CRASH MODIFICATION FACTORS IN PRACTICE

Using CMFs to Quantify Safety in the Value Engineering Process

The Crash Modification Factors (CMFs) in Practice: Using CMFs to Quantify Safety in the Value Engineering Process guide describes and illustrates several opportunities to incorporate the latest methods to quantify safety in the value engineering (VE) process using CMFs. The target audience includes VE program managers, VE study teams, and those supporting VE study teams. The purpose of this guide is to help raise awareness of opportunities to consider and quantify safety in the VE process, with a specific focus on the application of CMFs to support the process. The objectives are to 1) identify opportunities to consider safety in the various steps of the VE process, 2) describe various methods available for quantifying safety using CMFs, and 3) explain when it would be appropriate to employ each method. By providing safety awareness, VE practitioners will be better prepared to evaluate safety-related issues and explore opportunities to enhance safety during the VE 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 help raise awareness of safety, demonstrate the use of CMFs, and introduce other methods to quantify safety in these five activities.

INTRODUCTION

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

Methods and related tools have been available for several years to quantify the operational and environmental impacts of design decisions. Recently, similar methods and tools have been developed to quantify the safety impacts of these decisions, but these resources are relatively new. There is a need to raise awareness of the current level of road safety knowledge and the methods available to quantify safety in the value engineering (VE) process. Quantifying safety will help decision-makers better understand the safety impacts of design alternatives and allow safety impacts to be considered in conjunction with other factors. It is important for professionals involved in the VE process to understand the importance of quantifying safety and using appropriate methods to do so.

A VE study ensures that a project provides the needed functions safely, reliably, efficiently, and at the lowest overall cost. The VE review and analysis occurs during the concept and/or design phases of the project development process and the VE team can provide suggestions and recommendations to improve the overall value and quality of the project, and reduce the time to complete the project. As such, the VE process provides an added opportunity to consider safety early in the project development process. It also allows the VE team to identify, consider, and recommend potential safety enhancements to proactively address safety issues before a project is constructed.

Traditionally, safety is a consideration during the VE process, but much of the consideration has been qualitative in nature. Recently developed methods may allow VE teams to

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quantify the safety impacts of various design and operational features. If a VE team suggests changes to a specific project element, these methods may help them understand the safety implications of those changes and justify their suggestions and recommendations. In this way, safety can be considered in conjunction with the anticipated operational and environmental impacts.

Read more for an overview of opportunities to quantify safety in the VE process or skip to the section that describes available methods for quantifying safety using crash modification factors (CMFs). A decision-support chart is provided to help identify when CMF-related methods may be appropriate in the VE process. Examples are provided to illustrate how these methods can be applied and a case study illustrates how these methods have been applied in a particular state to quantify safety impacts in the VE process. Finally, potential challenges are presented along with options to overcome common application issues. While several examples are provided to demonstrate the basic application of CMF-related methods, a VE team may contact their State Highway Safety Engineer (or equivalent) or Federal Highway Administration (FHWA) Division Office for further guidance and assistance with the application of these methods and the interpretation of results.

Contact information for the FHWA field offices is available at: http://www.fhwa.dot.gov/about/field.cfm.

OVERVIEW OF SAFETY IN THE VALUE ENGINEERING PROCESS

Value engineering is "a systematic process of review and analysis of a project during the concept and design phases by a multidiscipline team of persons not involved in the project that is conducted to provide recommendations for (1) providing the needed functions safely, reliably, efficiently, and at the lowest overall cost; (2) improving the value and quality of the project; and (3) reducing the time to complete the project" *(1)*. The VE process considers several competing needs, including the cost, safety, operations, and environmental impacts. In the concept phase, there may be opportunities for large-scale changes in the design. In later design stages (e.g., 60-percent design), the major decisions have been made, but there are still opportunities to make changes to the project elements being designed at the time (i.e., maintenance of traffic, constructability, construction phasing, or specific safety strategies).

The multidiscipline VE study team is led by a facilitator through a systematic process that allows the team to learn about the project, identify high-cost elements of the project, investigate and develop potential alternatives, and present recommendations for possible incorporation into the project. The VE process typically consists of eight phases:

1. Selection.
2. Investigation.
3. Function Analysis.
4. Creative.
5. Evaluation.
6. Development.
7. Presentation.
8. Closeout/Implementation.

The following describes the eight-phase process *(1)*, noting the opportunities where safety can be considered and quantified. By incorporating safety analysis in the VE process, agencies can quantify the safety impacts of alternatives and better understand the potential effects of the VE team's suggestions and recommendations. The analysis will also demonstrate

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that safety was explicitly considered using a quantitative method. This is particularly useful for risk management and can help to defend against potential litigation. For example, a VE team may consider several opportunities for a given project and select the combination that achieves a reasonable balance between cost, safety, operations, and environmental impacts. While additional opportunities may be considered for a given project, it is unreasonable to enhance design features or implement additional countermeasures if the potential worth does not justify the cost. This is particularly important when resources could be used more cost-effectively on another project.

Selection Phase

The selection phase involves the identification of the project for VE analysis. The responsibility of this task is typically outside of the control of the VE study team. Project selection criteria can vary among agencies, but may include the following:

- High-cost projects.
- High-priority projects.
- Complex and/or challenging projects.
- Extensive/costly environmental or geotechnical requirements.
- Corridor/route-planning studies.
- Projects involving multiple stakeholders.

Investigation Phase

During the investigation phase, the VE study team reviews available information about the project. The project team with knowledge about the project provides background information, identifies challenges, and answers any project-related questions for the VE team. Project information should cover all of the primary factors including project safety, cost estimates, environmental commitments, design elements, traffic analysis, material requirements, and plans.

It is during this phase where the VE team, with the help of the project team, may begin to identify project elements (e.g., lanes, shoulders, signs, bridges, and pavement) for further analysis. The VE study team may select project elements for further analysis based on factors such as cost, operations, constructability, safety, and other project challenges.

Function Analysis Phase

During the first part of the function analysis phase, the VE study team defines the function of each project element. The function of each project element is defined using two words—an action verb and a measurable noun (that is acted upon). For example, the function of a bridge is to "cross obstacle", the function of signing is to "guide drivers", the function of pavement is to "improve ride", and the function of rumble strips is to "alert drivers."

During the next part of the function analysis phase, the VE study team analyzes project elements to determine their cost and worth. The cost is the actual cost to construct and maintain the project element. The worth is the least cost way to perform the function of the project element. The three fundamental concepts of VE—function, cost, and worth—are then discussed by answering key questions about the overall project and specific project elements:

- What is it?
- What must it do (i.e., what is the primary function)?
- What else does it do (i.e., what are the secondary functions)?
- What does it cost?
- What is it worth?

The value of a project or project element is based on a comparison of the cost and worth. The value of a project is reduced if proposed changes to a project element sacrifice the needed function. Functions beyond those that are needed are also of little value; hence, the value of a project is increased if unneeded functions are eliminated. The objective of the VE team is to develop a design for which the costs closely match the worth. At the conclusion of the function analysis phase, the VE team identifies a list of project elements that have the greatest potential for value improvement.

The value of project safety improvements may be quantified by determining the cost and worth of the proposed improvement(s). The societal worth of a project increases when safety is improved by a project element. There is value added to a project when the worth of safety improvements is greater than the cost of the improvements. The safety-related cost and worth can be quantified in the evaluation phase.

Creative Phase

Once the team determines which project elements should be analyzed for improved value, the team looks at the function of each element to generate potential opportunities to improve cost, delivery time, quality, and/or operations. This is called the "creative" phase because the team uses brainstorming techniques and an innovative spirit to identify opportunities to improve the project elements identified in the previous phase.

Multiple opportunities may provide the same function, but not at the same cost or the same level of safety. For example, the function of a median barrier is to "redirect vehicles." While there are several types of median barriers that can provide this function, there are tradeoffs in the relative cost and safety performance among the different types of barriers. The opportunities are further analyzed in the evaluation phase to determine the relative costs and impacts.

Evaluation Phase

During the evaluation phase, each of the opportunities is evaluated to determine which should be carried forward as either recommendations or suggestions. The advantages and disadvantages of each opportunity are evaluated as part of this process. Opportunities are compared on a number of project factors, including cost, safety impacts, operational performance, environmental impacts, and constructability.

Safety should be considered as a factor for all applicable project elements. Common project elements that impact safety include those related to the roadway geometry (e.g., lane and shoulder width), traffic operations (e.g., traffic control devices), and roadside design (e.g., slope of embankments). For example, a VE team may consider shoulder narrowing as an opportunity, focusing on the potential advantages related to project costs (reduced cost) and environmental impacts (improved worth). However, the VE team should realize that shoulder narrowing can impact safety and reduce the worth of the project element. Safety should also be considered as a factor for project elements that affect visibility, guidance, and vehicle performance. For example, the selection of materials such as sign sheeting and surface type affect visibility, guidance, and vehicle performance (i.e., sign visibility is dependent on the retroreflectivity provided by the type of sign sheeting and vehicle performance is dependent on the level of friction provided by the road surface).

Example: A VE study was conducted for a bridge replacement project. The existing structure was classified as "Structurally Deficient" due to a poor deck rating and "Functionally Obsolete" due to inadequate clearance under the bridge. The purpose and need of the bridge replacement project is to improve structural deficiencies and maintenance needs, eliminate the functionally obsolete condition, and address the scour critical needs as well as the roadway geometric deficiencies.

The VE team identified key issues for consideration, including cost ($), environmental impacts (E), operational performance (O), constructability (C), likelihood of acceptance (LOA), and safety (S). A rating system was developed to assess these six factors for each opportunity as shown below.

Rating	$	E	O	C	LOA	S
3	Significant Savings	Significant Improvement	Significant Improvement	Significant Improvement	Very Likely	Significant Improvement
2	Some Savings	Moderate Improvement	Moderate Improvement	Some Improvement	Likely	Some Improvement
1	No Savings	Minor Improvement	No Change	No Change	Possible	No Change
0	Additional Costs	Increased Impact	Decreased Performance	More Complex	Unlikely	Negative Impact

The VE team considered 21 opportunities related to the design and construction phasing of the bridge replacement. The individual ratings for each of the six factors were combined during the evaluation phase to compare the relative advantages and disadvantages of each opportunity. The following table shows a sample of the 21 opportunities and associated ratings. Higher overall ratings do not necessarily reflect the best ideas, solutions, or suggestions, but do help to generate discussion and support the decision-making process. It is clear that safety may not be applicable to all opportunities (e.g., #6: use grid and panel system); however, it is important to identify opportunities that negatively impact the overall safety performance of the facility (e.g., #3: eliminate shoulders on the bridge).

The New York State DOT conducted a VE Study dedicated primarily to Work Zone Safety. This study varied considerably from more traditional VE studies in that savings were not measured in dollars, but rather in terms of safety considerations and enhancements.

Opportunity	$	E	O	C	LOA	S	Total
1. Reduce outside shoulders from 10′ to 8′	2	2	1	1	2	0	8
2. Reduce lane width from 12′ to 11′	2	2	1	1	1	0	7
3. Eliminate shoulders on the bridge	2	3	0	1	0	0	6
4. Deck replacement only	3	3	0	0	1	1	8
5. Close bridge and build new bridge on existing footprint (utilizing detours to divert traffic)	3	3	1	0	0	1	8
6. Use grid & panel system – build supports under the existing bridge, and remove it in pieces	0	1	1	0	0	1	3

A combination of the overall and individual ratings can be used to screen opportunities for further discussion. For example, the VE team further considered opportunities that received an overall rating of 7 or higher, and a level of acceptance (LOA) of at least 1. Using these criteria, they eliminated opportunities #3 (eliminate shoulders on the bridge) and #6 (use grid and panel system).

The VE team further considered the remaining opportunities to identify an alternative that achieves a balance among the six factors. They eliminated opportunity #2 (reduce lane width from 12 feet to 11 feet), recognizing that it would create an inconsistent design with the approaches (12-ft lanes) and would have a negative impact on safety. Opportunity #4 (deck replacement only) was dismissed because the structure is scour critical and deck replacement would not address the scour issue. Opportunity #5 (close bridge during construction) was dismissed for operational reasons (i.e., there are no viable detours available for motorists). In the end, Opportunity #1 (reduce outside shoulders from 10' to 8') was selected. While the reduced shoulder width is associated with a negative safety impact compared to the proposed design, it is consistent with the shoulder width on the approaches and would result in substantial cost savings and reduced environmental impacts due to the 4-ft reduction in total bridge width.

Safety should be considered not only when it is identified as a project factor in the investigation phase, but anytime when a suggested change in the design impacts the safety of the facility.

The evaluation phase is the primary opportunity to employ CMFs and related methods and tools to quantify safety impacts in the VE process. The application of these methods may allow the VE team to quantify safety impacts as they determine and discuss the advantages and disadvantages of each opportunity. Safety performance is typically considered as part of VE studies but is often based on a qualitative analysis or quantified using rough approximations of expected cost savings at the corridor level. The CMF-related methods discussed in this guide can be used to more rigorously quantify the safety impacts of alternatives. Safety impacts (either benefits or disbenefits) can then be converted to a dollar value based on average crash costs to help determine the overall worth of an opportunity. In this way, safety is quantified and can be considered with other factors such as the cost to construct the opportunity, operational effects, and environmental impacts.

Development Phase

Once the viable opportunities have been determined, team members further develop the recommendations or suggestions in the development phase to clearly communicate the concept to engineers involved with the project. This includes cost estimates, sketches, validation of design elements, documentation of assumptions, and other technical work needed to develop recommendations. This is the final step before the VE team presents its recommendations.

Opportunities to integrate safety in the development phase include the documentation of safety analyses and consideration of potential mitigation measures. If safety is considered as a factor in the evaluation phase, then the process and results of the safety analysis should be documented in the development phase. If the VE team identifies safety-related disadvantages in the evaluation phase, then potential mitigation measures can be considered at this time. For example, a VE team is developing an opportunity to narrow the cross-section, including lane and shoulder width, as a means to improve the overall value by reducing construction costs (reduce cost) and environmental impacts (improve worth). Based on a safety analysis conducted in the evaluation phase, the VE team recognized that crashes may increase under this scenario, which is a disadvantage of the opportunity. To mitigate the potential negative safety impact, the VE team is considering shoulder rumble strips during the development of the recommended alternative.

Presentation Phase

In the presentation phase, the VE study team presents the findings of the analysis and its recommendations to the decision makers. The team documents each recommendation or suggestion in a formal report that identifies the steps taken to accomplish each phase of the analysis, including the team's discussions and considerations that led to its recommendations. If needed, a presentation may also be given to ensure proper understanding of the information. The safety analysis can play a valuable role in this phase by supporting or justifying the suggestions and recommendations of the VE study team. Presenting the results of the safety analysis in conjunction with the other factors will demonstrate the thought process used to determine the final suggestions and recommendations, which will help decision-makers to fully understand the alternatives developed by the VE team and the potential impact on the safety of the project.

Closeout/Implementation Phase

In the closeout phase, the project decision-makers consider each recommendation from the VE analysis and decide on the appropriate action. The estimated safety performance, along with other factors, can help guide these decisions and manage the risk of potential litigation. While it is not always feasible or reasonable to select the alternative or design features that result in the highest level of safety performance, it is important to justify why they are not selected. Safety is only one factor to consider in the project development process and other factors such as operational efficiency, cost-effectiveness, and environmental impacts may take priority in certain cases. After approved recommendations have been incorporated into the project, an evaluation should be conducted to determine the actual cost savings.

METHODS FOR QUANTIFYING SAFETY IMPACTS IN THE VALUE ENGINEERING PROCESS

There are several opportunities to identify and address safety impacts in the VE process. This section focuses on the *Evaluation Phase* and identifies several methods and related tools that can be used to compare the safety impacts of various opportunities or project elements. Safety impacts are quantified by estimating the extent to which each opportunity or given set of conditions is likely to impact the frequency and severity of crashes. The safety impacts can then be compared among the alternatives and considered in conjunction with other factors such as operational and environmental impacts and overall project cost.

The safety impacts can be estimated using a number of methods which incorporate one or more of the following inputs: CMFs, safety performance function (SPF), observed crash frequency, predicted crash frequency, and expected crash frequency. Engineering judgment is an essential component of each method. These terms are defined below,

Note that while there are several methods available to quantify safety impacts in the VE process, there is a clear order of preference based on the availability of data and reliability of the methods. Engineering judgment is an essential component of each method.

followed by a discussion of each method. The methods are presented in order of increasing reliability, with a discussion of their strengths and limitations. While the most reliable method is preferred, the most appropriate method depends on the complexity of the decision at hand and the availability of required inputs. Related tools are then identified and can be used to help implement the methods. This section concludes with guidance on how to select an appropriate method based on the decision at hand and availability of required inputs.

Inputs

The required inputs are defined below, followed by a discussion of each method. More rigorous methods can be employed when more inputs are available; the most rigorous method requires all of the following inputs.

Crash Modification Factors

A crash modification factor (CMF) is an index of the expected change in safety performance following a modification in traffic control strategy or design element. When applied correctly, CMFs can be used to estimate the safety effectiveness of a given strategy, compare the relative safety effectiveness of multiple strategies, and adjust the crash frequency estimated from observed, predicted, or expected crashes. Readers can refer to the *Introduction to Crash Modification Factors* for more information on CMFs and how they are applied *(2)*.

Safety Performance Functions

A safety performance function (SPF) is an equation used to predict the average number of crashes per year at a location as a function of traffic volume and, in some cases, roadway or intersection characteristics (e.g., number of lanes, traffic control, or median type). SPFs are developed for specific facility types based on data from a group of similar sites and the results apply to a set of specified baseline conditions. The results from an SPF can be multiplied by an applicable CMF to account for differences between the actual site conditions and the specified baseline conditions. If an SPF is developed using data from another jurisdiction or time period, then it may be necessary to adjust the SPF through calibration to better reflect local conditions or a different study period. Readers can refer to the *Introduction to Safety Performance Functions* for more information on SPFs and how they are applied *(3)*.

Observed Crashes

Observed crashes are those reported at a site of interest. For example, there were 15 crashes reported over a three-year period at an urban, stop-controlled intersection. One might estimate that, on average, there will be five crashes per year at this location based on the observed crash history. Using the observed crash history to estimate annual average future crashes assumes that the past performance is a good approximation of the future (e.g., no changes in traffic volume, site conditions, driver behavior, weather, etc).

Predicted Crashes

Predicted crashes are estimated from an SPF. The predicted number of crashes for a given site is an estimate of the average number of crashes per year based on the crash experience at other locations with similar characteristics (e.g., area type, geometry, and operations). One might use the predicted crashes to estimate the future safety performance of a site when the observed crash history is not a good approximation of future conditions (e.g., conditions change over time such as traffic volume, site conditions, driver behavior, weather, etc).

Area type defines the general characteristics of the surrounding environment as rural, suburban, or urban.

Expected Crashes

Expected crashes are estimated using the Empirical Bayes method, which is a weighted average of the observed and predicted crashes for a site of interest. One might use the expected crashes to estimate future safety performance when there is value in both the observed crash history and predicted crashes for a site of interest. One benefit of using the expected crashes is that it helps to account for the natural variation in crashes (i.e., regression-to-the-mean).

Engineering Judgment

Engineering judgment refers to decisions made based on an evaluation of available pertinent information and a sound understanding of established engineering principles and practices. Applying sound engineering judgment is necessary when selecting and utilizing all methods for quantifying safety impacts. It is also necessary when interpreting the results of a method and considering the safety impacts of opportunities in conjunction with other factors such as operational and environmental impacts as well as overall project cost.

Methods for Quantifying Safety Impacts

Several methods are available for quantifying safety impacts in the VE process. The following is a detailed discussion of each method, required inputs, and associated strengths and limitations. It is important to note that the methods are presented in order of increasing reliability and an appropriate method should be selected based on the complexity of the decision at hand and the availability of required inputs. Further guidance on the selection of an appropriate method is provided after the discussion of methods.

Relative Comparison of CMFs

This method is used to estimate the relative magnitude and direction of potential safety impacts based on the anticipated percent change in crash frequency. It does not provide an estimate of the change in the number of crashes (only the percent change). The required inputs for this method include the following:

- Applicable CMFs.
- Engineering judgment.

When there is a lack of required inputs or expertise to employ more rigorous methods, then it may be necessary to simply compare the relative values of applicable CMFs to estimate the safety impacts of a design element. For example, a CMF may be identified for the radius of curve and used to estimate the percent change in crashes when the radius is changed from 300 to 400 feet. CMFs are also used to compare the relative safety benefits of potential mitigation measures when selecting a strategy to address an identified safety issue. For example, CMFs may be identified for shoulder widening and shoulder rumble strips to determine which would likely be more effective in reducing total crashes. A numerical example is provided later in this document in the *Relative Comparison of Opportunities using CMFs* section.

The advantages of this method include the following:
- It is relatively simple to apply.
- It does not require an estimate of crashes without treatment to which the CMF would be applied.

The limitations of this method include the following:
- It requires applicable CMFs.
- It does not provide an estimate of the change in the number of crashes (only the percent change).
- It is difficult to compare multiple opportunities when the applicable CMFs are for different crash types or severities.

Observed Crash Frequency with CMF Adjustment

This method is used to estimate the crash frequency for opportunities of interest. The results can be used to compare the safety performance for opportunities of interest or included in a benefit-cost analysis to quantify the benefits. The required inputs for this method include the following:
- Observed crashes.
- Applicable CMF(s).
- Engineering judgment.

When there is a lack of required inputs or expertise to employ more rigorous methods, then it may be necessary to estimate the safety impacts of a design element based on observed crashes and CMFs. The observed crashes (e.g., five-year average) for the location of interest are used to estimate the average crash frequency for existing conditions. Appropriate CMFs are then applied to estimate the crash frequency for opportunities of interest. Compared to the previous method, the observed crash history is the only additional piece of information required. A numerical example is provided later in this document in the *Estimating the Safety Impacts of Opportunities using Observed Crashes and CMFs* section, comparing the safety effectiveness of shoulder widening and shoulder rumble strips.

The advantages of this method include the following:
- It is relatively simple to apply.
- It provides an estimate of the change in crash frequency (not just the percent change).
- It can be applied when an SPF is not available for the facility type of interest.

The limitations of this method include the following:
- Applicable crash history and CMF(s) are required.
- It does not properly account for changes in traffic volume.
- It is susceptible to regression-to-the-mean bias (i.e., random variation in crashes over time).

Predicted Crash Frequency

This method is used to estimate the crash frequency for opportunities of interest. The results can be used to compare the safety performance for opportunities of interest or to quantify the benefits in a benefit-cost analysis. The required inputs for this method include the following:

- Applicable SPF.
- Engineering judgment.

This method applies to situations where the observed crash history is not available (e.g., new construction) or applicable (e.g., proposed conditions differ drastically from the existing conditions). The predicted crash frequency is computed from an applicable SPF.

The advantages of this method include the following:

- It provides an estimate of the change in crash frequency (not just the percent change).
- It can account for changes in traffic volume over time.
- It can be applied when observed crash history is not available or not applicable for the location of interest.
- It includes data from similar sites to reduce the reliance on crash data for any one site.

The limitations of this method include the following:

- An applicable SPF is required that includes the variables of interest. For example, the SPF would need to include a variable for shoulder width if this was a design feature related to an opportunity. It may also be necessary to adjust the SPF through calibration to better reflect local conditions or a different study period.
- It is susceptible to regression-to-the-mean bias (i.e., random variation in crashes over time).

Predicted Crash Frequency with CMF Adjustment

This method is used to estimate the crash frequency for opportunities of interest. The results can be used to compare the safety performance for opportunities of interest or to quantify the benefits in a benefit-cost analysis. The required inputs for this method include the following:

- Applicable SPF.
- Applicable CMF(s).
- Engineering judgment.

This method applies to situations where observed crash history is not available (e.g., new construction) or applicable (e.g., proposed conditions differ drastically from the existing conditions) and where the SPF does not include one or more variables of interest. In these cases, an applicable SPF is used to estimate the predicted crashes for a set of baseline conditions and applicable CMFs are applied to estimate the predicted crashes for other conditions of interest. For example, an applicable SPF may be available for the facility type of interest, but not include a variable for shoulder width. The SPF would be used to estimate the predicted crashes for baseline conditions and CMFs would be applied to estimate the impacts of different shoulder widths.

The advantages of this method include the following:

- It provides an estimate of the change in crash frequency (not just the percent change).
- It can account for changes in traffic volume over time.
- It can be applied when observed crash history is not available or not applicable for the location of interest.
- It includes data from similar sites to reduce the reliance on crash data for any one site.
- It does not require an SPF that includes all variables of interest.

The limitations of this method include the following:

- An applicable SPF is required for the facility type of interest. It may also be necessary to adjust the SPF through calibration to better reflect local conditions or a different study period.
- Applicable CMFs are required to account for the additional variables of interest.
- It is susceptible to regression-to-the-mean bias (i.e., random variation in crashes over time).

Expected Crash Frequency

This method is used to estimate the crash frequency for opportunities of interest. The results can be used to compare the safety performance for opportunities of interest or to quantify the benefits in a benefit-cost analysis. The required inputs for this method include the following:

- Observed crashes from an applicable crash history.
- Predicted crashes from an applicable SPF.
- Engineering judgment.

This method applies to situations where the observed and predicted crashes can be estimated and where the SPF includes the variables of interest. In these cases, the predicted crash frequency is computed from the applicable SPF for the conditions of interest. The expected crash frequency is computed using the Empirical Bayes approach, which is a weighted average of the observed and predicted crashes; this improves the accuracy and reliability of the estimate. The weight is based on the statistical reliability of the SPF.

The advantages of this method include the following:

- It provides an estimate of the change in crash frequency (not just the percent change).
- It can account for changes in traffic volume over time.
- It includes data from the site of interest as well as data from similar sites to reduce the reliance on crash data for any one location.
- It can account for regression-to-the-mean bias (i.e., random variation in crashes over time) by considering the long-term average crash frequency rather than short-term observed crash frequency.

The limitations of this method include the following:

- An applicable SPF is required that includes the variables of interest. For example, the SPF would need to include a variable for shoulder width if this was a design feature related to an opportunity. It may also be necessary to adjust the SPF through calibration to better reflect local conditions or a different study period.
- An appropriate level of expertise is required to apply the Empirical Bayes method.

Expected Crash Frequency with CMF Adjustment

This method is used to estimate the crash frequency for opportunities of interest. The results can be used to compare the safety performance for opportunities of interest or to quantify the benefits in a benefit-cost analysis. The required inputs for this method include the following:

- Observed crashes from an applicable crash history.
- Predicted crashes from an applicable SPF.
- Applicable CMF(s).
- Engineering judgment.

This method applies to situations where the observed and predicted crashes can be estimated and where the SPF does not include one or more variables of interest. In these cases, the predicted crash frequency is computed from the applicable SPF for baseline conditions and multiplied by applicable CMFs to estimate crashes for the conditions of interest. The expected crash frequency is computed using the Empirical Bayes approach, which is a weighted average of the observed and predicted crashes; this improves the accuracy and reliability of the estimate. The weight is based on the statistical reliability of the SPF.

The advantages of this method include the following:

- It provides an estimate of the change in crash frequency (not just the percent change).
- It can account for changes in traffic volume over time.
- It includes data from the site of interest as well as data from similar sites to reduce the reliance on crash data for any one location.
- It does not require an SPF that includes all variables of interest.
- It can account for regression-to-the-mean bias (i.e., random variation in crashes over time) by considering the long-term average crash frequency rather than short-term observed crash frequency.

The limitations of this method include the following:

- An applicable SPF is required for the facility type of interest. It may also be necessary to adjust the SPF through calibration to better reflect local conditions or a different study period.
- Applicable CMFs are required to account for the additional variables of interest.
- An appropriate level of expertise is required to apply the Empirical Bayes method.

The following table provides a summary of the previous methods along with the required inputs. Note that engineering judgment is an essential component of all methods.

Methods for Quantifying Safety Impacts	Required Inputs			
	Applicable CMF	Applicable Crash History (Observed Crashes)	Applicable SPF (Predicted Crashes)	Engineering Judgment
Relative Comparison of CMFs	●			●
Observed Crash Frequency with CMF Adjustment	●	●		●
Predicted Crash Frequency			●	●
Predicted Crash Frequency with CMF Adjustment	●		●	●
Expected Crash Frequency		●	●	●
Expected Crash Frequency with CMF Adjustment	●	●	●	●

Related Tools for Implementing Methods

Several tools have been developed to help implement the methods presented above. This guide provides a brief introduction to various tools that are available for quantifying safety impacts in the VE process. Readers can refer to the specific references for more information on each tool.

Highway Safety Manual

The Highway Safety Manual (HSM) provides a new generation of safety analysis methods and represents the current state-of-the-art in highway safety analysis *(4)*. The knowledge and methods included in the HSM may allow users to explicitly consider and quantify safety in the VE process. The HSM includes four parts as follows:

- <u>Part A – Introduction, Human Factors, and Fundamentals:</u> Part A describes the purpose and scope of the HSM and includes the fundamentals and background information needed to apply the methods and tools provided in Parts B, C, and D of the HSM.
- <u>Part B – Roadway Safety Management Process:</u> Part B presents information related to each of the six steps in the safety management process. These steps include network screening, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation.
- <u>Part C – Predictive Method:</u> Part C provides a predictive method for estimating expected crash frequency of a network, facility, or individual site. This includes the use of SPFs to estimate the predicted crash frequency. Predictive methods are currently provided for roadway segments and intersections for the following facility types: 1) rural two-lane, two-way roads, 2) rural multilane highways, and 3) urban and suburban arterials. The predictive method for freeways and ramps has been developed and will be incorporated in the next edition of the HSM.
- <u>Part D – Crash Modification Factors:</u> Part D provides a catalog of CMFs for a variety of design and operational strategies. The material is organized by site type and includes CMFs for strategies related to roadway segments, intersections, interchanges, special facilities, and road networks.

With respect to the VE process, Part B is used to help guide the diagnosis of safety issues and the countermeasure selection process; however, this is already incorporated in the traditional VE approach. Part C and Part D are likely the most applicable as SPFs and CMFs are used to quantify and compare the safety impacts of various opportunities. Part C is used to estimate the safety performance of alternatives in terms of crash frequency and severity, but this may be beyond the expertise of a typical VE study team. Readers can refer to the *Introduction to Safety Performance Functions (3)* for more information on SPFs and how they are applied. For more information on the use of predictive methods to evaluate opportunities, refer to *Integrating the HSM into the Highway Project Development Process (5)*. If it is necessary to conduct this type of analysis, the VE study team could seek assistance from the State Highway Safety Engineer (or equivalent) or the FHWA Division Office.

Contact information for the FHWA field offices is available at: http://www.fhwa.dot.gov/about/field.cfm.

Crash Modification Factors Clearinghouse

The CMF Clearinghouse *(6)* is a web-based database of CMFs with supporting documentation to help users identify the most appropriate countermeasure for their safety needs. Four of the seven methods presented in the previous section rely on CMFs and the CMF Clearinghouse is a good source for this information. Users can search the site for applicable CMFs or submit CMFs to be included in the clearinghouse. The CMF Clearinghouse includes all CMFs from the HSM and many others. While the CMF Clearinghouse provides a wealth of information related to CMFs, sound engineering judgment is paramount to selecting an appropriate value, particularly when there are multiple CMFs for a given treatment. Readers can refer to the *Introduction to Crash Modification Factors (2)* for further guidance on selecting an appropriate CMF. Challenges and opportunities related to the applicability of CMFs are also discussed later in this document in the section titled: *Overcoming Potential Challenges*.

Interactive Highway Safety Design Model

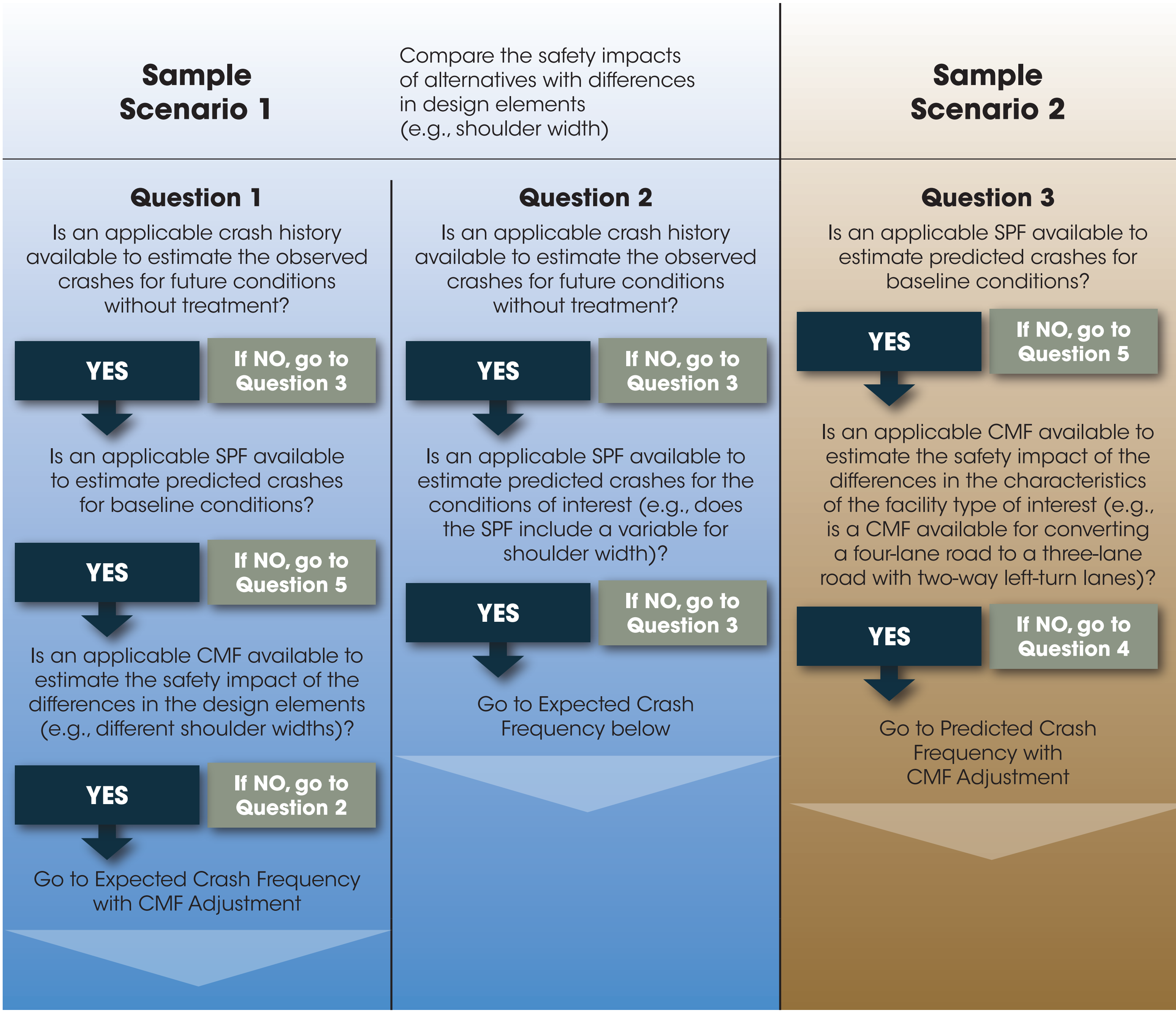
The Interactive Highway Safety Design Model (IHSDM) is a decision-support tool that provides a suite of analysis modules for evaluating the safety and operational impacts of geometric design decisions *(7)*. The predictive methods from Part C of the HSM are included in this free software to help users estimate the safety performance of an existing or proposed facility. Predictive methods are available for rural two-lane highways, rural multilane highways, urban/suburban arterials, and mainline freeway segments. A calibration tool is also available to assist users in implementing the calibration procedures described in Part C of the HSM. Other modules allow users to check existing or proposed highway designs against relevant design policy values, assess design consistency, conduct detailed intersection design reviews, analyze traffic operations, and simulate driver and vehicle factors for two-lane roads.

Interchange Safety Analysis Tool Enhanced

The Interchange Safety Analysis Tool Enhanced (ISATe) is a decision-support tool that provides the ability to estimate the safety impacts of design decisions related to interchanges *(8)*. The tool was developed as part of a larger research effort under the National Cooperative Highway Research Program (NCHRP) Project 17-45, *Enhanced Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges*, to develop predictive methods for freeways and interchanges to be included in future editions of the HSM. The ISATe tool can help users implement the predictive methods for freeway segments, ramps, and ramp terminal intersections.

Selecting an Appropriate Method

It is important to select an appropriate method to assess the safety impacts during the VE process. The selection of an appropriate method is based on the complexity of the decision at hand and the availability of required inputs. It does not depend on the specific phase of the project development process. For example, the preferred method is to estimate crashes based on the *Expected Crash Frequency with CMF Adjustment*; however, this method requires an applicable crash history and would not apply to new construction projects. As another example, the *Relative Comparison of CMFs* may not be appropriate when there are substantial differences in the fundamental characteristics of the alternatives (e.g., different area type, number of lanes, and/or traffic volume). In such cases, it is necessary to conduct a more detailed analysis, preferably using expected crashes with or without CMF adjustment. The following table is provided to help users select an appropriate method for quantifying safety impacts.



Sample Scenario 1

Compare the safety impacts of alternatives with differences in design elements (e.g., shoulder width)

Question 1

Is an applicable crash history available to estimate the observed crashes for future conditions without treatment?

YES — **If NO, go to Question 3**

Is an applicable SPF available to estimate predicted crashes for baseline conditions?

YES — **If NO, go to Question 5**

Is an applicable CMF available to estimate the safety impact of the differences in the design elements (e.g., different shoulder widths)?

YES — **If NO, go to Question 2**

Go to Expected Crash Frequency with CMF Adjustment

Question 2

Is an applicable crash history available to estimate the observed crashes for future conditions without treatment?

YES — **If NO, go to Question 3**

Is an applicable SPF available to estimate predicted crashes for the conditions of interest (e.g., does the SPF include a variable for shoulder width)?

YES — **If NO, go to Question 3**

Go to Expected Crash Frequency below

Sample Scenario 2

Question 3

Is an applicable SPF available to estimate predicted crashes for baseline conditions?

YES — **If NO, go to Question 5**

Is an applicable CMF available to estimate the safety impact of the differences in the characteristics of the facility type of interest (e.g., is a CMF available for converting a four-lane road to a three-lane road with two-way left-turn lanes)?

YES — **If NO, go to Question 4**

Go to Predicted Crash Frequency with CMF Adjustment

Expected Crash Frequency with CMF Adjustment

Process Compute the predicted crashes for baseline conditions and multiply by the applicable CMFs to estimate the predicted crashes for the conditions of interest. The expected crash frequency is then estimated using the Empirical Bayes approach.

Applicability[1] Simple and Complex Scenarios

Expected Crash Frequency

Process Compute the predicted crashes for the conditions of interest. The expected crash frequency is then estimated using the Empirical Bayes approach.

Applicability[1] Simple and Complex Scenarios

Predicted Crash Frequency with CMF Adjustment

Process Compute the predicted crashes for baseline conditions and multiply the predicted crashes by the applicable CMFs to estimate the predicted crashes for the conditions of interest.

Applicability[1] Simple and Complex Scenarios

Notes: 1. Simple scenarios include those with minor differences in the overall characteristics of the alternatives (e.g., same area type, number of lanes, and traffic volume). Complex scenarios include those with substantial differences in the overall characteristics of the alternatives (e.g., different area type, number of lanes, and/or traffic volume).

Compare the safety impacts of alternatives with different overall characteristics (e.g., existing four-lane undivided segment and proposed three-lane segment with two through lanes and a two-way left-turn lane)

Sample Scenario 3

Compare the safety impacts of alternatives with different safety treatments (e.g., shoulder widening and shoulder rumble strips)

Question 4

Is an applicable SPF available to estimate the predicted crashes for the conditions of interest (e.g., does the SPF include a variable for number of lanes and median type)?

YES

If NO, go to Question 5

Go to Predicted Crash Frequency

Question 5

Is an applicable crash history available to estimate the observed crashes for baseline conditions (without either treatment)?

YES

If NO, go to Question 6

Are applicable CMFs available to estimate the safety impacts of the conditions of interest (e.g., shoulder widening and shoulder rumble strips)?

YES

If NO, then it is not possible to quantify the safety impacts based on these methods

Go to Observed Crash Frequency with CMF Adjustment

Question 6

Are applicable CMFs available to estimate the safety impacts of the conditions of interest (e.g., shoulder widening and shoulder rumble strips)?

YES

If NO, then it is not possible to quantify the safety impacts based on these methods

Go to Relative Comparison of CMFs

Predicted Crash Frequency

Process Compute the predicted crashes for the conditions of interest.

Applicability[1] Simple and Complex Scenarios

Observed Crash Frequency with CMF Adjustment

Process Compute the observed crashes for baseline conditions and multiply the observed crashes by the applicable CMF to estimate crashes for the two conditions.

Applicability[1] Simple Scenarios

Relative Comparison of CMFs

Process Compare the CMFs to estimate the relative impacts of the two conditions.

Applicability[1] Simple Scenarios

APPLICATION OF CMF-RELATED METHODS IN THE VALUE ENGINEERING PROCESS

There are several opportunities to integrate safety in the VE process. The identification and development of safety opportunities can be accomplished during the investigation, function analysis, creative, evaluation, and development phases. The actual analysis to compare or quantify safety impacts would occur in the evaluation and development phases.

This section focuses on the application of CMFs to quantify the safety impacts of specific project elements during the evaluation phase of a VE study. Four of the six methods for quantifying safety impacts involve the use of CMFs. As such, the remainder of this guide focuses on only those methods that apply CMFs in the VE process as noted below. Specifically, it focuses on the quantification of safety in the evaluation phase when safety is a project factor and crash frequency and/or severity is the performance measure. Examples are provided, followed by a case study and a discussion of opportunities to overcome potential challenges.

Specific applications of CMF-related methods are presented below to demonstrate the use of CMFs to quantify the safety impacts of opportunities in the evaluation phase. The first demonstrates the *Relative Comparison of Opportunities using CMFs*, which uses CMFs alone to compare the anticipated percent change in crashes for various opportunities. The second application, *Estimating the Safety Impacts of Design Decisions using Observed Crashes and CMFs*, is slightly more advanced as CMFs are used within a benefit-cost analysis. The second application demonstrates the use of observed crash history to estimate future crashes for baseline conditions and the application of CMFs to estimate the change in crashes for a given opportunity. The estimated change in crashes is then converted to a monetary value based on average crash costs and compared to the project cost to estimate the benefit-cost ratio of the opportunity. The results can be used to compare the safety performance of opportunities in terms of estimated crashes or determine whether or not an enhanced design feature or specific countermeasure is cost-effective. The case study provides an additional example, featuring the *Predicted Crash Frequency with CMF Adjustment* method. For more information on the *Expected Crash Frequency with CMF Adjustment* method, refer to Part C of the HSM *(4)* and related documentation, Integrating the HSM into the Highway Project Development Process *(5)*.

Relative Comparison of Opportunities using CMFs

The following steps can be used to compare the relative safety impacts of various opportunities in the evaluation phase when:

- Safety is identified as a project factor.
- The opportunity is relevant (i.e., CMF is available for the opportunity).
- The relative comparison of CMFs is an appropriate method.

Step 1: Identify Applicable CMFs for Conditions of Interest
CMFs are first identified for the various conditions of interest. As discussed in the *Introduction to Crash Modification Factors (2)*, 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 *(6)* 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.

Step 2: Combine CMFs to Estimate Overall Impact of Alternatives
One or more features may vary among alternatives. If there is only one feature of interest that varies among alternatives (e.g., presence or absence of rumble strips), then it is not necessary to combine multiple CMFs and the user can proceed with Step 3. If there are multiple features that vary among alternatives (e.g., lane and shoulder width), then it may be necessary to combine multiple CMFs to represent the overall safety impact of each alternative before proceeding to Step 3. As discussed in the *Introduction to Crash Modification Factors (2)*, the current practice assumes that CMFs are multiplicative when the CMFs apply to the same crash type and severity. It is not appropriate to multiply CMFs that do not apply to the same crash type and severity. More information regarding the application of multiple CMFs is available in recent articles *(9, 10)*.

Step 3: Compare CMFs to Quantify Relative Impacts of Alternatives
Once CMFs are identified for the various alternatives and combined as necessary, they can be compared to estimate the relative safety impacts. CMFs indicate the expected change in crashes relative to a certain baseline

condition. For example, a CMF may indicate the expected change in crashes if lighting is installed compared to the condition without lighting. In this way, CMFs are used to estimate the benefit of one condition over another. The estimated percent change in crashes is equal to 100*(1-CMF). For example, a CMF equal to 0.95 indicates an expected five percent reduction in crashes.

Example: The following example presents a scenario where a VE study team is considering various alternatives to reduce the time and cost associated with a reconstruction project on a rural two-lane road. The length of the study section is one mile and the annual average daily traffic is 15,000 vehicles per day. The proposed design includes 11-ft lanes and 4-ft shoulders, which would require the acquisition of additional right-of-way. The VE study team identified opportunities to reduce the time and cost of the project by keeping all work within the existing right-of-way. The primary opportunity is to maintain the existing shoulder width, which is defined as "shoulder narrowing" compared to the proposed design. Understanding that shoulder narrowing may impact the overall safety performance, the VE study team also considered shoulder rumble strips as an opportunity to mitigate potential safety impacts. As part of the evaluation phase, the VE study team would like to quantify the potential safety impacts of shoulder narrowing with and without rumble strips compared to the proposed design. The safety impacts can then be considered in conjunction with other project factors such as time and cost. The following table summarizes the conditions for the proposed design and two opportunities identified for the evaluation phase.

Scenario	Lane Width (ft)	Shoulder Width (ft)	Presence of Shoulder Rumble Strips
Proposed Design	11	4	No
Existing Design	11	2	No
Alternative Design	11	2	Yes

It was determined that a relative comparison of CMFs would be an appropriate method for quantifying the safety impacts of the opportunities because the required inputs and expertise to apply more rigorous methods were not available to the VE study team. Applicable CMFs were identified from the HSM (4) and CMF Clearinghouse (6). The following table presents the CMFs for each opportunity along with the baseline condition and applicability. [Note that all CMFs apply to total crashes on rural, two-lane roads.]

Opportunity	CMF	Baseline Condition	Applicable Facility Type	Applicable Crash Type	Applicable Crash Severity
Reduce shoulder width (4 ft to 2 ft)	1.07[1]	4-ft shoulder	Rural 2-Lane	All	All
Install shoulder rumble strips	0.85[2]	No rumble strips	Rural 2-Lane	All	All

[1] American Association of State Highway and Transportation Officials (AASHTO). *Highway Safety Manual, 1st* Edition, Washington, DC, 2010.

[2] Torbic, D.J., Hutton, J.M., Bokenkroger, C.D., Bauer, K.M., Harwood, D.W., Gilmore, D.K., Dunn, D.K., Ronchetto, J.J., Donnell, E.T., Sommer III, H.J., Garvey, P., Persaud, B., and Lyon, C. *Guidance for the Design and Application of Shoulder and Centerline Rumble Strips.* National Cooperative Highway Research Program (NCHRP) Report 641, Transportation Research Board, Washington, DC, 2009. Also available online from the CMF Clearinghouse: http://www.cmfclearinghouse.org/detail.cfm?facid=3516.

The first opportunity (existing design) includes changes to only one feature (i.e., shoulder width) compared to the proposed design. As such, it is not necessary to combine CMFs (Step 2). Based on the CMF for shoulder narrowing, the existing design (shoulder narrowing without rumble strips) is expected to increase crashes by seven percent (100(1-1.07)) compared to the proposed design.*

*The alternative design includes changes to two features (i.e., shoulder width and rumble strips) compared to the proposed design. As such, it is necessary to combine the CMFs (Step 2) before comparing safety impacts of the opportunity. It is assumed that the two CMFs are multiplicative as they both apply to the same crash type and severity (i.e., total crashes). The combined CMF for shoulder narrowing with shoulder rumble strips is 0.91 (1.07*0.85). Based on the combined CMF, the alternative design (shoulder narrowing with rumble strips) is expected to reduce crashes by nine percent (100*(1-0.91)) compared to the proposed design.*

In this example, CMFs are used to assess the safety impacts of opportunities in the evaluation phase of a VE study where safety is a project factor and crash frequency is the performance measure. Based on the relative comparison of CMFs, it appears that the alternative design would enhance safety performance compared to the existing and proposed designs. As such, the VE study team may recommend the alternative design because it would enhance safety performance without the requirement of additional right-of-way for the proposed design; however, the final decision would also consider other project factors such as the time and cost of the opportunities.

Note that several methods are available for estimating crashes without treatment. The estimated crash frequency without treatment should correspond with the specific crash type and severity for which the CMF is applicable. If the CMF applies to total crashes, then one should estimate the total annual crashes without treatment. If the CMF applies to a specific crash type or severity, then the annual crashes without treatment should be computed for that crash type or severity.

Estimating the Safety Impacts of Opportunities using Observed Crashes and CMFs

The previous example is a relatively simple application of CMFs and is useful for estimating the relative safety effects of various alternatives or safety strategies. It does not, however, identify the expected change in the *number* of crashes or consider the relative cost of the alternatives. If the number of crashes without treatment is estimated, then the CMFs can be applied to estimate the change in the number of crashes. The change in crashes can then be converted to a monetary value, based on average crash costs, to estimate the value of the benefit (or disbenefit). Finally, these costs can be compared to the construction costs to estimate a benefit-cost ratio. The following example illustrates this process. Further details on the step-by-step process can be found in the companion guide, *CMFs in Practice: Quantifying Safety in the Roadway Safety Management Process (11)*.

Example: Continuing with the previous example, suppose now that the VE study team would like to determine if the opportunities are economically justified (benefit-cost ratio greater than 1.0). This analysis requires an estimate of the benefit and cost of each opportunity in terms of a dollar value. The observed crash frequency with CMF adjustment method is used to estimate the change in crashes. First, the proposed design (4-ft shoulders) is compared to the existing design (2-ft shoulders without rumble strips). Next, the safety impacts of the alternative design (2-ft shoulders with rumble strips) are compared to the existing design.

The cost to construct an additional two feet of shoulder (2 ft to 4 ft) for the proposed design compared to the existing design is estimated to be $300,000 per mile. The service life for shoulder widening is 12 years and the annual maintenance costs are negligible. The cost of installing shoulder rumble strips on both sides of the road is estimated to be $5,000/mile. The service life for rumble strips is seven years and the annual maintenance costs are negligible. [Note: These costs would be based on average construction costs provided by the State or local agency.]

The observed crash frequency for the existing 1.0 mile study section is estimated to be 5.20 crashes per year based on the most recent five-year crash history. This is used as the estimate of crashes for the existing conditions (without treatment). [Note that more rigorous methods should be used to estimate crashes without treatment when the required inputs are available.] The applicable CMFs are then applied to estimate the crashes for the proposed and alternative designs as follows:

*Estimated crashes with treatment = CMF * Estimated crashes without treatment*

Since the existing conditions are used as the baseline scenario, it is necessary to adjust the CMFs from the previous example accordingly. Instead of using a CMF of 1.07 for reducing the shoulder width from 4 ft to 2 ft, we now use a CMF of 0.93 (1.00/1.07) to represent the proposed design scenario of increasing the shoulder width from 2 ft to 4 ft. This is simply the reciprocal of the previous CMF. When comparing the alternative design to the existing design, it is now only necessary to apply the CMF for shoulder rumble strips (0.85) to the estimated crashes without treatment since the shoulder width is the same for the existing and alternative designs.

Proposed Design Compared to Existing Design: Increase shoulder width (2 ft to 4 ft)

*Estimated crashes with treatment = 0.93 * 5.20 crashes per year = 4.84 crashes/year*

Alternative Design Compared to Existing Design: Install shoulder rumble strips

*Estimated crashes with treatment = 0.85 * 5.20 crashes per year = 4.42 crashes/year*

The estimated change in crashes per year is calculated as the difference in estimated crashes for any two conditions. Comparing the proposed and existing designs, the estimated change in crashes is 0.36 crashes per year (5.20 crashes per year minus 4.84 crashes per year). Comparing the alternative and existing designs, the estimated change in crashes is 0.78 crashes per year (5.20 crashes per year minus 4.42 crashes per year).

The dollar value of the annual safety benefit is then computed by multiplying the change in crashes per mile-year by the average cost of a crash. Many agencies have developed or adopted their own crash costs, but national estimates are also available such as those provided by FHWA (12). The HSM (4) also provides comprehensive crash costs by severity level, which are based on the data from the FHWA report, Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries (12). In this case, total crashes were analyzed so the average cost of all crashes is used. The average cost of a crash, including all types and severities, is $32,236 (12). [Note that crash costs vary by type and severity and different costs would apply if the analysis was based on specific crash types or severities. If possible, the analyst should use local crash costs by severity level.] The annual benefit of the proposed design compared to the existing design is $11,734 (0.36 crashes per year times $32,236 per crash). The annual benefit of the alternative design compared to the existing design is $25,144 (0.78 crashes per year times $32,236 per crash).

The following equation is used to compute the present value for the proposed and alternative designs compared to the existing conditions, assuming an inflation rate of three percent. In the following equation, (A) is the annual benefit or disbenefit, (i) is the inflation rate, and (n) is the service life.

$$\text{Present Value} = A * \frac{(1+i)^n - 1}{i * (1+i)^n}$$

The present value of the safety benefit of the proposed design compared to the existing design is computed as follows, assuming a service life of 12 years:

$$\text{Present Value of Shoulder Widening} = \$11{,}734 * \frac{(1+0.03)^{12} - 1}{0.03 * (1+0.03)^{12}} = \$116{,}799$$

The present value of the safety benefit of the alternative design compared to the existing design is computed as follows, assuming a service life of seven years:

$$\text{Present Value of Rumble Strips} = \$25{,}144 * \frac{(1+0.03)^{7} - 1}{0.03 * (1+0.03)^{7}} = \$156{,}655$$

The benefit-cost ratio is computed as the present value of the benefits divided by the present value of the project costs. Comparing the proposed design to the existing design, the benefit-cost ratio is 0.4 ($116,799 / $300,000). Comparing the alternative design to the existing design, the benefit-cost ratio is 31.3 ($156,655 / $5,000). From this analysis, it is shown that the alternative design is economically justified with respect to safety compared to the existing design (benefit-cost ratio greater than 1.0), while the proposed design is not economically justified. The safety impacts can then be considered in conjunction with other project factors.

CASE STUDY: EVALUATING OPPORTUNITIES USING PREDICTED CRASH FREQUENCY WITH CMF ADJUSTMENT

The following case study illustrates how the *Predicted Crash Frequency with CMF Adjustment* method has been used to explicitly consider the safety impacts of opportunities during the VE process. Specifically, it focuses on the quantification of safety in the evaluation phase when safety is a project factor and crash frequency is the related performance measure. Information for the case study was provided by the Missouri Department of Transportation (MoDOT).

MoDOT integrates data-driven decision-making in many of their planning and design practices, including the VE process. While not part of their VE policy, MoDOT encourages the use of the AASHTO Highway Safety Manual to better understand the safety implications of design-related decisions.

Project Description

MoDOT Southeast District proposed a roadway improvement project on a rural, two-lane section of Route 34 in Bollinger County, MO. The existing 2.8-mile study section is characterized by a narrow cross-section with several horizontal curves and relatively unforgiving roadside. The proposed project involved resurfacing, lane and shoulder widening, horizontal realignment, installation of centerline rumble strips, and roadside improvements. The project was also listed on the district's VE work plan, which is created by the District Value Engineering Coordinator (DVEC) to identify priority projects for VE study. Suggested selection criteria are provided at the following link to aid the DVEC in selecting projects for the VE work plan: http://epg.modot.org/files/c/c0/130_VE_Project_Selection_Criteria.doc.

A VE study was conducted during the design phase of the project to review the proposed design and to identify opportunities to add value to the project. As part of the investigation phase, the VE study team reviewed the project information and original proposed design, focusing on three major factors: 1) grading and drainage, 2) base and surface, and 3) miscellaneous. Several project elements were identified and their functions were defined as part of the function analysis. In the creative phase, the VE study team proposed several opportunities, including an alternative alignment that would modify the design of one curve and two adjacent tangents. During the evaluation phase of the VE study, the District conducted an analysis, using the Part C Predictive Methods of the Highway Safety Manual, to predict the safety performance of the original proposed design and VE proposed design compared to the existing conditions. The remainder of this case study focuses on the analysis conducted as part of the evaluation phase.

Table 1 provides a summary of the existing conditions, original proposed design, and VE proposed design. The baseline conditions from the Highway Safety Manual are also provided in Table 1 *(4)*. The primary differences among the alternatives include the following:

- Lane width: The existing roadway includes 10-ft lanes while the original proposed and VE proposed designs would include 11-ft lanes.
- Shoulder width/type: The existing road includes no paved shoulders while the original proposed and VE proposed designs would include 4-ft paved shoulders.

- Horizontal alignment: The existing design includes 11 horizontal curves with an average radius of 591 feet. The original proposed design would include substantial improvements to the realignment and while the number of curves would remain the same (11 curves) the average radius would increase to 8,436 feet. The VE proposed design would include 12 curves with an average radius of 8,194 feet. The VE proposed design is nearly identical to the original proposed design, but recommends a compound curve in place of a single curve to better balance the cut and fill, which would reduce project costs.
- Centerline rumble stripes: The existing roadway does not include centerline rumble stripes while the original proposed and VE proposed designs would both include centerline rumble stripes.
- Roadside hazard rating: The existing roadway has a roadside hazard rating of 5, which is characterized by a clear zone width between 5 and 10 feet, virtually non-recoverable sideslope (1V:3H), and may have roadside objects including guardrail (offset 0 to 5 feet) or rigid obstacles or embankment (offset 6.5 to 10 feet). The original proposed and VE proposed designs would both include roadside improvements to upgrade the roadside hazard rating to 3, which is characterized by a clear zone width of 10 feet, marginally recoverable sideslope (between 1V:3H and 1V:4H), and a rough roadside surface.

Table 1. Summary of Roadway Characteristics and Baseline Conditions

Roadway Characteristics	Existing Conditions[1]	Original Proposed Design[1]	VE Proposed Design[1]	Baseline[2]
Traffic volume	2,800	2,800	2,800	0 – 17,800
Length (mi)	2.8	2.8	2.8	Not specified
Lane width (ft)	10.0	11.0	11.0	12
Shoulder width (ft)	0	4	4	6
Shoulder type	Turf	Paved	Paved	Paved
Horizontal curve length (mi)	Varies	Varies	Varies	0
Radius of curvature (ft)	Varies	Varies	Varies	0
Spiral transition curve (yes/no)	No	No	No	No
Superelevation variance (ft/ft)	0	0	0	0
Grade (%)	0	0	0	0
Driveway density (driveways/mi)	5	5	5	5
Centerline rumble stripes (yes/no)	No	Yes	Yes	No
Passing lanes (1 lane/2 lanes/no)	No	No	No	No
Two-way left-turn lane (yes/no)	No	No	No	No
Roadside hazard rating (1-7 scale)	5	3	3	3
Segment lighting (yes/no)	No	No	No	No
Auto speed enforcement (yes/no)	No	No	No	No

Notes:

1. Volumes on the side roads were low and the District did not consider intersections to be a significant factor in the study. Also, there is no change in the relative intersection conditions for the three scenarios. As such, intersections were not included in the analysis.
2. The baseline conditions represent those associated with the HSM Part C Predictive Method for Rural Two-Lane Roads.

Practical Application of Predicted Crash Frequency with CMF Adjustment

For this analysis, MoDOT utilized the predictive method for two-lane rural roads from Part C of the Highway Safety Manual. Using the predictive method, a user specifies an applicable SPF for baseline conditions and applies CMFs to adjust the baseline prediction to reflect other conditions of interest. In this case, the SPF for baseline conditions is given by Equation {1} and the baseline conditions are summarized above in Table 1 *(4)*.

$$N_{SPF} = AADT * L * 365 * 10^{-6} * e^{-0.312} \quad \{1\}$$

Where:

N_{SPF} = Predicted total crash frequency for baseline conditions.
AADT = Annual average daily traffic volume (vehicles per day).
L = Segment length (mi).

Before applying the predictive method from the Highway Safety Manual, it is first necessary to divide the study section into homogeneous segments. A homogeneous segment has similar roadway, roadside, and operational characteristics. For example, a new segment would be created where there is a change in traffic volume. The segmentation resulted in 23 homogenous segments, including 12 tangents and 11 curves. Each of the segments was analyzed separately and the results were combined to estimate the safety performance of the entire study section under the various conditions (i.e., existing, original proposed design, and VE proposed design).

For this case study, the detailed calculations are shown for Segment 1 (the first tangent segment) and the results are summarized for the study corridor as a whole. Applying Equation {1} to the existing conditions with an AADT of 2,800 vehicles per day and a segment length of 0.146 miles, the predicted total crash frequency for the baseline conditions is computed as follows:

$$N_{SPF} = 2{,}800 * 0.146 * 365 * 10^{-6} * e^{-0.312}$$

$$N_{SPF} = 0.109 \text{ crashes per year}$$

The length of Segment 1 was reduced to 0.095 miles for the original proposed design and the VE proposed design based on the realignment of the horizontal curves. Applying Equation {1} to the proposed conditions with an AADT of 2,800 vehicles per day and a segment length of 0.095 miles, the predicted total crash frequency for the baseline conditions is computed as follows:

$$N_{SPF} = 2{,}800 * 0.095 * 365 * 10^{-6} * e^{-0.312}$$

$$N_{SPF} = 0.071 \text{ crashes per year}$$

CMFs were then identified to reflect the conditions of interest for Segment 1. The Highway Safety Manual Part C Predictive Method for Rural Two-Lane Roads provides specific CMFs for use with the SPF from Equation {1}. The CMFs for Segment 1 are provided in Table 2 *(4)*. Note that the CMFs related to horizontal curvature would change for the curve segments based on the length and radius of curve.

Table 2. Summary of CMFs for Segment 1 Conditions of Interest

Roadway Characteristics	Existing Conditions	Original Proposed Design	VE Proposed Design
Lane width	1.17	1.03	1.03
Shoulder width and type	1.29	1.09	1.09
Horizontal curves	1.00	1.00	1.00
Super-elevation	1.00	1.00	1.00
Grades	1.00	1.00	1.00
Driveway density	1.00	1.00	1.00
Centerline rumble stripes	1.00	0.94	0.94
Passing lanes	1.00	1.00	1.00
Two-way left-turn lane	1.00	1.00	1.00
Roadside design	1.14	1.00	1.00
Lighting	1.00	1.00	1.00
Automated speed enforcement	1.00	1.00	1.00

The CMFs were then combined to estimate the overall safety impact of the conditions of interest for Segment 1. As recommended in the Highway Safety Manual *(4)*, the CMFs were multiplied using Equation {2} to estimate the cumulative effect of the combined treatments for each scenario.

$$CMF_{Combined} = CMF_1 * CMF_2 * \ldots * CMF_n \qquad \{2\}$$

Where:

$CMF_{Combined}$ = Crash modification factor for combined set of roadway characteristics.

CMF_i = Crash modification factor for individual roadway characteristic (i).

n = Number of individual roadway characteristics.

The calculations for the combined CMFs are shown below. Note that several of the CMFs are 1.00 and are summarized by 1.00 raised to a power in the calculations. The combined CMFs for the existing conditions, original proposed design, and VE proposed design are 1.721, 1.050, and 1.050 respectively.

$$CMF_{Combined}\ (\text{Existing}) = 1.17 * 1.29 * 1.14 * 1.00^9 = 1.721$$

$$CMF_{Combined}\ (\text{Original Proposed}) = 1.03 * 1.09 * 0.94 * 1.00^9 = 1.050$$

$$CMF_{Combined}\ (\text{VE Proposed}) = 1.03 * 1.09 * 0.94 * 1.00^9 = 1.050$$

The predicted crash frequency for the baseline conditions is adjusted with the combined CMFs, using Equation {3} to estimate the predicted crashes for the conditions of interest.

$$N_{Predicted} = N_{SPF} * CMF_{Combined} \qquad \{3\}$$

Where:

$N_{Predicted}$ = Predicted total crash frequency for conditions of interest.

Note that CMFs should only be multiplied if they apply to the same crash type and severity. In this case, all CMFs apply to total crashes.

Computations for the three scenarios of interest are shown below and summarized in Table 3. Note that the original proposed design and VE proposed design are identical for Segment 1. As such, the predicted crashes are identical for the original and VE proposed designs.

$$N_{Predicted}\text{ (Existing Design)} = 0.109 * 1.721 = 0.188$$

$$N_{Predicted}\text{ (Original Proposed Design)} = 0.071 * 1.050 = 0.075$$

$$N_{Predicted}\text{ (VE Proposed Design)} = 0.071 * 1.050 = 0.075$$

Table 3. Summary of Computations for Predicted Annual Crashes for Segment 1

Scenario	N_{SPF} Equation {1}	$CMF_{Combined}$ Equation {2}	$N_{Predicted}$ Equation {3}
Existing Conditions	0.109	1.721	0.188
Original Proposed Design	0.071	1.050	0.075
VE Proposed Design	0. 071	1.050	0.075

Using the procedure outlined above, Equations 1 through 3 were applied to each of the 23 homogeneous segments individually to compute the predicted annual crashes for each segment under each of the three conditions. The predicted crashes were then summed over the 23 segments to predict the total crashes for the corridor as a whole for the three conditions of interest. Table 4 presents a summary of the predicted annual crashes for each of the 23 homogeneous segments and the corridor as a whole. Note that for some individual segments, the existing design performs better than the proposed designs with respect to predicted crashes (i.e., segments 3, 5, 7, 9, and 21). This is due to the length of the analysis segments where the segment length of the existing design is shorter than the proposed designs in these cases. The primary difference between the original proposed design and VE proposed design is the design of segments 3 through 5. The VE study identified an opportunity to better balance the cut and fill by modifying one of the curves (Segment 4) and the two adjacent tangents (Segment 3 and Segment 5). Specifically, the VE proposed design would include a compound curve with two different radii rather than a single curve with constant radii as in the original proposed design.

Note that a calibration factor can also be applied to account for jurisdictional/regional variations such as driver population, weather, and crash reporting. At the time of this case study, MoDOT had not developed a local calibration factor. As a result, a local calibration factor of 1.0 was assumed.

It is preferred to use calibrated SPFs for computing predicted crashes to compare alternatives or to use in an economic analysis. Non-calibrated SPFs may overestimate or underestimate the predicted crash frequency, but provide a reasonable estimate of the percent difference in crashes among alternatives.

Table 4. Summary of Predicted Annual Crashes ($N_{Predicted}$) by Segment

Segment	Existing Conditions	Original Proposed Design	VE Proposed Design[1]
1	0.188	0.075	0.075
2	0.203	0.100	0.100
3	0.054	0.225	0.071
4	0.189	0.178	0.144 / 0.186
5	0.053	0.103	0.122
6	0.291	0.037	0.037
7	0.148	0.253	0.253
8	0.428	0.125	0.125
9	0.052	0.202	0.202
10	0.158	0.133	0.133
11	0.706	0.042	0.042
12	0.204	0.073	0.073
13	0.364	0.123	0.123
14	0.215	0.180	0.180
15	0.477	0.056	0.056
16	0.310	0.084	0.084
17	0.193	0.038	0.038
18	0.153	0.089	0.089
19	0.101	0.036	0.036
20	0.140	0.069	0.069
21	0.074	0.240	0.240
22	0.098	0.048	0.048
23	0.431	0.023	0.023
Total	**5.228**	**2.532**	**2.549**

[1] For segment 4, the VE proposed design would include a compound curve with two different radii rather than a single curve as in the existing and original proposed designs. As such, the predicted crashes for both curves within the compound curve are shown for the VE proposed design.

Based on the above calculations, the two alternative designs are predicted to perform better than the existing conditions with respect to safety. Specifically, the proposed alternatives are predicted to reduce total crashes by nearly 2.7 crashes per year, a 48 percent reduction, compared to existing conditions. The VE proposed design provides added value compared to the original proposed design by reducing project costs. Therefore, the VE proposed design is predicted to provide a similar level of safety to the original proposed design at a reduced cost.

MoDOT employs Microsoft Excel spreadsheets to assist with the computations. The spreadsheets can be used to estimate predicted crashes when the observed crash history is not available or applicable. When the observed crash history is available and applicable, the spreadsheets can be used to estimate the expected crashes using the Empirical Bayes method. Similar spreadsheets are available at: www.highwaysafetymanual.org. For more information about the case study, please contact Ashley Reinkemeyer, MoDOT; Senior Traffic Studies Specialist; 573-751-3728; Ashley.Reinkemeyer@modot.mo.gov.

It is possible to conduct additional analyses to predict the number of crashes by crash type and severity using Part C of the Highway Safety Manual.

It may be possible to employ the Empirical Bayes method to increase the reliability of the results. The Empirical Bayes method combines the observed crash history for the location of interest with the predicted crashes from an applicable SPF. The Empirical Bayes method is preferred when observed crash data are available and applicable.

Summary of Findings

SPFs can be used to predict crashes for baseline conditions and CMFs can be applied to adjust the baseline estimate to reflect specific conditions of interest. This is useful for quantifying and comparing the safety performance of scenarios with different design features and can aid in the decision-making process. Specifically, this approach can help an agency to better understand the potential safety impacts of individual design elements and changes proposed as part of a VE study when safety is a project factor and crash frequency and/or severity is the performance measure. In this case, Southeast District of MoDOT used the *Predicted Crash Frequency with CMF Adjustment* in order to quantify the safety impacts of road widening in conjunction with horizontal realignment, centerline rumble strips, and roadside improvements. Two alternative alignments (original proposed design and VE proposed design) were compared to the existing conditions. While the two alternative designs provide nearly identical levels of safety based on total predicted crashes, the VE proposed design would reduce project costs. The use of the *Predicted Crash Frequency with CMF Adjustment* demonstrated that the proposed improvements could result in a substantial reduction in crashes compared to existing conditions. It also showed that the VE proposed design would provide a similar level of safety to the original proposed design while providing additional benefits. Recall that non-calibrated SPFs may overestimate or underestimate the predicted crash frequency, but provide a reasonable estimate of the percent difference in crashes among alternatives. As such, it is desirable to use a calibrated SPF if it is necessary to estimate the change in predicted crash frequency or conduct a formal economic analysis.

OVERCOMING POTENTIAL CHALLENGES

Potential challenges may arise when quantifying safety in the VE process. Some are directly related to limitations in the progress of safety research, while others apply to a lack of training. General challenges related to limitations in the progress of safety research include availability of CMFs, applicability of CMFs, and estimating the effects of multiple treatments. Specific challenges related to the integration of safety in the VE process include insufficient expertise (i.e., understanding how to select and apply appropriate methods), scheduling and coordination with safety experts, and complex scenarios.

Availability of CMFs

A general challenge is the availability of CMFs for specific design elements or mitigation measures. The CMF Clearinghouse *(6)* 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 following table provides a summary of the design elements and mitigation measures for which the safety impacts can be assessed using the predictive method and CMFs in Part C of the HSM. Other CMFs are available in the CMF Clearinghouse *(6)* and recently completed research studies such as NCHRP Project 17-45 *(8)*. Additional research is underway to develop CMFs for other design elements and facility types where CMFs are currently unavailable. For example, NCHRP Project 17-53, *Evaluation of the 13 Controlling Criteria for Geometric Design*, is developing CMFs to help fill-in current gaps for several of the priority design criteria.

The CMF Clearinghouse *(6)* 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.

Design Element	Rural 2-Lane	Rural Multilane	Urban/Suburban Arterials
Segments			
Lane Width	•	•	
Shoulder Width	•	•	
Shoulder Type	•	•	
Horizontal Alignment	•		
Vertical Alignment	•		
Driveway Density	•		
Centerline Rumble Strips	•		
Passing Lanes	•		
Short Four-Lane Section	•		
Two-Way Left-Turn Lane	•		
Roadside Hazard Rating	•		
Lighting	•	•	•
Automated Speed Enforcement	•	•	•
Median Type		•	•
Median Width		•	•
Side Slopes		•	
On-Street Parking			•
Number of Lanes			•
Roadside Fixed-Objects			•
Intersections			
Number of Intersection Legs	•	•	•
Traffic Control Type	•	•	•
Intersection Skew Angle	•	•	
Left-Turn Lanes	•	•	•
Right-Turn Lanes	•	•	•
Lighting	•	•	•
Left-Turn Phasing			•
Right-Turn on Red			•
Red Light Cameras			•
Bus Stops			•
Schools			•
Alcohol Sales Establishments			•

Applicability of CMFs

CMFs are developed based on a sample of sites with specific conditions. While a CMF may be available for a given design element, it may not be appropriate for the scenario of interest. For example, there may be significant differences between the characteristics of a study site and the sites used to develop the CMF (e.g., different area type, number of lanes, or traffic volume). The HSM *(4)* and CMF Clearinghouse *(6)* provide information to help users identify the applicability of CMFs.

A related challenge may be that multiple CMFs exist for the same design element and conditions. This is particularly challenging when multiple studies have estimated CMFs for the same feature 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 situations 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 anticipated 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 *(6)* 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 *(4)* and posted on the CMF Clearinghouse *(6)*. 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 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 *(9, 10)*.

Insufficient Expertise

A specific challenge for the VE team could be that there is insufficient expertise within the team to identify and apply appropriate methods to quantify safety impacts. The HSM and related resources are relatively new tools. As such, they have only recently gained popularity among transportation professionals and their use has been mostly limited to applications within the roadway safety management process. There are a number of opportunities to integrate safety analysis in other aspects of the project development process (e.g., VE process), but it may be necessary to solicit input or assistance from those who are more familiar with these methods. If the VE team does not have the requisite expertise, then they can solicit outside expertise from the State Highway Safety Engineer (or equivalent), FHWA Division Office, or consultants for further guidance and assistance with the selection and/or application of CMF-related methods and interpretation of results. The National Highway Institute also offers several courses related

Contact information for the FHWA field offices is available at: http://www.fhwa.dot.gov/about/field.cfm.

to the quantification of safety using CMFs, including the Application of CMFs (#380093) and Science of CMFs (#380094).

Scheduling and Coordination

The VE process is typically completed within one week. If the VE 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. Three options are provided to help overcome this potential issue.

Option 1: Include a safety expert on the VE team. If it is necessary to conduct a detailed safety analysis (i.e., applying CMF-related methods), and this is recognized in advance of the VE study, then it may be useful to include an experienced CMF user or safety analyst as a member of the VE team.

Option 2: Coordinate with a road safety audit (RSA) team. The FHWA defines an RSA as a "formal safety performance evaluation of an existing or future road or intersection by an independent, multidisciplinary team" *(13)*. RSAs can be used to evaluate road safety issues and identify opportunities for improvement on any type of facility during any stage of the project development process.

Many aspects of the RSA and VE processes are similar, and the RSA team generally includes a member with safety analysis experience. Under this option, an RSA could be conducted in coordination with the VE study to identify specific safety issues and develop suggestions for consideration by the VE team. The RSA team (or individual with safety analysis experience) could then join the VE team or provide safety-related support, including the selection and/or application of appropriate methods to quantify safety impacts. For more information on RSAs and their link to VE studies, refer to the FHWA Road Safety Audit Guidelines *(13)*.

Option 3: Coordinate with a safety engineer. A safety engineer could be contacted prior to the VE study to communicate the timeframe of the study and identify the level of assistance that may be needed. This way, the safety engineer can be prepared to conduct the necessary analysis within the timeframe of the VE study.

Complex Scenarios

Another potential challenge is that certain methods (i.e., *Relative Comparison of CMFs*) are not appropriate to analyze complex scenarios. For example, a relative comparison of CMFs may not be appropriate when there are significant differences among the alternatives (e.g., different area type, number of lanes, and/or traffic volume). In these cases, it would be necessary to apply more rigorous methods to estimate the safety performance for each scenario separately. A decision-support table is provided in the section titled: *Selecting an Appropriate Method*, to help users identify an appropriate method for quantifying safety impacts. For more information on predictive methods, refer to Part C of the HSM *(4)* and related documentation, Integrating the HSM into the Highway Project Development Process *(5)*.

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For More Information:

For more information about CMFs or the CMFs in Practice series, contact Karen Scurry, FHWA Office of Safety, karen.scurry@dot.gov, 609-637-4207.

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