CRASH MODIFICATION FACTORS IN PRACTICE

Quantifying Safety in the Roadway Safety Management Process

CMF

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The Quantifying Safety in the Roadway Safety Management Process guide describes and illustrates opportunities to incorporate the latest tools and techniques to quantify safety in the roadway safety management process. The target audience includes safety program managers and safety analysts. The purpose of this guide is to help raise awareness of opportunities to apply crash modification factors (CMFs) in the roadway safety management process. The objectives are to 1) identify opportunities to apply CMFs in the various steps of the safety management process, 2) describe the process of applying CMFs to quantify safety, and 3) explain potential challenges related to the application of CMFs and opportunities to overcome those challenges. Readers will better understand the purpose of CMFs and how they can be applied in the roadway safety management process.

Crash modification factors (CMFs) support a number of safety-related activities in the project development process. The CMFs in Practice series includes five separate guides that identify opportunities to consider and quantify safety in specific activities, including roadway safety management processes, road safety audits, design decisions and exceptions, development and analysis of alternatives, and value engineering. The purpose of the CMFs in Practice series is to illustrate the value of CMFs in these five activities and demonstrate practical application of CMFs.

INTRODUCTION

Historically, it has been very challenging to quantify safety explicitly along with other factors such as design, operational, and environmental impacts during the project development process. Instead, safety has been assumed to be inherent in design policies and practices.

Tools have been available for several years to quantify the operational and environmental impacts of design. Recently, similar tools have been developed to quantify the safety impacts of design decisions, but the tools and resources are relatively new. There is a need to raise awareness of the current level of road safety knowledge and the tools that are available to quantify safety in the project development process. Quantifying safety will help decision-makers to better understand the safety impacts of design decisions and allow safety impacts to be considered in conjunction with other factors in the project development process. It is necessary for professionals involved in the project development process to understand the importance of quantifying safety and apply appropriate methods or seek assistance to do so.

Crash modification factors (CMFs) are one tool that state and local transportation agencies are applying to better understand the safety impacts of their decisions. CMFs are a measure of the safety effectiveness of a particular treatment or design element. When applied correctly, CMFs can be used to estimate the safety effectiveness of a given treatment or compare the relative safety effectiveness of multiple treatments and determine the potential benefit for a benefit-cost analysis. Readers can refer to the *Introduction to Crash Modification Factors (1)* for more information on CMFs and how they are applied.

CMFs can be applied in the roadway safety management process to help select countermeasures and prioritize projects through an economic evaluation (e.g., benefit-cost analysis). Read more for an overview of CMFs in the roadway safety

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management process or skip to the step-by-step process for applying CMFs. Examples are provided to illustrate how CMFs can be applied and a case study illustrates how CMFs have been applied in the roadway safety management process. Finally, potential challenges are presented along with opportunities to overcome these common application challenges.

OVERVIEW OF CMFS IN THE ROADWAY SAFETY MANAGEMENT PROCESS

The roadway safety management process is a six-step process as shown in Figure 1 and outlined in the *Highway Safety Manual (HSM) (2)*.

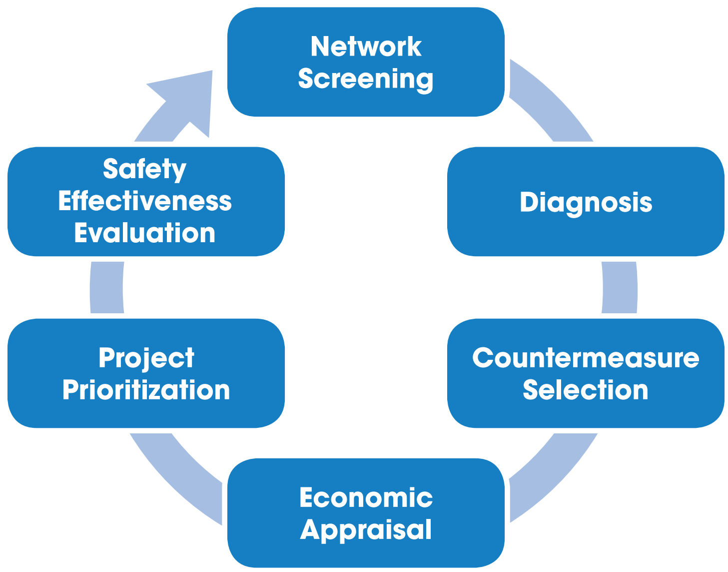

Figure 1. HSM 6-Step Roadway Safety Management Process

The *Highway Safety Improvement Program (HSIP) Manual (3)* identifies this process as planning, implementation, and evaluation, where planning covers problem identification, countermeasure identification, and project prioritization. In either case, CMFs can play a role in the countermeasure selection and project prioritization components of the roadway safety management process. While not directly applicable to the *application* of CMFs, one can develop new CMFs in the safety effectiveness evaluation component of the process. A brief summary of these three opportunities follows.

Countermeasure Selection

In this step, potential countermeasures are developed to address the contributing factors identified in the safety diagnosis. Physical, financial, and political constraints need to be taken into consideration during this task as well as the potential impacts on safety, mobility, and the environment. **CMFs can provide valuable information to assist in the countermeasure selection process, particularly the quantification of safety impacts.**

With respect to countermeasure selection, CMFs can play a valuable role by indicating which candidate treatments are associated with the greatest expected

CONTENTS

reductions in crashes. From the diagnosis step, a list of contributing factors is generated. The first step in the countermeasure selection process is to identify a list of potential countermeasures to address the specific contributing factors. Contributing factors and related treatments are identified in the *NCHRP Report 500 Series (4)* for several specific topics.

CMFs can help to reduce the list of potential treatments to more manageable levels by grading the treatments in terms of expected safety effectiveness. For example, those treatments with CMFs less than 1.0 could be carried forward for further evaluation, while treatments with CMFs greater than or equal to 1.0 may be eliminated from further consideration as they are likely to result in an increase in crashes. Of course, there may also be physical, financial, and political constraints, but CMFs are a useful tool for sifting through the initial list of potential treatments.

The CMF alone is not always enough information to immediately include or discount a treatment from further consideration. CMFs are developed using various study designs, sample sizes, and study periods. As such, there is a wide range in the quality and reliability of CMFs. The standard error of a CMF should be considered as it indicates the potential variability in the estimate. The standard error can be used to define a confidence interval which indicates the range of values that contain the true treatment effect with a given level of confidence. A CMF confidence interval which includes 1.0 suggests that a treatment is not highly effective and may be completely ineffective. Consequently, it would be reasonable to give less consideration to treatments for which the associated CMF has a confidence interval that includes 1.0. Furthermore, it may be prudent in some situations to give greater consideration to treatments with smaller confidence intervals because of the greater level of certainty in the results.

Economic Appraisal

The economic appraisal step of the highway safety management process seeks to compare the benefits of safety improvements to the costs of implementing those improvements. There are two main types of economic appraisals: benefit-cost analysis and cost-effectiveness analysis. In benefit-cost analyses, the safety benefits of potential treatments are translated into monetary values and then compared to treatment costs. In contrast, a cost-effectiveness analysis does not convert safety benefits into monetary terms. Instead, the cumulative treatment costs are divided by the estimated number of reduced crashes to approximate the cost per crash reduced. **CMFs may be utilized in either type of analysis to estimate the reduction in crashes.**

With respect to the economic appraisal, the main function of CMFs is to help estimate the benefits of proposed treatments as part of benefit-cost or cost-effectiveness analyses. Depending on which type of economic appraisal is conducted, benefits may be quantified in different forms. In a benefit-cost analysis, benefits are measured in terms of monetary values. Specifically, estimated crash reductions are converted to monetary values using average crash costs. In a cost-effectiveness analysis, benefits are quantified simply as the estimated reduction in crashes. In either case, CMFs are used to estimate the change in crash frequency associated with proposed treatments.

Safety Effectiveness Evaluation

The safety effectiveness evaluation step of the roadway safety management process assesses how an implemented safety treatment or set of safety treatments affected the frequency and severity of crashes. During this step, evaluations of individual treatments or combinations of treatments can be carried out based on various performance measures. **It is often possible to develop CMFs in this step of the process**. If the goal is to develop CMFs, there are numerous study designs that can be utilized which have varying levels of complexity and quality. More information about the various approaches to develop CMFs can be found in *A Guide to Developing Quality Crash Modification Factors (5)* and *Recommended Protocols for Developing Crash Modification Factors (6)*. This step is intended to provide quantitative indicators of effectiveness in order to guide future highway safety decision-making and policy development.

APPLICATION OF CMFS IN THE ROADWAY SAFETY MANAGEMENT PROCESS

This section presents the step-by-step process for applying CMFs in the roadway safety management process. Specifically, it covers the two related areas discussed in the overview, countermeasure selection and economic appraisal.

Countermeasure Selection

CMFs can be used to help reduce the list of potential treatments in the countermeasure selection process. The following steps can be applied to the entire list of countermeasures, but it may be more useful to complete the following steps for each specific contributing factor or groups of target crashes identified in the diagnosis phase of the roadway safety management process.

Step 1: Identify Applicable CMFs and Standard Errors for the List of Potential Countermeasures

CMFs are first identified for each potential countermeasure. As discussed in the *Introduction to Crash Modification Factors (1)*, the CMF selection process involves several considerations including the availability of related CMFs, the applicability of available CMFs, and the quality of applicable CMFs. The *CMF Clearinghouse (7)* contains more than 3,000 CMFs for various design and operational features and also provides detailed information for each CMF to help users identify applicable scenarios and the related quality of the CMF. The most applicable CMF should be listed for each countermeasure along with the standard error (if available) and applicable crash types and severities.

Step 2: Apply Screening Techniques and Engineering Judgment to Reduce the List

There are several potential screens to reduce the list of countermeasures. In addition to physical, financial, and political constraints, the following CMF screens may be applied:

1. Absolute value of the CMF: Countermeasures are eliminated if the associated CMF is greater than a given threshold. For example, those treatments with a CMF greater than or equal to 1.0 may be eliminated as they are likely to be counterproductive.
2. Relative value of the CMF: Countermeasures are eliminated based on the relative values of the associated CMFs. For example, those treatments with the greatest CMFs (i.e., least effective treatments) are eliminated. Note that countermeasures should only be compared if the respective CMFs apply to the same crash conditions (i.e., crash type and severity). For example, it would be appropriate to compare multiple countermeasures if the associated CMFs are related to angle crashes of all severities. If the applicable CMFs are related to different crash types and severities, it is not appropriate to make direct comparisons without further analysis (e.g., benefit-cost analysis).
3. Confidence interval: Countermeasures are eliminated based on the absolute or relative confidence in the associated CMF. For example, treatments could be eliminated if the confidence interval for the associated CMF includes 1.0 as this indicates that the treatment could be ineffective or produce a negative effect. The confidence interval is computed as follows:

Confidence Interval = CMF ± [Cumulative Probability*Standard Error]

The following table gives the cumulative probability for common confidence intervals.

Confidence Interval	Cumulative Probability
99%	2.576
95%	1.980
90%	1.645

This process is highly dependent on engineering judgment, but supported by CMFs. While it may be desirable to reduce the list of potential countermeasures, it is important not to eliminate treatments prematurely. The economic appraisal can be used to further compare the potential effectiveness of countermeasures, incorporating the relative costs.

Economic Appraisal

Economic appraisal is a more formal application of CMFs in the roadway safety management process. Again, the economic appraisal may be based on a benefit-cost or cost-effectiveness analysis. The following steps outline the two approaches and the process would be repeated for each potential countermeasure.

Step 1: Estimate Cost of Treatment

The treatment cost includes the installation and annual maintenance costs over the life of the project (e.g., repainting, replacing parts, and repairing hits). The expected service life should also be identified.

Step 2: Estimate Annual Crashes WITHOUT Treatment

The annual crashes *without* treatment have to be estimated before applying CMFs. The HSM presents several methods for estimating the future safety performance of a roadway or intersection *(2)*. The most simplistic method to estimate crashes without treatment is to compute the long-term average (i.e., 5+ years) based on ***observed*** crash frequency before treatment. In this method, it is assumed that the observed crash history before treatment will represent the future safety performance in the absence of any changes. Safety performance functions (SPFs) are another method to estimate crashes without treatment. SPFs provide an estimate of the ***predicted*** annual crashes for the site of interest based on the crash history of other similar sites. The Empirical Bayes method, described in the HSM, is a rigorous method for estimating the ***expected*** crashes without treatment as it combines the observed crash history from the site of interest with predicted crashes from a SPF. Drawbacks and opportunities to overcome potential challenges related to these methods are discussed in *Estimating Annual Crashes without Treatment* in the *Overcoming Potential Challenges* section.

Step 3: Estimate Annual Crashes WITH Treatment

The CMF is multiplied by the estimated annual crashes *without* treatment from Step 2 to estimate the annual crashes *with* treatment for each year of the service life.

Note that the confidence interval can only be computed for those CMFs with a standard error.

Observed crashes are based on reported crashes for the site of interest.

Predicted crashes are based on estimates from a safety performance function.

Expected crashes are based on the Empirical Bayes method, which combines the observed and predicted crashes.

The annual crashes should be estimated for each year over the service life and also correspond with the specific crash type and severity for which the CMF is applicable. If the CMF applies to total crashes, then Step 2 should estimate the total annual crashes without treatment. If the CMF applies to a specific crash type or severity, the annual crashes should be computed for that crash type or severity.

Step 4: Estimate Annual Reduction in Crashes

The estimated annual reduction in crashes is computed as the estimated annual crashes *without* treatment minus the estimated annual crashes with treatment for each year of the service life.

At this point, there is enough information to conduct a cost-effectiveness analysis. The cost-effectiveness is simply the treatment cost divided by the estimated reduction in crashes. The result is a cost per crash reduced. For a benefit-cost analysis, it is necessary to complete one more step (Step 5).

Step 5: Convert Estimated Annual Crash Reduction to Monetary Benefit

The estimated annual crash reduction is converted to a monetary benefit by multiplying the estimated annual crash reduction by the appropriate average crash cost for each year of the service life. Many agencies have developed or adopted their own crash costs, but national estimates are also available such as those provided by FHWA. The following table shows the comprehensive crash costs, in 2001 dollars, by severity level from the HSM *(2)*, which are based on the costs from the FHWA report, *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries (8)*. These costs should be adjusted by the gross domestic product (GDP) to better reflect the actual costs associated with the analysis period. The FHWA crash cost report also provides crash costs disaggregated by crash type, severity, and posted speed *(8)*.

Crash Severity	Estimated Cost
Fatal (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Possible Injury (C)	$44,900
Property Damage Only (PDO)	$7,400

It is necessary to adjust the annual monetary benefits to a present dollar value. This can be accomplished by multiplying the computed monetary benefit in a given year by its present value factor. The present value factor is computed from the following equation.

$$\text{Present Value Factor} = \frac{1}{(1 + \text{Discount Rate})^{\text{Year of Service Life}}}$$

It should be noted that the discount rate is dependent on the service life and may change over time. Discount rates typically range between three and seven percent. The current discount rate can be obtained from the Office of Management and Budget (http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c) or agencies may have a standard discount rate.

At this point, the estimated annual benefit (i.e., cost savings) can be summed and divided by the treatment cost to estimate the benefit-cost ratio.

Example: As part of the network screening process, a mid-block pedestrian crossing was selected for further investigation. The crossing is located on an urban, four-lane, divided arterial with a posted speed of 45 mi/h. Based on a site diagnosis, it was determined that a marked crosswalk alone was inappropriate given the posted speed and number of lanes. Several potential countermeasures were identified during the countermeasure selection process, including a pedestrian hybrid beacon. The following example presents a benefit-cost analysis for a pedestrian hybrid beacon that is being considered in the economic appraisal. A CMF for fatal and injury (FI) crashes was obtained from the CMF Clearinghouse based on a study by Fitzpatrick and Park (9). The CMF was developed from intersections in Arizona with a suburban or urban area type and it is assumed that the CMF is applicable to the location of interest. The treatment cost was estimated from another study, assuming a $100,000 installation cost, 10-year service life, and negligible annual maintenance costs (10). A five percent discount rate is also assumed for the computations. The mean comprehensive crash cost for FI crashes is assumed to be $158,177 (8).

The following table presents the estimated crashes for each year of the service life. These values were estimated using the procedures outlined in the HSM. The CMF is applied to each of the estimated annual crashes without treatment to estimate the annual crashes with treatment. The annual crash reduction is estimated as the difference between the estimated annual crashes without and with treatment, and the mean comprehensive crash cost ($158,177) is applied to the reduction to estimate the annual monetary benefit. Present value factors are then computed and applied to estimate the annual benefit in terms of present dollars.

The present monetary benefit is estimated to be $236,427 while the monetary cost is estimated to be $100,000. Thus, the BCR is 2.36 indicating a favorable result of the proposed treatment.

Year	Estimated FI Crashes Without Treatment	CMF	Estimated FI Crashes With Treatment	Estimated Reduction in FI Crashes	Estimated Monetary Benefit	Present Value Factor	Estimated Present Benefit
1	0.96	0.849	0.82	0.14	$22,929	0.95	$21,837
2	1.00	0.849	0.85	0.15	$23,885	0.91	$21,664
3	1.05	0.849	0.89	0.16	$25,079	0.86	$21,664
4	1.12	0.849	0.95	0.17	$26,751	0.82	$22,008
5	1.20	0.849	1.02	0.18	$28,662	0.78	$22,457
6	1.30	0.849	1.10	0.20	$31,050	0.75	$23,170
7	1.41	0.849	1.20	0.21	$33,677	0.71	$23,934
8	1.55	0.849	1.32	0.23	$37,021	0.68	$25,057
9	1.72	0.849	1.46	0.26	$41,082	0.64	$26,482
10	1.92	0.849	1.63	0.29	$45,859	0.61	$28,153
Total	13.21		11.23	2.00	$315,995		$236,427

CASE STUDY

CMFs can be applied in the roadway safety management process to help select countermeasures and prioritize projects through an economic evaluation (e.g., benefit-cost analysis). The following case study illustrates how CMFs have been applied in the roadway safety management process. It also identifies lessons learned, including noteworthy practices and challenges encountered by agencies with respect to the application of CMFs in the roadway safety management process.

Program Description

In 2007, the Virginia Department of Transportation (VDOT) started a new program, Strategically Targeted Affordable Roadway Solutions (STARS), aimed at critical safety and congestion hot spots throughout the State. The primary goals of the STARS program are to identify roadway improvements on the interstate and primary systems that:

- Are relatively low-cost.
- Address existing mobility and safety problem areas.
- Require minimal preliminary engineering and right-of-way.
- Can be implemented quickly (24 months or less).

The STARS program allows VDOT to better incorporate operations and safety into the long-term planning process and involves the following four steps.

1. Study area selection.
2. Detailed safety and operational analysis.
3. Prioritization of recommendations.
4. Programming and implementation.

In this process, the study team identifies potential safety and operational issues in Step 2 along with a list of potential countermeasures. CMFs are then applied in Step 3 to help justify and prioritize the suggestions. Specifically, CMFs are used to estimate the safety impacts associated with each countermeasure.

Project Description

The project highlighted for this case study is a hot spot analysis conducted in Wise County, Virginia in 2009. The study area, developed by the Southwest Regional Operations (SWRO) Study Team, encompasses the intersection of Orby Cantrell Highway (Route 23) and Wise Norton Road (Route 757), shown below in Figure 2.

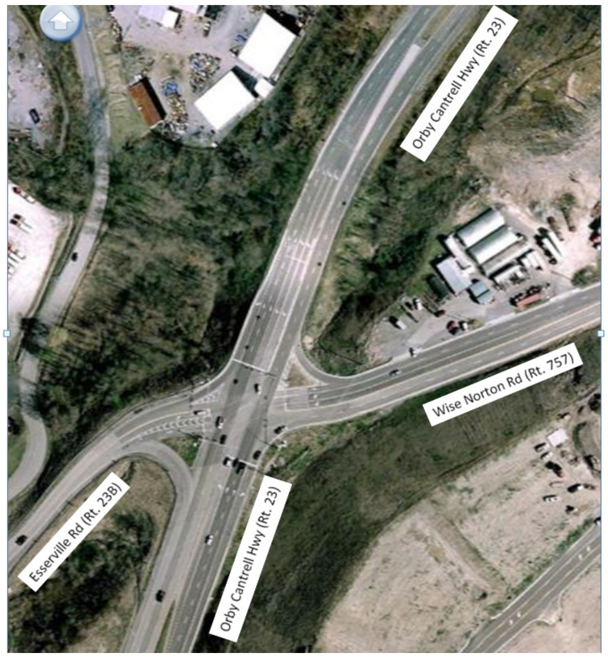

Figure 2. Study location.

This location was prioritized by the SWRO study team based on a review of the crash history and peak hour operations. The study location is a signalized intersection controlled by an actuated traffic signal and both intersecting roads are maintained by VDOT. Right-turn-on-red operations are allowed from all approaches and all left-turn movements at the intersection operate under fully-protected phasing. There are no crosswalks or sidewalks at or near the intersection and each approach is characterized by the following variables.

Feature	Route 23 (northbound/southbound)	Route 757 (westbound)	Route 23B (eastbound)
Functional Classification	Principal Arterial	Minor Arterial	Minor Arterial
Annual Average Daily Traffic (vehicles per day)	23,000 (year 2007)	5,600 (year 2007)	5,600 (year 2007)
Area Type	Urban	Urban	Urban
Number of Lanes	4	4	2
Median Type	Grass	Undivided	Undivided
Approach Grade	Downgrade on Both	Moderate Downgrade	Upgrade
Posted Speed (mph)	55	25	25

The study team reviewed several pieces of information, including peak hour turning movement volumes, operational performance measures, and three years of police crash reports (2005-2007). The study team then conducted a field review to identify potential safety and operational issues and developed a list of possible measures to mitigate the identified issues. These measures were further analyzed to determine the timeframe for implementation (near-term, intermediate, or long-term), cost, and estimated benefit.

Practical Application of CMFs

The study team identified the following potential safety issues at the study location.
1. Inconsistent and unmaintained signs.
2. Faded and missing pavement markings.
3. Sight distance obstructions (vegetation).
4. Limited guidance (ground-mounted street signs and lack of reflectors on guardrail)
5. Limited intersection lighting (30 percent of crashes occurred at night).
6. Short cycle length (queue does not clear).
7. Alignment issue (southbound receiving lanes don't align with approach lanes).
8. Narrow and inconsistent shoulder width.
9. Multiple access points in close proximity to the intersection

The study team also developed several potential countermeasures to address the identified issues. Near-term measures are typically implemented by VDOT personnel within 12 months and include basic signing and pavement marking improvements, vegetation control, and minor signal timing improvements. Long-term measures are considered for inclusion in the long-range planning process. Intermediate measures are further analyzed to determine the benefit-cost ratio and potential for implementation. The economic evaluation is used to support the application for funding through the HSIP.

The following intermediate measures were identified to address potential safety issues at the study location.
1. Convert constant-flash 'signal ahead' warning sign to signal-actuated warning.
2. Install intersection lighting.
3. Restripe southbound approach to improve alignment and conspicuity.

VDOT has developed an application form with an associated list of prescribed CMFs to be used when applying for funding for highway safety projects (see *Sample Materials* for a link to the application form and a sample of VDOT's CMFs). This standardized form and application process help to enhance consistency across the nine districts in Virginia when applying for safety funding.

The VDOT application form is a spreadsheet that incorporates many of the necessary computations to estimate the benefit-cost ratio.The sample calculations below are based on the benefit-cost analysis for the three intermediate measures above and the following steps outline the process for computing the benefit-cost ratio.

Step 1 – Estimate Cost of Treatment

The total and annualized construction costs are shown in Table 1 along with the expected service life for each treatment. For the economic evaluation, the annual operating costs, maintenance costs, and salvage values were assumed to be negligible. A discount rate of five percent was assumed to compute the annualized cost.

Note the steps followed in the case study are similar, but not identical, to those presented in the *Application of CMFs in the Roadway Safety Management Process*. Notably, the VDOT application form compares the annualized construction costs with the annual safety benefit. In the previous section, the total construction cost is compared to the present value of the safety benefit over the life of the project. Either method will produce similar results, but it is important to compare costs and benefits that are based on the same timeframe (e.g., present value, annual value, or future value).

Table 1. Estimated Construction Costs

Countermeasure	Service Life (years)	Total Cost	Annual Cost
Convert to Signal-Actuated Warning	10	$9,737	$1,261
Install Lighting	20	$34,002	$2,728
Restripe Southbound Approach	7	$42,838	$7,403

Step 2 – Identify CMFs

CMFs were obtained from the VDOT prescribed list of CMFs (refer to the *Sample Materials*), which is based on various studies and references. The applicable CMFs are shown in Table 2. Note that the CMFs are given by crash severity. In this case, the CMFs are the same across severity level for each treatment; however, the CMF may change by severity for other treatments.

Table 2. Applicable CMFs

Countermeasure	CMFs by Severity			Applicability
	Fatal	Injury	PDO	
Convert to Signal-Actuated Warning	0.75	0.75	0.75	Right Angle, Rear End, Run-Off-Road
Install Lighting	0.75	0.75	0.75	Nighttime Crashes
Restripe Southbound Approach	0.80	0.80	0.80	All Crashes on Treated Approach

Step 3 – Estimate Annual Crashes WITHOUT Treatment

The target crashes without treatment were estimated from historical crash data. Specifically, the average annual crashes were computed by severity based on three years of observed crash data. The *total* target crashes by severity are shown in Table 3 for the three-year crash history at the study location.

Table 3. Total Target Crashes by Severity (3-year history)

Crash Severity	Right Angle, Rear End, Run-Off-Road	Nighttime Crashes	All Crashes on South-Bound Approach
Fatal (K)	0	0	0
Incapacitating Injury (A)	2	0	0
Non-Incapacitating Injury (B)	1	0	1
Possible Injury (C)	6	1	3
Property Damage Only (O)	14	9	10

The estimated *annual* target crashes by severity are shown in Table 4 for each of the three treatments. Again, the estimated annual crashes were computed as the three-year average.

The Empirical Bayes method is an alternative for computing the expected crashes. The Empirical Bayes method helps to account for the natural fluctuation in crashes by combining the observed crash history with the predicted crashes obtained from a safety performance function.

Table 4. Estimated Annual Target Crashes without Treatment

Crash Severity	Right angle, Rear end, Run-off-road	Nighttime crashes	All crashes on south-bound approach
Fatal (K)	0.00	0.00	0.00
Incapacitating Injury (A)	0.67	0.00	0.00
Non-Incapacitating Injury (B)	0.33	0.00	0.33
Possible Injury (C)	2.00	0.33	1.00
Property Damage Only (O)	4.67	3.00	3.33

Step 4 – Estimate Annual Reduction in Crashes

To estimate the change in target crashes, it is first necessary to estimate the annual crashes with treatment. To estimate the annual crashes with treatment, the annual crashes without treatment (Table 4) is multiplied by the applicable CMF (Table 2). The difference between the estimated crashes with and without treatment is then computed to estimate the change in target crashes. The computations are shown in Table 5 for the first treatment and the results for all three treatments are summarized in Table 6.

Table 5. Computations for Estimated Change in Crashes for Treatment 1 (Convert to Signal-Actuated Warning)

Crash Severity	Estimated Annual Crashes Without Treatment	Applicable CMF	Estimated Annual Crashes With Treatment	Estimated Change in Crashes
Fatal (K)	0.00	0.75	0.00	0.00
Incapacitating Injury (A)	0.67	0.75	0.50	0.17
Non-Incapacitating Injury (B)	0.33	0.75	0.25	0.08
Possible Injury (C)	2.00	0.75	1.50	0.50
Property Damage Only (O)	4.67	0.75	3.50	1.17

Table 6. Estimated Change in Target Crashes by Severity by Treatment

Crash Severity	Convert to Signal-Actuated Warning	Install Lighting	Restripe SB Approach
Fatal (K)	0.00	0.00	0.00
Incapacitating Injury (A)	0.17	0.00	0.00
Non-Incapacitating Injury (B)	0.08	0.00	0.07
Possible Injury (C)	0.50	0.08	0.20
Property Damage Only (O)	1.17	0.75	0.67

Step 5 – Convert Estimated Annual Crash Reduction to Monetary Benefit

Crash costs were obtained from the National Safety Council, which provides updated average comprehensive costs for motor vehicle crashes. The value of estimated annual safety benefit (i.e., crash cost savings) is computed by multiplying the change in target crashes (Table 6) by the applicable crash cost. The computations are shown in Table 7 for the first treatment and the results for all three treatments are summarized in Table 8.

Table 7. Computations for Value of Safety Benefit for Treatment 1 (Convert to Signal-Actuated Warning)

Crash Severity	Estimated Change in Crashes	Crash Cost[1]	Value of Safety Benefit
Fatal (K)	0.00	$3,760,000	$0
Incapacitating Injury (A)	0.17	$188,000	$31,960
Non-Incapacitating Injury (B)	0.08	$48,200	$3,856
Possible Injury (C)	0.50	$22,900	$11,450
Property Damage Only (O)	1.17	$6,500	$7,605
1. "Estimating the Costs of Unintentional Injuries, 2005" from the National Safety Council website www.nsc.org.			

Table 8. Annual Value of Safety Benefit by Treatment

Crash Severity	Convert to Signal-Actuated Warning	Install Lighting	Restripe SB Approach
Fatal (K)	$0	$0	$0
Incapacitating Injury (A)	$31,960	$0	$0
Non-Incapacitating Injury (B)	$3,856	$0	$3,374
Possible Injury (C)	$11,450	$1,832	$4,580
Property Damage Only (O)	$7,605	$4,875	$4,355
Total	$54,871	$6,707	$12,309

Step 6 – Compute Benefit-Cost Ratio

The benefit-cost ratio is computed as the average annual benefit divided by the annual cost. The results of the analysis are presented in Table 9.

Table 9. Benefit-Cost Ratios

Countermeasure	Annual Benefit	Annual Cost	B/C Ratio
Convert to signal-actuated warning	$54,871	$1,261	43.5
Install lighting	$6,707	$2,728	2.5
Restripe southbound approach	$12,309	$7,403	1.7

It is worth noting that the benefit-cost ratio in the VDOT application is only used to assess the eligibility of a proposed improvement for HSIP funding. Improvements expected to provide crash reductions resulting in a benefit-cost ratio greater than one (1.0) are eligible for HSIP funding. However, a high benefit-cost ratio does not guarantee funding. Other factors such as the validity of treatment, project cost, and timeframe to complete the project are also considered to prioritize the eligible improvements. In general, projects that are low-cost, relatively quick to install, and target high-crash locations will receive more favorable consideration.

Sample Materials

Details regarding the VDOT Highway Safety Project application and general HSIP process, including the prescribed list of CMFs, are documented in the VDOT Highway Safety Improvement Program Manual. The VDOT Highway Safety Improvement Program Manual and Highway Safety Project application form can be downloaded at: http://www.virginiadot.org/business/ted_app_pro.asp.

Note that the computations in the above case study are based on the FY 2009-2010 HSIP application form. The current application form from the above link may contain some modifications, including updated crash costs.

The following table is a sample of the prescribed reduction factors issued by VDOT. The table identifies the improvement type, expected service life of treatment, reduction factor, and target crashes. Note that the reduction factor may be different for different crash severities. Also, these reduction factors indicate the expected percent reduction in crashes, which could be converted to a CMF (e.g., expected 30 percent reduction in all crashes with the installation of a school zone warning sign is equivalent to a CMF of 0.7).

Improvement Type	Service Life	CRF			Target Crashes												
		Fatal	Injury	PDO	All	Head On	Rear End	Right Angle	Side Swipe	Left Turn	Right Turn	Fixed Object	Pedestrian	Run Off Road	Overturn	Wet Pavement	Night
Traffic Sign Improvement																	
Warning Sign																	
Curve Warning	10	0.30	0.30	0.30		X								X	X		X
School zone	10	0.15	0.15	0.15	X												
Regulatory Signs																	
Stop Sign (Two-way)	10	0.30	0.30	0.30				X		X	X		X				
Yield	10	0.25	0.25	0.25				X	X								
All-way Stop	10	0.50	0.50	0.50				X		X	X		X				

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Summary of Key Findings

There are several potential benefits associated with the application of CMFs in the safety management process. Specifically, CMFs provide a means to quantify the safety impacts of decisions and help to raise awareness of safety. The application of CMFs also helps to prioritize potential treatments and provides decision-makers with the information needed to identify cost-effective strategies. VDOT indicated that the STARS program has helped to raise awareness of safety issues at both the State and local level, which has led to more safety-focused projects.

The goal of the STARS program is to identify where safety and congestion issues overlap on the State's roadways. As demonstrated in the case study, CMFs are used in the benefit-cost analysis to quantify the safety impact of the suggested countermeasures. The results of the benefit-cost analysis are beneficial in the prioritization of recommendations as well as the programming and implementation stage. VDOT indicated that STARS-based projects have addressed more crashes and typically involve lower impact treatments (less utility and right of way) that can be implemented more quickly than proposals submitted prior to the STARS program.

Using CMFs as part of the benefit-cost analysis is not only beneficial to prioritizing the suggested countermeasures for a particular site, but also helps in the management of a safety program. The STARS program actively utilizes HSIP funds for many of the hot spot locations throughout the State. The CMFs used in the benefit-cost analysis are instrumental in the application process for HSIP funding.

OVERCOMING POTENTIAL CHALLENGES

Potential challenges may arise when applying CMFs in the roadway safety management process. Many are directly related to limitations in the progress of CMF research, while others apply to the lack of understanding of CMFs. Despite decades of advancement in CMF research, there are still knowledge gaps that present obstacles for practitioners seeking to apply CMFs in the roadway safety management process. The *Introduction to Crash Modification Factors (1)* provides general guidance related to the application of CMFs. The following are general challenges associated with the application of CMFs and opportunities to overcome challenges. The discussion includes specific concerns and lessons learned based on actual experiences with the application of CMFs in roadway safety management efforts.

Availability of CMFs

A notable potential challenge is the availability of CMFs for specific countermeasures. The *CMF Clearinghouse (7)* contains over 3,000 CMFs for a wide range of safety countermeasures under a variety of conditions. However, CMFs are still lacking for a large number of treatments, especially combination treatments and those that are innovative and experimental in nature. Furthermore, CMFs may not be available for certain crash types and severities.

The *CMF Clearinghouse (7)* provides a "Most Wanted List" for CMFs. Users can access the website and add to the list by submitting ideas for future CMF research or current needs. While the research would need to be completed, this link provides users with the opportunity to share their CMF needs.

Applicability of CMFs

CMFs are developed based on a sample of sites with specific conditions. While a CMF may be available for a given treatment, it may not be appropriate for the scenario under consideration. For example, there may be significant differences between the characteristics of a proposed treatment site and the sites used to develop the CMF (e.g., different area type, number of lanes, or traffic volume). The *CMF Clearinghouse (7)* and HSM *(2)* provide information to help users identify the applicability of CMFs.

A related challenge may be that multiple CMFs exist for the same treatment and conditions. This is particularly challenging when multiple studies have estimated CMFs for the same countermeasure and combination of crash type and severity level, but yielded dissimilar results. If the CMFs also apply to the same roadway characteristics, then the selection can become even more difficult. A star quality rating—which appraises the overall perceived reliability of a CMF using a range of one to five stars—is provided by the CMF Clearinghouse and may be helpful in these circumstances to identify the most suitable CMF. However, the ratings of the different CMFs may be similar as well. If the various CMFs have a fairly small range of values, then this situation may not be of great concern. Yet, it is possible for the CMFs to vary significantly and even have contradictory expected outcomes (i.e., some CMFs greater than 1.0 and others less than 1.0). In such cases, this potential situation would be highly challenging to overcome. Additional guidance on how to select the most applicable CMF is posted on the *CMF Clearinghouse (7)* under FAQs.

Estimating the Effects of Multiple Treatments

The current practice for many agencies is to assume that CMFs are multiplicative; this is the current method presented in the *HSM (2)* and posted on the *CMF Clearinghouse (7)*. There are relatively few studies that estimate CMFs for combinations of countermeasures. It is far more common for studies to estimate CMFs for individual treatments. Consequently, it is difficult to accurately estimate the effects of combinations of treatments. In brief, the recommended approach (and many of the alternatives) is problematic in the sense that applying the combined CMF may overestimate or underestimate the true crash effects, particularly if the treatments target similar crash types. More information regarding the application of multiple CMFs is available in recent articles *(11, 12)*.

The VDOT HSIP funding application spreadsheet accounts for multiple treatments by multiplying the CMFs for the respective treatments. This is the method recommended in the HSM *(2)*. However, users should recognize the treatments may target different crashes and the associated CMFs may apply to different crash types. If this is the case, then the CMFs should not be multiplied together to estimate the combined effect. Instead, the CMFs should be applied separately to the respective target crashes to estimate the expected impact of each treatment individually. At that point, the results can be aggregated to estimate the combined effect of the treatment.

Insufficient Expertise

A specific challenge could be that there is insufficient expertise within an agency to apply CMFs. While CMFs are not a new tool, they have only recently gained popularity among safety professionals. There are a number of opportunities to apply CMFs in aspects of transportation engineering (e.g., roadway safety management process), but it may be necessary to solicit input or assistance from those who are more familiar with the selection and application of CMFs. If an agency does not have the needed expertise related to CMFs, then they can solicit outside expertise from the State Safety Engineer, FHWA Division Office, or consultants for further guidance and assistance with the selection and/or application of CMFs and interpretation of results. The National Highway Institute also offers several courses related to the quantification of safety using CMFs, including the *Application of CMFs* (#380093) and *Science of CMFs* (#380094).

VDOT has participated in various training sessions related to CMFs and the application of the methods in the HSM.

Inconsistency across Decentralized States

Where multiple districts/divisions/regions exist within a State, there is the potential for inconsistency with respect to the selection and application of CMFs. This can result from a number of factors, including available resources and range in expertise. There is need to encourage the consistent selection and application of CMFs in the roadway safety management process within a State, particularly if the districts/divisions/regions are competing for the same pool of funding.

The VDOT STARS program is based on a formal and repeatable process. In particular, the State has developed an HSIP manual that identifies the process for evaluating safety issues and applying for funding, including a prescribed list of CMFs. The standardized process helps to enhance consistency across the nine districts in Virginia when applying for safety funding. Specifically, it discourages districts from selecting and applying CMFs that may show a more favorable result. It does not, however, prevent districts from identifying more applicable CMFs, but they need to receive approval from the central office before using a different CMF in the funding application.

Estimating Annual Crashes without Treatment

To quantify the expected safety performance for a given alternative, it is necessary to estimate the annual crashes *without* treatment. The applicable CMFs are then applied to the annual crashes *without* treatment to estimate the annual crashes *with* treatment. The annual crashes without treatment can be estimated using several methods, with each bringing certain strengths and weaknesses. The most basic approach is to use the ***observed*** crash history of the site of interest (i.e., short-term or long-term average) to estimate annual crashes without treatment. This method is relatively simple but is highly susceptible to regression-to-the-mean bias (i.e., random fluctuation in crashes over time) and could overestimate or underestimate the annual crashes without treatment. Another option to estimate annual crashes without treatment is to employ SPFs, which provide the ***predicted*** number of crashes. SPFs help to account for the random nature of crashes at a single site by incorporating data from other similar sites. The drawback to using SPFs is that, unless they are developed using local data, they may not accurately reflect local conditions and again could overestimate or underestimate the annual crashes without treatment. The *HSM (2)* presents the Empirical Bayes method as yet another option, which combines both the ***observed*** crash history of a site and the ***predicted*** crashes from the SPF to compute the ***expected*** crashes.

The prior discussion assumes that the crash history is available and applicable for a given site. In some cases, the crash history may not be available (e.g., new construction); in others, the crash history may not be applicable (e.g., significant changes in the alignment). For both scenarios, it may be necessary to rely on SPF predictions, but it is suggested that the SPFs be calibrated to local conditions before applying them, whenever possible. The *Introduction to Safety Performance Functions (13)* provides general guidance related to the selection, calibration, and application of SPFs.

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For More Information:

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