Crash Modification Factors Development

NCHRP 17-50 TECHNICAL BRIEFINGS

This series of technical briefings provides a reference for highway agencies that are interested in initiating the implementation of the American Association of State Highway and Transportation Officials (AASTHO) Highway Safety Manual (HSM) 1st Edition principles and philosophy within their organization. The series summarizes lessons learned, best practices, challenges, and other aspects of implementation of the 13 lead states and 8 support states that participated in the research project.

Background

Crash Modification Factors are traditionally used as measures to estimate the effectiveness of different treatments or design elements. This effectiveness is expressed in terms of values or functions describing whether there is an increase or decrease of the crash frequency after implementing the safety strategy.

The FHWA CMF Clearinghouse is an excellent source of CMFs. This is a data repository containing thousands of CMFs maintained by FHWA. The CMF Clearinghouse is regularly updated with newly developed CMFs, and provides users with educational information on how to use CMFs. However, there are still gaps in the CMFs available and more research is needed. Information related to how the CMF was developed, its statistical properties, as well as a star quality rating criteria is included as part of the Clearinghouse database. Not all the CMFs have been developed using the same criteria and statistical rigor leading to different levels of quality and reliability, which translates into different star quality ratings. Hence, the need to develop high quality jurisdiction specific CMF values/functions.

This technical briefing provides a brief overview of best practices to develop high quality CMFs using state-specific data.

Crash Modification Factors

The CMFs effectiveness is applied as a multiplicative factor to see the change in crash frequency after implementing a given countermeasure at a specific site. A CMF less than 1.0 indicates that the treatment has the potential to reduce crashes, whereas a CMF greater than 1.0 indicates a potential increase in crashes. For example, a CMF of 0.7 indicates a 30% reduction in crashes. A CMF of 1.15 indicates a 15% increase in crashes.

Crash Modification Functions

Crash Modification Functions (CMFunctions) are equations used to compute CMF values based on different variables including traffic volumes and site characteristics. A CMFunction allows the CMF to change over a range of a variable or combination of variables. One example is the CMF for horizontal curves included in the HSM Chapter 10. This CMFunction considers the length, radius of curvature, and presence or absence of spiral transitions on horizontal curves. Another example is the CMFunction for skew angle, which varies based on how acute/obtuse is the intersection angle.

Developing High Quality CMFs

Developing reliable CMFs typically require accuracy, precision, and good documentation about the general applicability of the study results. It is important to include as many common characteristics of high-quality CMFs to ensure a good product. Some of these common characteristics include:

- Use a study design that is statistically rigorous with reference group or randomized experiment and control

- Use a large sample size that covers multiple years with a variety of sites
- Verify that the standard error is small in relation to the CMF
- Make sure the study controls for all sources of known potential bias
- Use datasets that include states representing different geographies

The CMF Clearinghouse includes information about the CMFs quality, which is assessed by a star rating that is based on the five criteria listed above. The ratings are from 1 to 5 stars, with 5 stars representing the best quality. There are other study design methods, data limitations, and other factors that may affect the quality of the CMFs. For this reason, good documentation it is important because it provides practitioners with access to the study approach, allows assessing its quality, and helps identifying in which situations it is appropriate to apply the CMF. The CMF clearinghouse presents all available CMFs along with their star rating, so analyst may select the most appropriate for their analysis.

Commonly Used Study Types and Designs

Observational studies are commonly used to evaluate safety improvements. They can be classified into before-after studies and cross-sectional studies. Before-after studies include "all techniques by which one may study the safety effect of some change that has been implemented on a group of entities (road sections, intersections, drivers, vehicles, neighborhoods, etc.)" (Hauer, 1997, p. 2). Cross-sectional studies include those where "one is comparing the safety of one group of entities having some common feature (say, STOP controlled intersections) to the safety of a different group of entities not having that feature (say, YIELD controlled intersections), in order to assess the safety effect of that feature (STOP versus YIELD signs)" (Hauer, 1997, p. 2, 3). Both studies present strengths and weaknesses, and they are discussed in detail in the Recommended Protocols for Developing Crash Modification Factors report (Carter et al., 2012).

Some potential issues and biases with before-after studies include regression-to-the-mean (RTM), changes in traffic volume, changes in crash reporting, and accounting for state-to-state difference if using multiple states.

Similarly, some potential issues and biases with cross-sectional models include control of cofounders (most important), unobserved heterogeneity and omitted variable bias, accounting for state-to-state differences if using multiple states, selection of appropriate functional form, correlation or collinearity among the independent variables, overfitting of prediction models, low sample mean and small sample size, and correlation between crash types and injury severities.

Before-After Studies

Before-after studies are used to develop CMFs at locations with and without the implementation of safety treatments. These studies use crash and traffic volume data for time periods before and after improvement of treated sites. Careful consideration is needed when selecting the treated sites to avoid introducing any type of bias toward high crash frequency locations. Different before-after study designs that are used in research studies are listed below

Simple Before-After Study. Also known as naïve before-after. In this study the safety effectiveness of a treatment is determined by comparing the crash frequency of the after period and the before period. This method does account for regression-to-the-mean, or other effects or trends.

Before-After with Comparison Group Studies. This study design uses an untreated comparison group of sites with similar traffic volumes and characteristics to a treatment group sites. It is essential that the trends in crash frequency over time should be comparable between the comparison group and the treatment group. Hauer (1997) suggests the use of a method that uses a sequence of sample odds ratios to determine if the trends are similar. There are multiple approaches to apply this method.

- Using the comparison group, calculate a comparison ratio or the ratio of observed crash frequencies in the after period to the before period. This ratio is multiplied to the observed crash frequency at the treatment sites in the before period, to come up with the expected number of crashes in the after period had the treatment not occurred. This expected number of crashes is compared with the actual crash frequency at the treatment sites in the after period to determine the safety effect of the treatment (Gross et al., 2010). One main assumption for this approach is to assume that trends in crash history are similar for both treatment and comparison groups.

- An alternate approach is to develop Safety Performance Functions using data from the comparison group. Predicted crash frequencies for the after and before period are calculated for the comparison group, and are used to calculate the comparison ratio. Follow the same steps as the first method. The comparison group method does not directly account for regression to the mean (RTM).

Empirical Bayes Before-After Studies. Also known as EB method, it accounts for RTM, changes in traffic volume, and temporal effects (i.e. weather, demography, and crash reporting thresholds). The method is used to estimate the expected crash frequency without the treatment, and compares it with the number of observed crashes after the treatment was implemented.

The method is similar in principle to the comparison group; however, the difference is that SPFs are developed using data from reference sites without the treatment. Reference sites are similar to the treatment sites, with similar crash risks, traffic volumes, and other characteristics. Similar to the comparison group, it is key that the crash trends are similar at both reference and treated sites. The sample odds ratios method can be used for the assessment. Specific details about the EB method are included in the protocols for developing CMFs report (Carter et al., 2012).

The expected number of crashes without the treatment in combination with the variance and the observed crash data after the treatment are used to estimate the index of effectiveness, also known as crash modification factor.

Full or Hierarchical Bayes Studies

The previous methods uses a reference group to estimate the expected crash frequency from a SPF. These estimates are then combined with the observed crash frequency in the before period of the treatment group to estimate after period expected crash frequency without the treatment. The difference with the full or hierarchical Bayes approach, is that the distribution of likely values from the reference group is used instead of the point estimate. Application of these distributions will lead to more accurate estimates of the CMF and its variances (Gross et al., 2010).

Before-After Studies to Evaluate Shifts in Collision Crash Type Proportions

This method uses data only for the treatment sites, and does not require data for non-treatment or comparison sites. The methodology used to assess shifts in proportion is derived from FHWA SafetyAnalyst software tools. The target collision types addressed in this type of evaluation may include specific crash severity levels or crash types. The average shift in proportion is calculated by comparing the after treatment proportion of target collision type relative to the total crashes and the before treatment proportion of target collision type and total crashes. Then an assessment of the statistical significance of the shift of proportions is conducted using the Wilcoxon signed rank test. More details about this approach are provided in the HSM Chapter 9.

Cross-Sectional Studies

Cross-sectional studies are traditionally used to compare different roads, used by different road users, located at different place and subject to different external factors such as weather conditions (Elvik, 2011, p. 263). Cross-sectional studies are commonly used for developing CMFs when data for other design types are not available. i.e. when installation dates are not available, when crash and traffic volume data for the before period are not available, when the analysis requires to account for effects of roadway geometry or others by creating a CMF function.

CMFs developed using cross-sectional studies are calculated by taking the ratio of the crash frequency of sites with the treatment to the crash frequency of site without the treatment. For this approach to be reliable, it is important that all sample sites are similar to each other in regard of all the factors that contribute to crash risk.

One of the main issues with cross sectional studies is the control of confounders. A confounder is a variable that is a significant predictor of the outcome. For instance, AADT is a strong predictor of crash frequency, and is likely to be associated with other geometric characteristics such as lane width and shoulder width. If the safety effects of a specific design characteristic are in question, then the effects of traffic volume must be separated before the true effects of the variable of interest may be known (Persaud et al., 1999). The following variations of cross-sectional studies may provide some additional control of confounders.

Case-Control Studies

This study type uses cross-sectional data, but sites are selected based on outcome status, and then determine the prior treatment status within each outcome group (Gross et al., 2010). They are used to show the relative effects of treatments using different statistical techniques to evaluate the risk/benefit of one factor while controlling for other factors. This method is very useful for studying rare events.

Cohort Studies

Cohort studies have not been widely used in highway safety, but have potential as alternative methods for evaluating safety effectiveness. They are designed to estimate relative risk, resulting in the estimation of the percent change in the probability of a crash given the treatment. In other words, sites are assigned to a particular cohort, or sites with particular geometric or operational characteristics with and without the treatment, and followed over time to asses when the risk is disproportionate between cohorts. This indicates the relative effect of the treatment.

Sample Size Requirements

There are no specific guidelines regarding the sample size for before-after and cross-sectional studies. A general rule of thumb is to use a sample large enough to produce a statistical significant CMF. This means that with a given level of significance that confidence interval for the CMF does not include 1.0. Hauer (1977) states that there are four variables that help determining whether the sample size is adequate:

1. The size of the treatment group
2. The relative duration of the before and after periods
3. The likely CMF value
4. The comparison group before and after crash frequency

Cross-sectional studies require data for many more sites than a standard before-after study. This mainly because sample size depends on many factors including the number of variables included in the models.

The HSM provides a tabular overview of the data needs for the different safety evaluation methods, including the number of treatment sites required for analysis.

	Safety Evaluation Method			
Data Needs and Inputs	EB Before/After	Before/After with Comparison Group	Before/After Shift in Proportion	Cross-Sectional
10 to 20 treatment sites	✓	✓	✓	✓
10 to 20 comparable non-treatment sites		✓		✓
A minimum of 650 aggregate crashes in non-treatment sites		✓		
3 to 5 years of crash and volume "before" data	✓	✓	✓	
3 to 5 years of crash and volume "after" data	✓	✓	✓	✓
SPF for treatment site types	✓	✓		
SPF for non-treatment site types		✓		
Target crash type			✓	

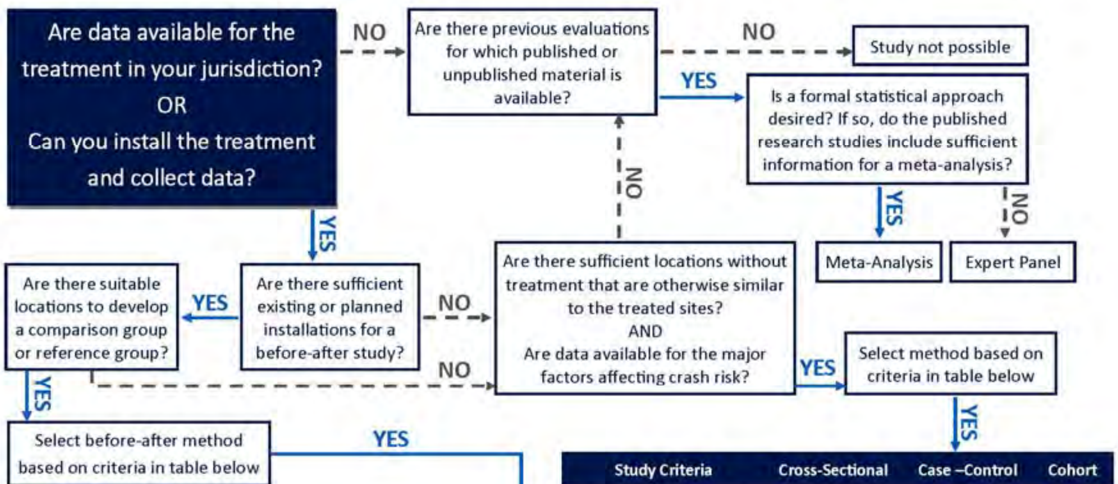
Standard Error: A Measure of CMF Precision

The standard error is the standard deviation of a sample mean. It indicates the precision of an estimated CMF, and it is used as a measure of reliability. The smaller the standard error, the more reliable the CMF estimate. It can also be used to calculate the confidence interval for the estimated change in expected crashes. If the confidence interval does not include 1.0, then it implies that the mean value of the CMF is statistically significant at the given confidence level.

Selection of Appropriate Study Type and Design

The Guide for Developing Quality CMFs contains a chart that provides guidance determining the appropriate study design for developing quality CMFs.

FIGURE 5. Flow Chart for Study Design Selection



Study Criteria	CG	EB	FB
Regression-to-the-mean may be a factor	No	Yes	Yes
Treatment is likely to impact traffic volumes	No	Yes	Yes
Include spatial correlation (either among treated sites or among treated and comparison or reference sites)	No	No	Yes
A complex model form is required	No	No	Yes
Include prior knowledge of model or CMF estimates in the analysis	NO	No	Yes

Study Criteria	Cross-Sectional	Case –Control	Cohort
Crash type is rare	No	Yes	No
Treatment is rare	No	No	Yes
Accounts for locations with multiple crashes (rather than first occurrence)	Yes	No	No
CMFunction desired	Yes	No	No

Flow Chart Legend

EB = Empirical Bayes

FB = Full Bayes

CG = Comparison Group

Documentation

Good documentation is important because it provides readers with an opportunity to assess the quality of the study. The document should include details indicating where the CMF can be applied, and also the bias documentation. The applicability of the CMF should provide details regarding the site characteristics including traffic volumes range, type of roadway, number of lanes, area type, and crash characteristics affected by the CMF such as crash type, severity, or time of day. The bias documentation should include details regarding the design and execution of the study, and what factors could affect the quality of the CMF. This information is used by the reviewers of the HSM and CMF clearinghouse to assign a star rating. Some of these factors include the study design selected, sample size, data source, and standard error. Carter's report (Carter et al., 2012) provides detailed information on what documentation should be included.

Resources

Highway Safety Manual Users Guide (pdf)

Highway Safety Manual Lead State Peer Exchange Irvine, California (pdf)

Highway Safety Manual Lead State Second Peer Exchange Baltimore, Maryland (pdf)

Highway Safety Manual Lead State Third Peer Exchange Nashville, Tennessee (pdf)

Better CMFs, Safer Roadways: Tips for Building High Quality CMFs (pdf)

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Contact Information

Mark Bush
Senior Program Officer Cooperative Research Programs
Transportation Research Board, The National Academies
mbush@nas.edu