CMF CRASH MODIFICATION FACTORS IN PRACTICE

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.

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Federal Highway Administration

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CRASH MODIFICATION FACTORS IN PRACTICE

Quantifying Safety in the Road Safety Audit Process

The Quantifying Safety in the Road Safety Audit (RSA) Process guide describes and illustrates opportunities to incorporate the latest tools and techniques to quantify safety in the RSA process. The target audience includes RSA program managers, RSA study teams, and those supporting RSA study teams. The purpose of this guide is to help raise awareness of opportunities to apply crash modification factors (CMFs) in the RSA process. The objectives are to 1) identify opportunities to apply CMFs in the various steps of the RSA 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 RSA process.

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 decisions. 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* for more information on CMFs and how they are applied *(1)*.

CMFs can be applied in the RSA process to quantify the potential safety effects of various treatments and justify the suggestions of the RSA team to the project owner and/or design team. Read more for an overview of CMFs in the RSA 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 RSA process. Finally, potential challenges are presented along with opportunities to overcome common application issues. While several examples and a case study are provided to demonstrate the basic application of CMFs, an RSA team could also contact the State Highway Safety Engineer or Federal Highway Administration (FHWA) Division Office for further guidance and assistance with the application of CMFs and interpretation of results.

OVERVIEW OF CMFS IN THE RSA PROCESS

RSAs are a valuable tool used to evaluate road safety issues and identify opportunities for improvement. The FHWA defines an RSA as a "formal safety performance evaluation of an existing or future road or intersection by an independent, multidisciplinary team" *(2)*. RSAs can be used on any type of facility during any stage of the project development process.

RSAs result in a formal report that identifies existing and/or potential safety issues and mitigation opportunities. The suggested improvements can range from low-cost maintenance activities to high-cost, long-term projects that involve considerable planning and design work. It is emphasized that the opportunities for improvement are "suggestions" by the RSA team and require further consideration from the project owner/design team before implementation.

The RSA process is an eight-step process as shown in Figure 1 and outlined in the *FHWA Road Safety Audit Guidelines (2)*. Steps 1 through 4 of the RSA process lead up to conducting the RSA, but do not involve the quantification of safety. Specifically, Steps 1 through 4 involve the selection of a study location and RSA team as well as data sharing and gathering through a pre-RSA meeting and field review. Steps 5 through 8 provide opportunities to quantify and consider the safety impacts of the RSA team's suggestions. Steps 5 through 8 are discussed in more detail through the remainder of this section, noting how CMFs can be applied in each step. By applying CMFs in the RSA process, agencies can quantify the safety impacts and better understand the potential effects of the RSA team's suggestions. The application of CMFs will also demonstrate that safety was explicitly considered using a quantitative method.

Conduct RSA Analysis and Prepare Report Findings (RSA Step 5)

The RSA team conducts an analysis to identify safety issues based on data from the field visit and preliminary review of documents. The safety issues may be prioritized by the RSA team based on the perceived risk. For each identified safety issue, the RSA team generates a list of possible measures to mitigate the crash potential and/or severity of a potential crash. The RSA team then prepares a summary of the safety issues and related suggestions for improvement. In the past, RSA teams have used qualitative measures such as low, medium, and high to define the potential effectiveness and prioritize treatments. **CMFs can be applied in this step to help the RSA team quantify the potential safety effectiveness of a given treatment or compare the relative safety effectiveness among multiple potential treatments.**

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In Idaho, the FHWA Division Office is supporting the use of CMFs in the RSA process. RSAs conducted for State and local agencies have included CMFs in the final report to identify the potential effectiveness of the RSA suggestions.

Road Safety Audit Process: Typical RSA steps include:

Step 1: Identify project or existing road to be audited

As a result of this step, the project or existing road to be audited is determined and the parameters for a RSA are set.

Step 2: Select RSA Team

As a result of this step, an independent, qualified, and multidisciplinary team of experts suitable for the specific RSA stage is selected.

Step 3: Conduct a pre-audit meeting to review project information

The meeting brings together the project owner, the design team and the audit team to discuss the context and scope of the RSA and review all project information available.

Step 4: Perform field reviews under various conditions

The objective of project data review is to gain insight into the project or existing road, prepare for the field visit and identify areas of safety concerns. The field visit is used to get further insight into the project or existing road and to further verify/identify areas of safety concern.

Step 5: Conduct audit analysis and prepare report of findings

As a result of this step, the safety issues are identified and prioritized and suggestions are made for reducing the degree of safety risk. The RSA results are then succinctly summarized in the formal RSA report.

Step 6: Present audit findings to Project Owner/Design Team

In this step, audit team orally reports the key RSA findings to the project owner and design team in order to facilitate the understanding of RSA findings.

Step 7: Prepare formal response

Once submitted, the formal response becomes an essential part of the project documentation. It outlines what actions the project owner and/or design team will take in response to each safety issue listed in the RSA report and why some of the RSA suggestions could not be implemented.

Step 8: Incorporate findings into the project when appropriate

This final step ensures that the corrective measures outlined in the response report are completed as described and in the time frame documented.

Figure 1. FHWA 8-Step RSA Process

The RSA report should include a listing of the data and information used in conducting the RSA and a summary of findings and proposed safety measures. It may also include pictures and diagrams that are useful to illustrate issues and countermeasures. **CMFs can be included in the RSA report as additional information for the owner and/or design team to consider during the decision-making process.**

Present RSA Findings to Owner/Design Team (RSA Step 6)

During this step of the RSA process, the RSA team presents the preliminary results of the study to the project owner and/or design team. The purpose of this meeting is to establish a basis for writing the RSA report and to ensure that the report will adequately address issues that are within the scope of the RSA process. This is an opportunity for the project owner and/or design team to discuss and clarify any safety issues and suggestions with the RSA team. The project owner and/or design team may ask questions to seek clarification on the RSA findings or suggest additional/alternative mitigation measures. **The RSA team can reference the applicable CMFs in this step to justify the suggested improvements.**

In some cases, the RSA findings may be presented in a public meeting, or the report could be made available to the public to help garner support for the findings and the overall RSA process. While public opinions can be beneficial on projects with a high degree of public involvement, such as pedestrian facilities, it is common for community members to pre-determine the "needed" treatment for a given location without fully understanding the potential safety effects. These preconceived notions may differ from the suggestions presented by the RSA team. **CMFs can be highlighted from the RSA report during the presentation to quantify the relative effects of various potential countermeasures and support the team's suggestions.**

Prepare Formal Response (RSA Step 7)

Once the owner and/or design team have reviewed the RSA report, they should prepare a written response to its findings. A letter, signed by the project owner, is a valid method of responding to the RSA report. The response should identify those suggestions from the RSA report that will be implemented and document the reasons why the other actions may not be taken or why they may be delayed. In effect, the project owner identifies an improvement plan. In some cases, the plan is incremental where some of the near-term and/or low-cost suggestions are implemented and monitored to determine if the targeted safety issue was addressed. In this way, limited resources are not wasted on more costly improvements that may not be necessary if the low-cost measures achieve the desired effect. **CMFs, along with treatment cost and implementation timeframe, can be used in this step to help the project owner and/or design team justify or prioritize actions to be taken.**

Incorporate Findings into the Project when Appropriate (RSA Step 8)

After the response to the RSA report is prepared, the project owner and/or design team should work to implement the agreed-upon safety measures or create an implementation plan. **CMFs can be applied during this step to help set priorities or further evaluate the alternatives.**

With respect to the implementation of countermeasures, 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 indicate the potential change in crash frequency associated with proposed treatments.

RSA findings can be incorporated into an agency's planning process. Once the suggestions have been implemented, an important consideration is to evaluate the RSA program and share lessons learned. In the near-term, an RSA "after action review" can be scheduled for the RSA team to perform a qualitative safety evaluation of the implemented measures. The qualitative review would help to identify any issues with the implemented suggestions, ensure that road users are responding appropriately, and to determine if other measures are needed. In the long-term, it is also important that the implemented measures be evaluated quantitatively, or at least tracked so that others may quantify the safety effects. This information will allow an agency to show the benefits of RSAs and possibly develop new CMFs or refine existing CMFs for future decision-making.

APPLICATION OF CMFS IN THE RSA PROCESS

As discussed in the overview, there are several opportunities for applying CMFs in the RSA process, including the following:

- Conduct RSA Analysis and Prepare Report of Findings (RSA Step 5).
- Present RSA Findings to Project Owner/Design Team (RSA Step 6).
- Prepare Formal Response (RSA Step 7).
- Incorporate Findings into the Project when Appropriate (RSA Step 8).

The application and level of analysis varies among these four opportunities, ranging from a cursory review of potential treatment effects to a detailed benefit-cost analysis. This section presents the step-by-step process for applying CMFs in each of the four opportunities.

Conduct RSA Analysis and Prepare Report of Findings (RSA Step 5)

CMFs can be used to help reduce the list of potential treatments in the RSA analysis or at least be included in the final report to help the project owner in further evaluating the options. The following steps define the process of applying CMFs to reduce the list of potential treatments, but the first step would also apply to situations where CMFs are simply identified and included in the RSA report.

CMF Step 1: Identify Applicable CMFs and Standard Errors for Potential Countermeasures

CMFs are first identified for each potential countermeasure developed in Step 5 of the RSA process. 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 (3)* 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.

CMF Step 2: Apply Screening Techniques and Engineering Judgment to Reduce 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 result in an increase in crashes.
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:

Note that the confidence interval can only be provided if the standard error is available.

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

The following table indicates 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. As such, the RSA team may choose not to eliminate potential treatments and simply present the project owner with the complete list of suggestions and related CMFs. The project owner can then conduct a more formal economic appraisal to compare the potential effectiveness of countermeasures, incorporating the relative costs.

CMF Step 3: Present CMFs in RSA Report

The RSA report documents the findings and suggestions of the RSA team. A typical report includes a detailed explanation of each safety issue identified by the RSA team and the related suggestions to address or mitigate the issues. The following provides an example template for presenting the most applicable CMF information with the detailed RSA results.

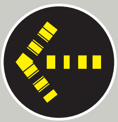
Identified Safety Issue	Suggested Improvements
Lack of exclusive turn lanes. There are no existing turn lanes along Main Street at First Street, which requires all turning movements to be made from the through lanes. There are heavy turning movements at this intersection during the AM and PM peak periods and the RSA team observed several potential conflicts between turning vehicles and through vehicles.	**Consider installation of exclusive left-turn lanes.** • CMF: 0.53 • Standard error: 0.04 • Confidence interval: 0.45 – 0.61 • Applicable crash types: All • Applicable crash severities: All • Source: CMF Clearinghouse • Reference: Harwood et al. Safety Effectiveness of Intersection Left- and Right-Turn Lanes. Report number FHWA-RD-02-089, Federal Highway Administration, Washington, DC, 2002.

The following is an example from an RSA conducted for the City of Nampa, Idaho. The RSA report included common elements such as a description of each issue, suggestions for mitigating the safety issue, and photos/illustrations. The report also identified applicable CMFs (when available), noted the relevant crash type/severity, and identified the source of the CMFs.

2. Flashing Left-Turn Yellow Arrow Signal Indication

A steady red arrow means STOP. Drivers turning left must stop.

A steady yellow arrow means the signal is getting ready to turn red. Drivers turning left should stop if it is safe to do so.



A flashing yellow arrow means left-turns are permitted. Drivers may turn left but must first yield to oncoming traffic and pedestrians and then proceed with caution.

A steady green arrow means left-turns are protected. Drivers may turn left. Conflicting traffic must stop.

To decrease confusion regarding the meaning of the green ball for permissive left-turns on the existing five-section traffic signal head, replace all units with a four-section flashing left-turn yellow arrow (FYA) signal indication. This is the preferred display for permitted left-turn indications. See MUTCD Section 4D.04 and 4D.20 among others.

From NCHRP Report 705, Evaluation of Safety Strategies at Signalized Intersections (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_705.pdf), converting from protected-permissive to FYA: CMF=0.922 (all crashes), 0.806 (left-turn crashes), although these were not statistically significant.

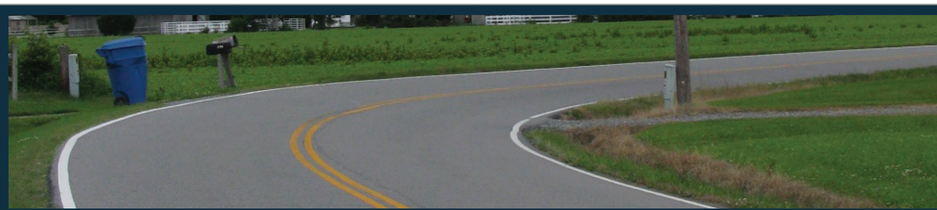
The RSA report may also include a summary table of results, indicating the primary safety issues identified by the RSA team, perceived risk rating for each issue, and suggestions to address or mitigate the potential safety issues. The summary table could also include the most applicable CMFs for the specific suggestions as shown in the following example.

Safety Issue		Risk Rating	Suggestions	CMF	Applicability
1	Lack of Left-Turn Lanes: Turning movements are made from the through lanes, which creates conflicts between turning and through vehicles.	C	Consider Installation of Left-Turn Lanes.	0.53	Total Crashes
2	Narrow Shoulders: Narrow shoulders increase the potential for run-off-road crashes.	D	Consider Installation of Edge Line Rumble Strips.	0.67	Fatal/Injury Crashes

Present RSA Findings to Project Owner/Design Team (RSA Step 6)

CMFs can be used to justify the RSA team's suggestions or to show the relative safety effectiveness of various countermeasure options. No further work is required for this step of the RSA process as the CMFs identified during the RSA analysis are simply presented with the list of suggestions. The most applicable CMF should be listed for each countermeasure along with the standard error (if available) and applicable crash types and severities. The following provides an example template for presenting CMF information with the RSA results.

Identified Safety Issue:
Severe Horizontal Alignment



Potential Treatments	Timeframe	CMF	Standard Error	Crash Type	Crash Severity
Install Chevrons	Near-Term	0.96[1]	0.09	All	All
Install Advance Curve Warning Signs	Near-Term	0.90[2]	Not Reported	All	Fatal/Injury
Flatten Curve	Long-Term	0.33[3]	0.32	All	All

[1] Srinivasan, R., Baek, J., Carter, D., Persaud, B., Lyon, C., Eccles, K., Gross, F., Lefler, N., "Safety Evaluation of Improved Curve Delineation." Report No. FHWA-HRT-09-045, Federal Highway Administration, Washington, D.C., (2009).
[2] Montella, A., "Safety Reviews of Existing Roads: A Quantitative Safety Assessment Methodology." Vol. TRB#05-1295, Washington, D.C., 2005 TRB 84th Annual Meeting: Compendium of Papers CD-ROM, (2005)
[3] Pitale, J.T., Shankwitz, C., Preston, H., and Barry, M."Benefit-Cost Analysis of In-Vehicle Technologies and Infrastructure Modifications as a Means to Prevent Crashes Along Curves and Shoulders." Minnesota Department of Transportation, (2009).

Prepare Formal Response (RSA Step 7)

Agencies may not have the necessary funds or staff available to implement all suggestions from the RSA report; however, the project owner is expected to consider each of the suggestions. If the project owner does not intend to implement one or more suggestions, they are expected to document the reasons. CMFs can be used to justify the project owner's intended course of action. Specifically, the project owner may choose not to implement treatments that are relatively ineffective with respect to safety. This process is similar to the three-step process discussed previously under *Conduct RSA Analysis and Prepare Report of Findings (RSA Step 5)*.

Incorporate Findings into the Project when Appropriate (RSA Step 8)

Project owners may be able to implement near-term and low-cost suggestions using internal staff, such as maintenance personnel. For more costly improvements, it may be necessary to conduct a formal economic appraisal to prioritize treatments, particularly if the project is competing for other safety funds or transportation funds in general. An economic appraisal may be based on a benefit-cost or cost-effectiveness analysis. The following steps outline the two approaches, which incorporate CMFs to estimate project benefits. The process would be repeated for each potential countermeasure identified in the RSA report.

CMF Step 1: Estimate Cost of Treatment

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

CMF Step 2: Estimate Annual Crashes WITHOUT Treatment

The annual crashes without treatment have to be estimated before applying CMFs. The *Highway Safety Manual (HSM)* presents several methods for estimating the future safety performance of a roadway or intersection *(4)*. 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.

CMF 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.

CMF 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 (CMF Step 5).

CMF 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 *(4)*, which are based on the cost from the FHWA report, *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries (5)*. 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 *(5)*.

Crash Severity	Estimated Cost
Fatal (K)	$4,008,900
Incapacitating Injury (A)	$216,000
Non-Incapacitating Injury (B)	$79,000
Possible Injury (C)	$44,900
Property Damage Only (O)	$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.

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

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 without treatment 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.

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: An RSA was conducted at a midblock pedestrian crossing on an urban, four-lane, divided arterial with a posted speed of 45 mi/h. The purpose of the RSA was to identify potential safety issues and to develop suggestions to address the specific concerns. The following is a benefit-cost analysis for one of the RSA team's suggestions, a pedestrian hybrid beacon. A CMF for fatal and injury (FI) crashes was obtained from the CMF Clearinghouse based on a study by Fitzpatrick and Park (6). 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 (7). 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 (5).

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 RSA process to quantify the safety effects of various treatments and justify the RSA team suggestions to the project owner and/or design team. The following case study illustrates how CMFs have been applied in the RSA process. It also identifies noteworthy practices and actual challenges encountered by agencies with respect to this process.

Project Description

The Michigan Department of Transportation (MDOT) conducted an Operational and Preliminary Design Stage RSA along the first horizontal curve on M-26 north of the village limits of South Range, in Houghton County. The RSA location is circled in Figure 2. This curve was chosen by MDOT on the basis of crash history.

The objectives of the RSA were to:

- Review road safety at the curve.
- Identify physical and operational issues that may affect road safety.
- Review the proposed plan concept.
- Develop and evaluate potential countermeasures to reduce the frequency and severity of collisions.

An aerial image of the site is shown in Figure 3 and site photographs are provided in Figure 4. The RSA curve is characterized by the following variables.

- Functional classification: principal arterial.
- Land use: surrounded by homes and small businesses.
- Annual average daily traffic (AADT): 5,003 vehicles per day.
- Area type: rural.
- Number of lanes: two-lane road.
- Posted speed: 45 mph.
- Horizontal curvature:
    - Radius: ~637 ft.
    - Length: ~609 ft.
- Vertical curvature: located on down-slope of crest curve.
- Existing countermeasures: curve warning signs, chevrons, and shoulder rumble strips.

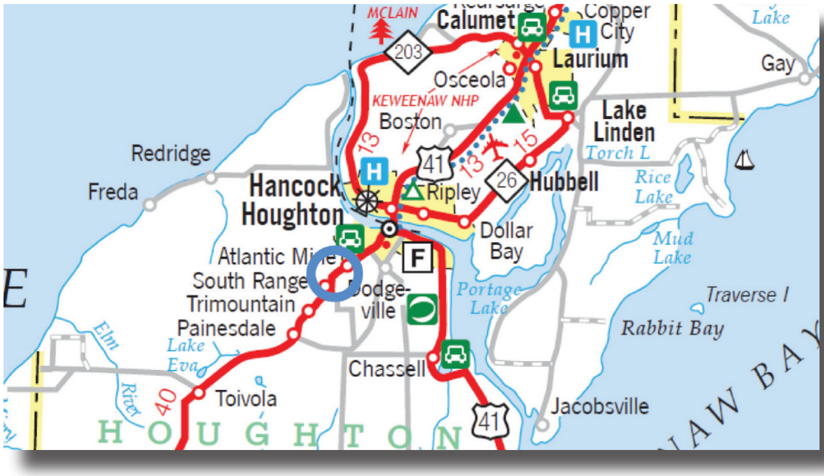


Figure 2. Study Location

Practical Application of CMFs

The RSA team identified six potential safety issues at the study location including the following.

1. Limited curve radius.
2. Inconspicuous signing.
3. Winter weather crashes.
4. Violations of driver expectation.
5. Vertical curve obstructs sight distance.
6. Poor visibility of Academy Road Intersection.

The RSA team also developed several potential countermeasures to address the identified issues including the following.

- Increase curve radius.
- Flatten crest vertical curve.
- Upgrade signing.
- Install variable speed limit signs.

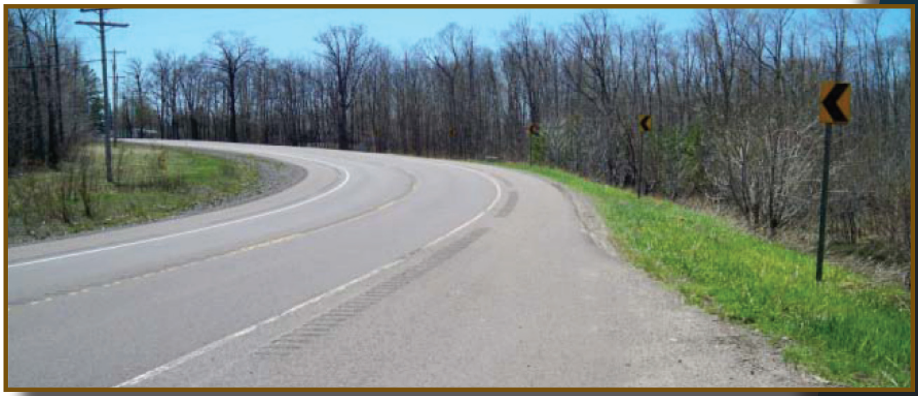
The RSA report is generally the final deliverable of an RSA team, including a list of potential safety issues and associated countermeasures. It is then the responsibility of the project owner/design team to consider the RSA team's suggestions and determine which countermeasures will be implemented and the relative timeframe for implementation.

In this case, the RSA team provided additional information in the final report to assist the project owner/design team with their subsequent decision-making. The additional information included the identification and application of CMFs, which resulted in an estimate of the potential safety benefits of the identified countermeasures. The RSA team also estimated the construction costs for each countermeasure and compared these costs to the safety benefits in a benefit-cost analysis. The following explains the process involved in the identification and application of CMFs in the benefit-cost analysis.

Figure 3. Site Aerial

Northbound M-26 approach (south of curve POB)

Northbound M-26 (at curve POB)



Southbound M-26 (at curve POE)

Southbound M-26 approach (north of curve POE)

Figure 4. Site Photos

CMF Step 1: Identify CMFs

CMFs were obtained from the CMF Clearinghouse. The applicable CMFs are shown in Table 1.

Table 1. Applicable CMFs

Countermeasure	CMF	Applicability
Increase Curve Radius	0.33[1]	All Crashes
Flatten Crest Curve	0.50[2]	All Crashes
Upgrade Signing	0.70[3]	All Crashes
Install Variable Speed Limits	0.54[4]	All Crashes

Source:
[1] Pitale, J.T., Shankwitz, C., Preston, H., and Barry, M."Benefit-Cost Analysis of In-Vehicle Technologies and Infrastructure Modifications as a Means to Prevent Crashes Along Curves and Shoulders." Minnesota Department of Transportation, (2009).
[2] Agent, K. R., Stamatiadis, N., and Jones, S., "Development of Accident Reduction Factors." KTC-96-13, Kentucky Transportation Cabinet, (1996).
[3] Montella, A. "Safety Evaluation of Curve Delineation Improvements An Empirical Bayes Observational Before-After Study." TRB 88th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C., (2009).
[4] Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." Oxford, United Kingdom, Elsevier, (2004).

CMF Step 2 – Estimate Crashes WITHOUT Treatment

The crashes without treatment were estimated from historical crash data. Specifically, the average annual crashes were computed by severity based on five years of observed crash data. The total and average observed crashes by severity are shown in Table 2.

The Empirical Bayes method is an alternative method for estimating the annual crashes without treatment. 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 2. Estimated Crashes without Treatment

Crash Severity	Total Crashes (5 Years)	Estimated Crashes (Crashes/ Year)
Fatal (K)	1	0.2
Incapacitating Injury (A)	1	0.2
Non-Incapacitating Injury (B)	0	0
Possible Injury (C)	3	0.6
Property Damage Only (O)	6	1.2

CMF Step 3 – Estimate Crash Costs

Crash costs were obtained from the National Safety Council, which provides updated average comprehensive costs for motor vehicle crashes. The costs are shown in Table 3.

Table 3. Crash Costs by Severity

Crash Severity	Estimated Cost
Fatal (K)	$1,300,000
Incapacitating Injury (A)	$67,800
Non-Incapacitating Injury (B)	$21,900
Possible Injury (C)	$12,400
Property Damage Only (O)	$8,200

Source: "Estimating the Costs of Unintentional Injuries, 2009" from the National Safety Council website www.nsc.org.

CMF Step 4 – Compute Value of Safety Benefit

The value of the annual safety benefit (i.e., crash cost savings) was computed by Equation 1.

$$EAB = (1 - CMF) * (C_K * E_K + C_A * E_A + C_B * E_B + C_C * E_C + C_O * E_O) \quad (1)$$

Where: EAB = estimated annual benefit ($).
CMF = applicable crash modification factor.
C_i = average cost for crash severity (i).
E_i = estimated annual crashes for crash severity (i).

Taking the countermeasure "increase curve radius" as an example, the following shows the computations using Equation 1.

EAB = (1 - 0.33) * ($1,300,000 * 0.2 + $67,800 * 0.2 + $21,900 * 0 + $12,400 * 0.6 + $8,200 * 1.2)
EAB = $194,863

CMF Step 5 – Estimate Countermeasure Costs

The total construction costs are shown in Table 4. For the purpose of the economic evaluation, the net annual operating costs, maintenance costs, and salvage values were assumed to be negligible. A discount rate of three percent was assumed to compute the annualized cost.

Table 4. Estimated Construction Costs

Countermeasure	Service Life (Years)	Total Cost	Annual Cost
Increase Curve Radius	15	$650,000	$54,450.50
Flatten Crest Curve	15	$350,000	$29,319.50
Upgrade Signing	3	$10,000	$3,535.30
Install Variable SpeedLimits	7	$250,000	$40,127.50
Source: Cost and service life data were obtained from the RSA report, "M-26 (north of South Range) Houghton County Road Safety Audit, Michigan Department of Transportation, July, 2011."			

CMF 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 5.

Table 5. Benefit-Cost Ratios

Countermeasure	B/C Ratio
Increase Curve Radius	3.6
Flatten Crest Curve	4.8
Upgrade Signing	24.7
Install Variable Speed Limits	3.3

The computation of EAB could have been performed in two steps by estimating the change in crashes and then converting the change in crashes to a monetary value using the average crash costs. It is necessary to apply a two-step process if the CMF is different for different severities.

Sample Materials

A spreadsheet was developed to assist with the computations presented in the case study. This spreadsheet shows the numbers from the case study as sample inputs along with the results of the calculations. The user inputs crash costs, total crashes, number of years, name of improvements, applicable CMFs, service life for each treatment, estimated project cost, and recovery factor. The remaining values, including the B/C ratio, are calculated automatically using the equations shown in the spreadsheet on the following page.

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Summary of Key Findings

The RSA process is typically a qualitative evaluation of the safety performance of a given facility. The RSA report is generally the final deliverable of an RSA team, including a list of potential safety issues and associated countermeasures. It is then the responsibility of the project owner/design team to consider the suggestions identified by the RSA team and determine which countermeasures will be implemented and the relative timeframe for implementation. The application of CMFs not only helps an agency to compare the relative effectiveness of suggested countermeasures, but it also provides information to be used in a benefit-cost analysis. A benefit-cost analysis can be used to prioritize suggested improvements and may be required when applying for funding.

In this case, the RSA team provided additional information in the final report to assist the project owner/design team with their subsequent decision-making process. The additional information included the identification and application of CMFs, which resulted in an estimate of the potential safety benefits of the identified countermeasures. The RSA team also estimated the construction costs for each countermeasure and compared these costs to the safety benefits in a benefit-cost analysis.

	A	B	C	D
1	**Crash Severity Level**	**Crash Cost**	**Total Crashes**	**Estimated Annual Crashes**
2	Fatal (K)	1,300,000	1	0.2 [=C2/B8]
3	Incapacitating Injury (A)	67,800	1	0.2 [=C3/B8]
4	Non-Incapacitating Injury (B)	21,900	0	0.0 [=C4/B8]
5	Possible Injury (C)	12,400	3	0.6 [=C5/B8]
6	Property Damage Only (O)	8,200	6	1.2 [=C6/B8]
7				
8	Number of Years	5		
9				
10	**Improvement**	**CMF**	**Service Life**	
11	Increase Curve Radius	0.33	15	
12	Flatten Crest Vertical Curve	0.50	15	
13	Upgrade Signing	0.70	3	
14	Variable Speed Limit Signs	0.54	7	
15				
16	**Improvement**	**Estimated Annual Benefit**		
17	Increase Curve Radius	$194,863 [=(1-B11)*(B2*D2+ B3*D3+ B4*D4+ B5*D5+ B6*D6)]		
18	Flatten Crest Vertical Curve	$145,420 [=(1-B12)*(B2*D2+ B3*D3+ B4*D4+ B5*D5+ B6*D6)]		
19	Upgrade Signing	$87,252 [=(1-B13)*(B2*D2+ B3*D3+ B4*D4+ B5*D5+ B6*D6)]		
20	Variable Speed Limit Signs	$133,786 [=(1-B14)*(B2*D2+ B3*D3+ B4*D4+ B5*D5+ B6*D6)]		
21				
22	**Improvement**	**Construction Cost**	**Recovery Factor**	**Annualized Cost**
23	Increase Curve Radius	$650,000	0.08377	$54,451 [=B23*C23]
24	Flatten Crest Vertical Curve	$350,000	0.08377	$29,320 [=B24*C24]
25	Upgrade Signing	$10,000	0.35353	$3,535 [=B25*C25]
26	Variable Speed Limit Signs	$250,000	0.16051	$40,128 [=B26*C26]
27				
28	**Improvement**	**B/C Ratio**		
29	Increase Curve Radius	3.6 [=B17/D23]		
30	Flatten Crest Vertical Curve	4.8 [=B18/D24]		
31	Upgrade Signing	24.7 [=B19/D25]		
32	Variable Speed Limit Signs	3.3 [=B20/D26]		
33				
34	Shaded Cells = User Input			

OVERCOMING POTENTIAL CHALLENGES

Potential challenges may arise when applying CMFs in the RSA 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 RSA process. The *Introduction to Crash Modification Factors (1)* provides general guidance related to the application of CMFs. The following were identified as specific challenges, lessons learned, and opportunities to overcome challenges based on discussions with transportation agencies.

Availability of CMFs

A notable potential challenge is the availability of CMFs for specific countermeasures. The *CMF Clearinghouse (3)* 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.

As a starting point, the *CMF Clearinghouse (3)* 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.

Lance Johnson (FHWA, Idaho Division Office) noted that CMFs are not always available for the recommendations identified in the RSA report. This limitation is related to the current state of research.

Jeff Bagdade (Opus International, consultant to MDOT) indicated that CMFs are available for approximately two-thirds of the suggestions included in the RSA report.

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 given scenario. 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 (3)* and *HSM (4)* 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 indicate contradictory 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

Jeff Bagdade (Opus International, consultant to MDOT) indicated that it is necessary to use engineering judgment during the selection of an appropriate CMF. Considerations include the general driver population, road conditions, and crash reporting thresholds.

how to select the most applicable CMF is posted on the CMF Clearinghouse *(3)* under FAQs.

Insufficient Expertise

A specific challenge for the RSA team could be that there is insufficient expertise within the team to apply CMFs. While CMFs are not a new tool, they have only recently gained popularity among safety professionals and their use has been mostly limited to applications within the roadway safety management process. There are a number of opportunities to apply CMFs in other aspects of transportation engineering (e.g., RSA 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 the RSA team does not have the expertise to apply CMFs, then they may decide to simply identify and report the applicable CMFs in the RSA report. They can also solicit outside expertise from the State Highway Safety Engineer, FHWA Division Office, or consultants. 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).

Michigan DOT establishes contracts with consultants to help conduct RSAs. The consultants are knowledgeable in the selection and application of CMFs and include a detailed analysis of the potential impacts of suggested strategies in the RSA report.

Scheduling and Coordination

RSAs are typically completed within one week to one month. If the RSA team does not have the expertise to apply CMFs and quantify safety impacts, then it may be difficult to coordinate with others to provide this support without some planning. To help overcome this potential issue, it may be useful to include an experienced CMF user as a member of the RSA team or coordinate with an experienced CMF user in advance.

Estimating Annual Crashes without Treatment

To quantify the potential safety impact of 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 (4)* 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 (8)* provides general guidance related to the selection, calibration, and application of SPFs.

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For More Information:

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Visit us on the web at:
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