Step 2.* *Adjust the AMF*

For the study at hand, assume RTM was present and AMF needs to be corrected by X/B=0.1; then:

AMF = 0.85+(0.1*0.85) = 0.935

*Exhibit 7: Statistical analysis of a before-after study with comparison group*

**Statistical analysis of a 'Before-After' study with a Comparison Group**

| INPUT: | Treatment | Comparison |
|---|---|---|
| Accident Count 'Before' = | **173** | **897** |
| Accident Count 'After' = | **144** | **870** |
| Variance of odds ratio* = | **0.0055** | |

**Instructions: Enter five input values. Examine Delta-hat, Theta-hat and their standard deviations.**

*See section 9.3 of Hauer (1997) If no information about the variance of the odds ratio is available, examine sensitivity to assuming values between 0.001 to 0.01

| | OUTPUT: | | |
|---|---|---|---|
| Step 1: | Lambda-hat= | 144.00 | |
| | rT=rC= | 0.97 | |
| | pi-hat= | 167.61 | |
| Step 2: | Var{lambda-hat}= | 144.00 | |
| | Var{pi-hat}= | 380.49 | |
| Step 3: | Delta-hat= | 23.61 | Difference between expected and observed accidents 'After' |
| | Theta-hat= | 0.85 | *Estimate of Index of Effectiveness (t)* |
| Step 4: | Sigma{Delta-hat}= | 22.90 | Estimate of standard deviation of difference |
| | Sigma{Theta-hat}= | 0.12 | *Estimate of standard deviation of Index of effectiveness (s ideal)* |

For detailed explanation see: Ezra Hauer, OBSERVATIONAL BEFORE-AFTER STUDIES IN ROAD SAFETY, Pergamon, 1997

NOTE: From Table 9.8, page 125 of (*1*)

*Step 3.* *Determine the ideal standard error*

Using Exhibit 7: $s_{ideal}$ =0.12

*Step 4.* *Apply MCF*

For this example, assume the reviewer identified the Method Correction Factor of 3 (Exhibit 4):

$s_{MCF}=s_{ideal} \times MCF = 0.12\times3=0.36$

*Step 5.* *Adjust the corrected standard error*

Since a correction for RTM was applied in Step 2, the amount of correction to t is added to s. For the study at hand, AMF was corrected by (0.1*0.85) = 0.085; then

$s = \sqrt{(0.36^2+0.085^2)} = 0.370$

*Conclusion*

AMF = 0.935, s = 0.370

## Non-regression cross-section study

For this study type, the estimate of safety effect is based on comparing sites with treatment X to sites with treatment Y, and the AMF under consideration is a change from X to Y. Therefore, in analogy to the Before-After method described previously, X will correspond to 'Before' and Y to 'After'.

For a non-regression cross-section comparison with the following circumstances:

- Accident frequency of sites with X is 320
- Accident frequency of sites with Y is 221
- Exposure with X is 5,000 veh/day; Exposure with Y is 3,000 veh/day
- Ratio of (Exposure with Y)/(Exposure with X) = 0.6
- Only exposure was accounted for in this study

*Step 1. Determine the AMF*

AMF = (Accidents Y/Exposure Y)/(Accidents X/Exposure X)

= (221/3000) / (320/5000)

= 1.15

*Step 2. Adjust the AMF*

Not applicable for non-regression cross-section studies.

*Step 3. Determine the ideal standard error*

The ratio of Exposures (in this example = 0.6) is analogous to the "After to Before duration ratio, r" for a simple before-after study. Thus, Equation 5 can be applied for cross-section studies as for before-after studies; for this example AMF=1.15, r =0.6, and B = 320:

$$s_{ideal}^{2} = \frac{AMF_{unbiased} / r + AMF_{unbiased}^{\ 2}}{B}$$

$s_{ideal}$ = 0.101

*Step 4. Apply MCF*

For this example, assume the reviewer identified the Method Correction Factor of 5 (Exhibit 5):

$s = s_{ideal} \times MCF = 0.101 \times 5 = 0.505$

*Step 5. Adjust the corrected standard error*

Not applicable for non-regression cross-section studies.

*Conclusion*

AMF = 1.15, s = 0.505

## Regression cross-section study

Suppose that the study under review shows:

Accident frequency = $\alpha(AADT)^{0.9}(Lane\ width)^{-0.70}$

and the t-statistic for lane width = -0.82

*Step 1. Determine the AMF*

To determine the AMF for lane widening from 10' to 11', calculate the corresponding ratio of accident frequencies:

AMF = $(11/10)^{-0.70} = 0.93$

*Step 2. Adjust the AMF*

Not applicable for regression cross-section studies.

*Step 3. Determine the ideal standard error*

When results of regression modeling are given, authors often describe the statistical precision of parameter estimates of $s_{parameter}$ by giving a t-statistic for that parameter. Then $s_{parameter}$ can be calculated by:

$s_{parameter}$= Parameter Estimate / t-statistic

For this example:

Parameter estimate = -0.70; t-statistic for lane width = -0.82

$s_{lane\ width\ parameter} = -0.70 / -0.82 = 0.85$

a) Add 1 $s_{lane\ width\ parameter}$ to the parameter estimate = (-0.70 + 0.85 = 0.15), then calculate: $(11/10)^{-0.15} = 1.01$

b) Subtract 1 $s_{lane\ width\ parameter}$ from the parameter estimate = (-0.70 - 0.85 = -1.55), then calculate: $(11/10)^{-1.55} = 0.86$

c) Calculate the estimate of the standard error for t = 0.93:

$s_{ideal} = (1.01 – 0.86) / 2 = 0.07$

*Step 4. Apply MCF*

For this example, assume the reviewer identified the Method Correction Factor of 3 (Exhibit 6):

$s=s_{ideal} \times$ (Method Correction Factor) = $0.07\times3=0.21$

*Step 5. Adjust the corrected standard error*

As noted in Step 2, this step is not applicable to regression cross-section studies.

*Conclusion*

AMF = 0.93, s = 0.14

## References

1. Hauer, E., "Observational Before-After Studies in Road Safety." Oxford, N.Y., Pergamon Press Inc., (1997) pp. ix-289.