Crash Modification Factor Recommendation List

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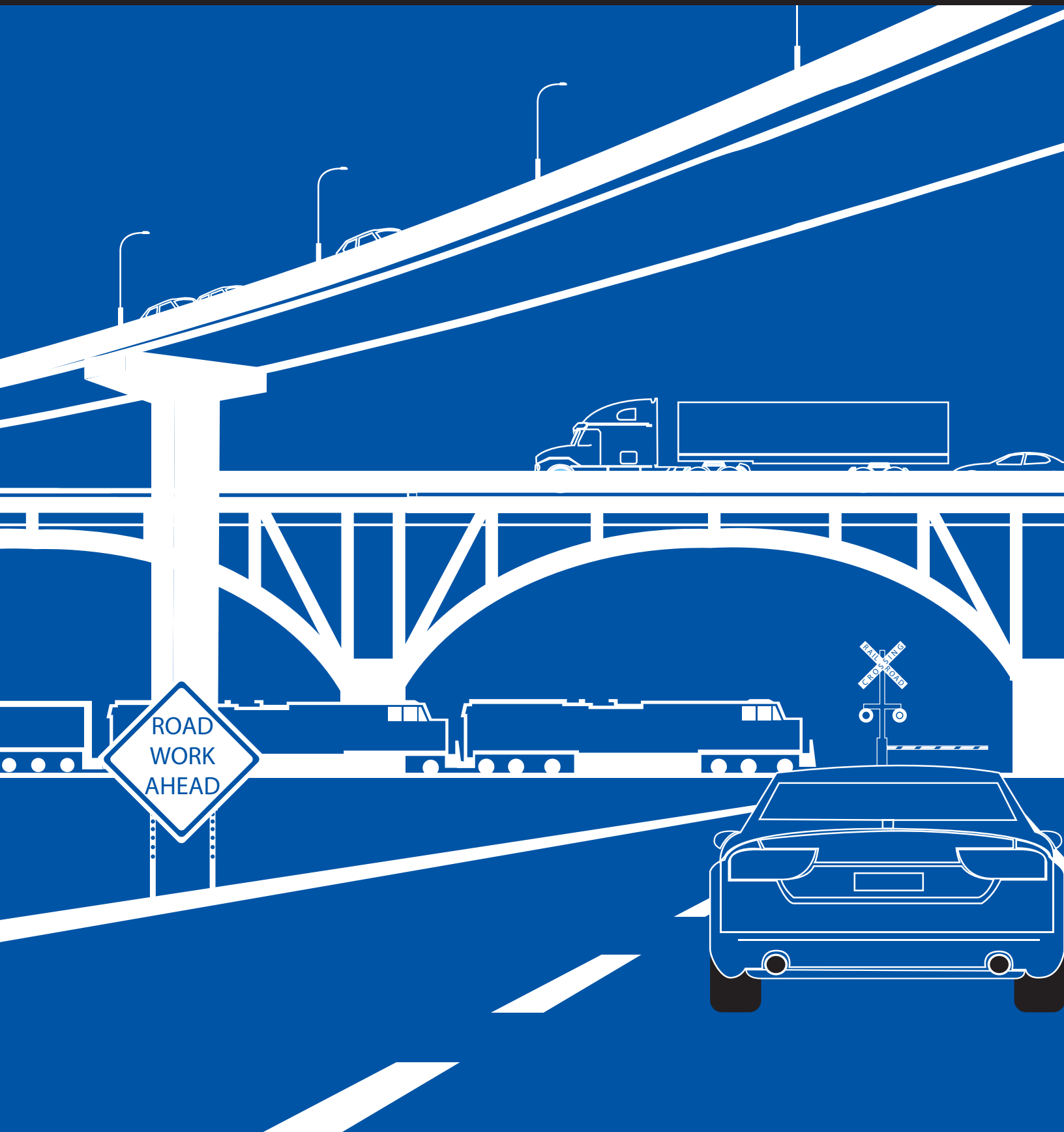

Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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University of Kentucky

Research Report
KTC-20-22/SPR19-578-1F

Crash Modification Factor Recommendation List

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16. Abstract

Practitioners use Crash Modification Factors/Functions (CMFs) to calculate the number of crashes expected once a countermeasure has been implemented. When evaluating design alternatives, CMFs can be used in conjunction with safety performance functions (SPFs) to derive crash predictions. The Federal Highway Administration (FHWA) maintains the CMF Clearinghouse as a repository for CMFs. Contributions are submitted by researchers across the U.S., Canada, and throughout the world. Typically, multiple CMFs are associated with a single countermeasure. Some CMFs only apply to specific facility or crash types. Furthermore, CMF quality varies, and some only apply to specific facility and/or crash types, regions, or times. Using the Clearinghouse to identify an appropriate CMF for a given situation demands considerable time and significant expertise. This report describes the development and implementation of a spreadsheet-based tool that Kentucky Transportation Cabinet staff and the agency's design consultants can use to select CMFs most appropriate for the state's highways and conditions. Guidance instructs users on use of the tool. A web-based form was also developed, which must be filled out and submitted to KYTC's CMF committee when a CMF is planned for use on a project.

17. Key Words Crash Modification Factors, CMF Clearinghouse, selection tool, countermeasures		**18. Distribution Statement** Unlimited	
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Table of Contents

List of Tables

Chapter 1 Introduction

Practitioners use Crash Modification Factors/Functions (CMFs) to calculate the number of crashes expected once a countermeasure has been implemented. When transportation agency personnel evaluate design alternatives, they can use CMFs along with safety performance functions (SPFs) to generate crash predictions. A primary source of CMFs is the Federal Highway Administration's (FHWA) CMF Clearinghouse. It includes contributions from researchers located in the U.S., Canada, and throughout the world. Most countermeasures have multiple CMFs associated with them. CMF quality varies, and some only apply to specific facility and/or crash types, regions, or times. Identifying an appropriate CMF through the Clearinghouse demands considerable time and significant expertise.

This report describes a spreadsheet-based tool developed by our team of Kentucky Transportation Center (KTC) researchers which helps practitioners select appropriate CMFs. We designed the tool so it can readily be expanded and modified to accommodate the Kentucky Transportation Cabinet's (KYTC) future needs. It has also been tailored to address countermeasures most frequently used for Kentucky highways and conditions. Chapter 4 instructs users on how to navigate and use the tool. Another product of this research is a web-based form that must be filled out and submitted to KYTC's CMF committee when a CMF is planned for use on a project.

Chapter 2 Literature Review

2.1 National

According to the FHWA, "A crash modification factor (CMF) estimates a safety countermeasure's ability to reduce crashes and crash severity" (FHWA 2017). Transportation officials frequently use CMFs when conducting benefit-cost analyses to identify countermeasures that will confer the greatest safety benefit. Typically, multiple CMFs are associated a single countermeasure because countermeasure effectiveness varies based on roadway attributes (e.g., number of lanes, median type, setting). While CMFs are often conflated with crash reduction factors (CRFs), they are distinct — albeit mathematically related — concepts. Equation 1 indicates their relationship.

$$CRF = (1\text{-}CMF)*100 \quad \text{(Equation 1)}$$

In many cases, a CMFunction is used to calculate a countermeasure's safety benefit. CMFunctions are equations used to compute a CMF based on the characteristics of the site where the countermeasure will be installed. They are often applied when countermeasures are intended to bring about incremental changes (e.g., increasing retroreflectivity of striping by a certain amount, increasing lane width).

Countermeasure safety benefits may be contingent on weather condition, time of day, crash type, or other attributes/ situations. These factors must be considered when selecting countermeasures. Fortunately, resources are available that compile and categorize CMFs, including the *Highway Safety Manual* (HSM) and *Desktop Reference for Crash Reduction Factors*. Most CMFs are sourced from the FHWA's CMF Clearinghouse, which houses thousands of categorized CMFs and provides great detail on each and links to or cites original source documents. Even though the CMF Clearinghouse has excellent search tools, selecting from over 7,400 CMFs is a daunting task for practitioners. Some state transportation agencies narrow CMFs to a predefined list for suggested use on agency projects.

2.2 Variation in State Practices

Agencies organize their CMFs lists differently. Typically, they classify CMFs according to crash type, benefit-cost ratio, jurisdiction, functional class, design type, quality rating, appropriateness for project funding source, or some other factor. We reviewed practices at seven agencies to develop a CMF short list for Kentucky. Our review did not proceed in a specific order, and documentation was for the most part available publicly online. Previous efforts have resulted in CMF lists for Kentucky. In 2018, the firm VHB produced a list of 94 CMFs that can be used in the state for planning purposes. KTC researchers also developed a list that associated CRFs with types of highway improvement (Agent et al. 1996).

The Oregon Department of Transportation (DOT) categorizes its CMFs by countermeasure. Countermeasures fall into two categories: 1) those eligible for *hotspot* funding, and 2) those eligible for *systemic* or *hotspot* funding. The systemic categories are subdivided further, but for informational purposes only. Oregon's list catalogues all relevant information about each countermeasure on an individual page. It references the CMF Clearinghouse, HSM, and the older FHWA *Desktop Reference for CMFs* (McDaniel-Wilson 2018).

The Washington DOT maintains a *CMF Short List* which divides up countermeasures in a manner similar to the CMF Clearinghouse (the only reference cited). Multiple CMFs are displayed for each countermeasure and provide all relevant information that would be found in the Clearinghouse. Before any countermeasure is added to the list, an engineer must fill out a CMF Review Form, after which it is reviewed by a committee. The CMF Short List is not comprehensive and users are free to explore CMFs from external sources (e.g., FHWA *Desktop Reference*, HSM) (WSDOT Crash Modification Factor (CMF) "Short List" 2015)

The North Carolina DOT established a Crash Reduction Factor Committee (CRFC) that oversees maintenance of the agency's CMF short list and votes on adding new CMFs to the list. For countermeasures with multiple CMFs, the committee is most likely to select the CMF with the highest star rating and lowest standard error. The CRFC is also responsible for using values not catalogued in the CMF Clearinghouse, where a CMF is calculated in-house using the state's crash data and project history until proper research is conducted. To evaluate a countermeasure, a before/after

Empirical Bayes analysis is conducted on similar projects in the state and a typical benefit-cost analysis is performed. Consult Smith and Scopatz (2016) for specific examples.

The Wisconsin DOT has developed a simple table of CMFs organized by countermeasure in an Excel-based tool. Users can apply filters to countermeasure categories to find the needed countermeasure. Similar to Washington's CMF Short List, the table mostly contains information found in the CMF Clearinghouse and notes when to properly consider each factor. Wisconsin only includes CMFs for countermeasures commonly used in the state. If more than one CMF is linked to a countermeasure, the most appropriate CMF is selected by matching the CMF's characteristics to the roadway and crash characteristics of the most common sites being evaluated (Wisconsin DOT 2005).

The Florida DOT has implemented a method automate updates to existing CRFs as new improvement projects become available. The agency developed a web-based application known as the Crash Reduction Analysis System Hub (CRASH), which records all safety improvement projects throughout the state and updates CRFs using a before/after analysis of Florida-specific crash data. This system can also carry out benefit-cost analysis to evaluate projects. When the agency began its efforts to manage CRFs, staff compiled a literature review that summarized best practices being used in each state (Gan et al. 2005).

The Pennsylvania DOT prepared a document that discusses the proper use of CMFs, outlines methods for integrating CMFs into safety plan, and which served as a first draft of CMFs relevant to the state. Additionally, the document presents a training protocol which instructs staff on the proper use of CMFs. Only high-quality CMFs were considered for the document, which were selected based on criteria such as star rating and standard error (Donnell and Gayah 2014). Later, the agency narrowed search criteria for CMFs. The Pennsylvania DOT first developed state-specific SPFs for rural two-lane roads and then modified the CMF list accordingly. The agency gave priority to CMFs in the FHWA Clearinghouse the rely on data unique to Pennsylvania and other states with similar characteristics. If no CMF was available that met agency-set criteria, alternative CMFs with 5-star ratings were substituted. If more than one CMF had a 5-star rating, stakeholders reviewed each in the Clearinghouse (Scopatz and Smith 2016).

Chapter 3 Identification of Countermeasures

To evaluate Kentucky's CMF needs, our research team held two meetings to gather feedback from engineers throughout the state. The first of these took place as part of a presentation at the 2018 KYTC Partnering Conference. At the conference, our presentation discussed the prospect of compiling a Kentucky-specific list of CMFs that would be used as a standard for all design and planning projects across the state. Attendees, which included engineers from KYTC and highway design consultants, were receptive to this idea. During the presentation, we administered a brief survey consisting of the following questions:

- Have you used CMFs in the past for any design projects?
  - If so, which countermeasures did you need CMFs for and what was your process for selecting the CMFs?
- Please list the most common safety countermeasures you use in Kentucky transportation designs that would benefit from a standardized CMF (e.g., increasing lane widths, high friction surface treatments, increased signage).
- What is the format of your ideal CMF database — Excel, online tool, other?

Survey responses helped guide our efforts identify CMF needs for selected countermeasures.

Wanting to capture as many of the state's CMF needs as possible from the outset of list development, we held a workshop with experienced KYTC engineers from the Divisions of Planning, Design, and Traffic Operations in the Cabinet's Central Office as well as several engineers from district offices. These engineers were familiar with countermeasures used most often in Kentucky and had a vision for future countermeasures the state would like to implement on the roadway system. After identifying a pool of safety countermeasures, our team asked the group to rate the importance of each countermeasure for creating a prioritized list of safety countermeasures that could be used to develop the Kentucky-specific CMF list. Table 3.1 presents these results (1 is highest priority, 4 is lowest).

Table 0.1 Prioritized list of Kentucky Safety Countermeasure CMF Needs

Rank	Countermeasure	Rating	Rank	Countermeasure	Rating
1	Intersection Improvement	1.27	21	High friction Curves	2.60
2	Striping	1.36	22	Sidewalk	2.60
3	Guardrail	1.40	23	Positive turn lane offsets	2.64
4	Signing	1.50	24	High friction interchange ramps	2.70
5	Shoulder widening (paved)	1.60	25	Slope improvements	2.70
6	Rumble strips	1.60	26	Interchange improvement	2.90
7	Pavement markers	1.91	27	J-Turns	2.91
8	Cable median barrier and median barrier	2.00	28	Bike Lanes	3.00
9	Curve Widening	2.09	29	Drainage structure improvements*	3.00
10	Superelevation Improvements	2.09	30	Lighting	3.10
11	Dedicated left turn lane	2.10	31	Convert intersection to roundabout	3.18
12	Lane widening/narrowing	2.10	32	High friction intersection*	3.20
13	Sight distance improvements	2.18	33	Displaced LT turn intersection*	3.30

14	Shoulder widening (earth)	2.20	34	Gates/Signals at Railroad Crossing	3.30
15	Add turn lane	2.20	35	Road diet	3.40
16	High friction	2.30	36	2 + 1	3.50
17	Improve clear zone	2.30	37	Shared Use Path	3.60
18	Culvert extensions*	2.50	38	Transit turnouts*	3.80
19	Curve Flattening	2.55	39	Intersection grade separation	3.80
20	Improve access management	2.55	40	Improve passing opportunities	4.00

After the workshop, several engineers from the group gave us documents from recent KYTC projects on which some of the countermeasures listed in Table 1 had been implemented. This project documentation offered valuable information which helped our team select appropriate CMFs based on how KYTC integrates countermeasures into practice.

* CMFs for these countermeasures are unavailable in CMF Clearinghouse.

Chapter 4 Spreadsheet Tool

4.1 Data source

We obtained CMFs from the CMF Clearinghouse for all but five of the countermeasures identified in Table 3.1. Whenever search results yielded limited or no results, we used modified keywords (e.g. *superelevation* instead of *superelevation improvements*, *curve* instead of *curve widening/flattening*). Identified CMFs were exported into Microsoft Excel. Spreadsheets were then reduced, modified, and formatted to make them user-friendly. Table 4.1 lists recommendations for the five countermeasures not included in the spreadsheet tool.

Table 0.1 Comments on CMFs unavailable in CMF Clearinghouse

Countermeasure	Suggested spreadsheets/Comments
High friction intersections	See "High friction" (#16)
Culvert extensions	See "Improve clear zone (#17)
Drainage structure improvements	Unavailable in CMF Clearinghouse
Transit turnouts	Unavailable in CMF Clearinghouse
Displaced LT turn intersection	Unavailable (In CMF Clearinghouse's most wanted list)

4.2 Organization and Methodology

In their native format, each spreadsheet downloaded from the CMF Clearinghouse had 59 columns (Appendix A1). After the spreadsheets were imported into Excel workbooks, material was organized into three worksheets:

- **CMF_Filters**: A filterable worksheet used to search for CMFs. We modified this sheet and it contains limited information of the CMFs.
- **All Information:** A worksheet that contains all information directly imported from the CMF Clearinghouse. Users may consult this when they need detailed information on a CMF.
- **Non-US CMF:** A worksheet that compiles CMFs developed using data from outside the United States. This worksheet is not available for some workbooks.

We modified the *CMF_Filters* worksheets as follows:

- ***Deleting Rows***
  - We deleted irrelevant records or duplicate CMFs from other countermeasures. CMFs developed using non-US data were moved to a different worksheet and deleted from the *CMF_Filters* sheet. For example, the *Lane Widening* countermeasure had CMFs for increasing bike lane widths. As there is a separate countermeasure for *Bike Lanes*, those CMFs were deleted from the *Lane Widening* worksheet.

- ***Adding New Columns***
  - ***Countermeasure Group and Countermeasure Sub-Group***
    The countermeasure column is now split into two columns — *Countermeasure Group* and *Countermeasure Sub-Group* — to improve searchability. The *Countermeasure Group* column contains generalized countermeasures, whereas the *Countermeasure Sub-Group* under each general countermeasure contains more specific information. Table 4.2 provides an example from *Dedicated Left-Turn Lanes*.

Table 0.2 Example from Dedicated Left-Turn Lanes

Countermeasure Group	Countermeasure Sub-Group
Two-way left-turn lanes (TWLTL)	Add TWLTL
	Replace TWLTL with a raised median
Channelization	Painted channelization of both major and minor roads
	Introduce raised/curb left-turn channelization

- ***Comments***
  Information from the *Public Comments* and *Prior Condition* columns are now merged into one column — labeled *Comments* — and summarized for convenience of the user.
- ***Additional Information***
  This column links to detailed information on a CMF. Links are connected to the *All Information* tab. Users wanting to learn more about the CMF and its origin should refer to this tab.

- ***Deleting columns***
  - We selected columns most relevant for choosing CMFs. We deleted the remaining columns from the *CMF_Filters* worksheet to reduce clutter and allow focus.

- ***Columns remaining***
  - The final *CMF_Filters* sheet has 21 columns (see Appendix A2). Columns are divided into color-coded subcategories (Table 4.3).

Table 0.3 Columns in *CMF Filters*

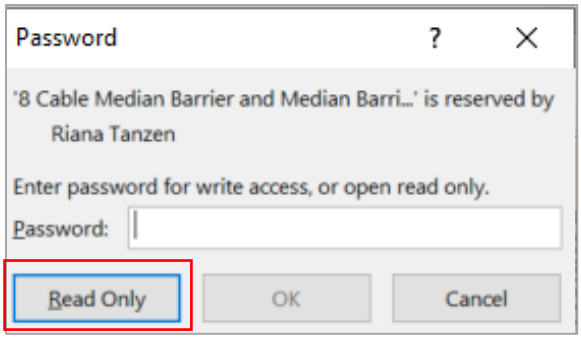
Primary Deciders	Secondary Deciders	Others
• Countermeasure group/ Precondition • Countermeasure sub-group/Postcondition • Crash type • Crash severity • Roadway type • Area type • Star quality rating • Standard error • CMF	• State • Intersection related • Average ADT (non-intersection) • Average major road ADT • Average minor road ADT • No of lanes • Intersection geometry • Roadway division type • Traffic control type • CMF ID	• Comments • Additional information

4.3 User Guide

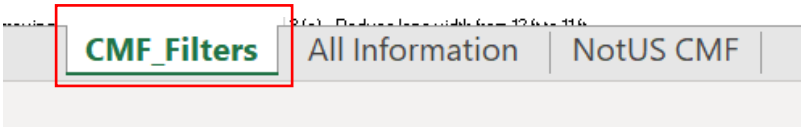
What follows are some guidelines which can help users chose appropriate CMFs from any of the worksheets described above.

4.3.1 Applying Filters

1. To open a workbook, double click the file name and select *Read Only*.



2. Activate the *CMF_Filters* worksheet by clicking on the *CMF_Filters* tab.



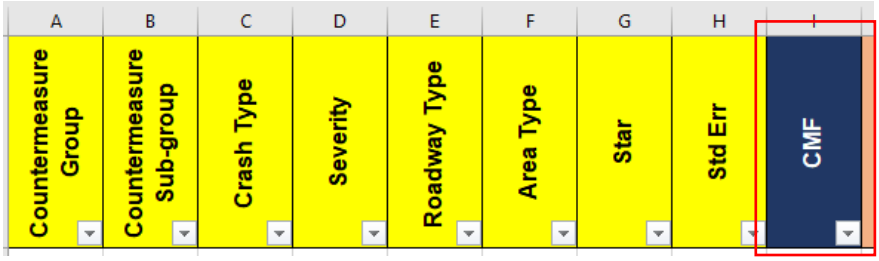
3. Each worksheet has columns labeled A-U. The following image denotes the color codes for the columns:

A-H	Primary Deciders
J-S	Secondary Deciders
I	CMF
T	Comments
U	Additional Information

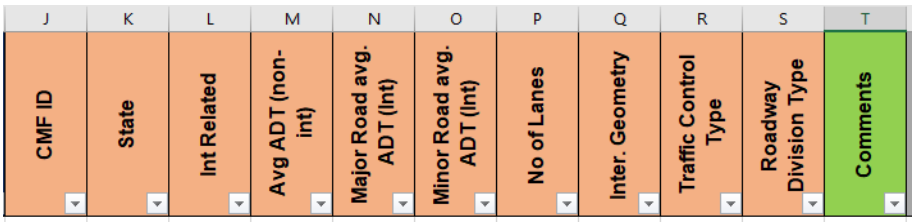
   a. Select a Countermeasure *Group/Precondition* (Column A) from the drop-down menu.
   b. Next, select a *Countermeasure Sub-Group/Postcondition* (Column B).
   c. Select the required *Crash Type* (Column C), *Severity* (Column D), *Roadway Type* (Column E), and *Area Type* (Column F).
      - For these columns, we recommend first applying the filter to the column which is most essential according to user requirements. Once that filter has been applied, move through the remaining columns and apply additional filters until a reasonable number of CMF options remain.

4. Filtering the first six columns (A-F) will narrow down the dataset. Choose the CMF with the highest star rating (*Star*, Column G) and lowest standard error (*Std. Err*, Column H) unless it provides too few options based on the other specified criteria.

5. Column I lists the CMFs which meet the search criteria.



6. Use Columns K-S (shaded orange) as secondary deciders (if needed). Even if the user declines to filter using these criteria, they be aware of limitations that may affect the chosen CMF's applicability to the project.

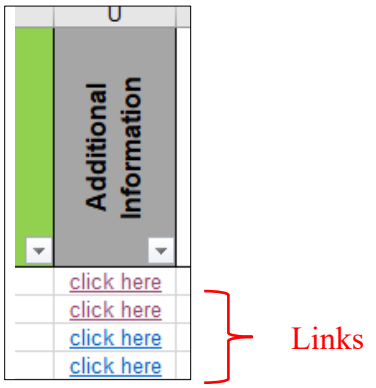


7. Read through the comments (Column T) before choosing a CMF.

8. If no choice remains after applying all filters and criteria (Deciders), relax some of the filter conditions or criteria and try again.

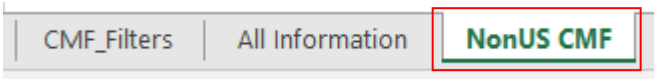
4.3.2 Additional Information

1. If a user wants more details on a CMF (e.g., source, study parameters, prior condition), they should look at Column U (*Additional Information*). Clicking on this link takes the user to the *All Information* tab, Column A (*CMF ID*). CMF IDs can be found in the *CMF_Filters* tab, Column J.



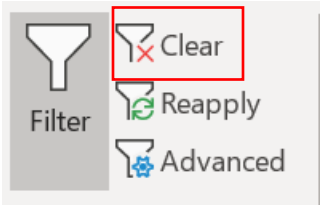
4.3.3 Non-US CMF

1. Sometimes CMFs derived from studies based outside the US are available. In general, we do not recommend using them. However, if the user cannot find a CMF befitting their situation, they can try searching in the *Non-US CMF* worksheet (not available in all workbooks).



4.3.4 New Search

1. Always clear *Filters* (located on Excel's Data tab) before starting any new search. Then, repeat the steps listed above.



Chapter 5 Approval Process

KYTC has formed a committee that is responsible for approving CMFs for use on both internal and consultant-led projects. If a CMF is needed on a project, the engineer/analyst/designer should fill out the form in Appendix B and submit it to the committee for approval. The form should note which filters were applied in the CMF selection tool. If a CMF is selected for the project that did not appear on the list of CMFs after the filters had been applied, the form should explain why the CMF has been chosen — irrespective of whether it is sourced from the CMF Clearinghouse or elsewhere.

5.1 Future work

Future work should focus on implementing the form and spreadsheet tools in an online system. Our research team has begun preliminary work on such a system.

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12. WSDOT Crash Modification Factor (CMF) "Short List." WSDOT, June 2015.

Appendix A: Spreadsheet Tool

Table A1 List of columns in the spreadsheet extracted from CMF Clearinghouse.

CMF ID	Before Sample Size Crashes
Study Title	After Sample Size Crashes
Countermeasure Category	Sample Size Mile Years
Countermeasure Subcategory	Before Sample Size Mile Years
Countermeasure	After Sample Size Mile Years
Countermeasure Group	Sample Size Site Years
Countermeasure Sub-group	Before Sample Size Site Years
CRF	After Sample Size Site Years
CMF	Begin Year of Data
Crash Type	End Year of Data
KABCO Crash Severity	Intersection Related
Roadway Type	Traffic Volume Unit
Area Type	Minimum Traffic Volume (non-intersection)
Publication Year	Maximum Traffic Volume (non-intersection)
Star Quality Rating	Average Traffic Volume (non-intersection)
Prior Condition	Minimum Major Road Traffic Volume (intersection)
Adjusted Standard Error of CRF	Maximum Major Road Traffic Volume (intersection)
Unadjusted Standard Error of CRF	Average Major Road Traffic Volume (intersection)
Adjusted Standard Error of CMF	Minimum Minor Road Traffic Volume (intersection)
Unadjusted Standard Error of CMF	Maximum Minor Road Traffic Volume (intersection)
Included in First Edition of Highway Safety Manual	Average Minor Road Traffic Volume (intersection)
Type of Study Methodology	Number of Lanes
State	Intersection Type
Municipality	Intersection Geometry
Sample Size Sites	Traffic Control Type
Before Sample Size Sites	Speed Limit (mph)
After Sample Size Sites	Crash Time of Day
Sample Size Miles	Roadway Division Type
Before Sample Size Miles	Date CMF Added to Clearinghouse
After Sample Size Miles	Public Comments
Sample Size Crashes	

Table A2 Spreadsheet tool filters (first tab in worksheets)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Countermeasure Group	Countermeasure Sub-group	Crash Type	Severity	Roadway Type	Area Type	Star	Std Err	CMF	CMF ID	State	Int Related	Avg ADT (non-int)	Major Road avg. ADT (Int)	Minor Road avg. ADT (Int)	No of Lanes	Inter. Geometry	Traffic Control Type	Roadway Division Type	Comments	Additional Information

APPENDIX B: APPROVAL FORM

KYTC CMF Review Form

Countermeasure description: Click or tap here to enter text.
Number of CMFs in Clearinghouse: Click or tap here to enter text.
Date Reviewed in Clearinghouse: Click or tap to enter a date.
Reviewed by:
NAME:
TITLE:
EMAIL:

Information from the clearinghouse may be copy-pasted into the following table

In list	CMF	CRF (%)	Quality (Star Rating)	Crash Type	Crash Severity	Area Type	Reference	Comments
1								
2								
3								
4								
5								

Please justify the selection: Why were these CMFs selected for the project?

CMF List #	Reason for selection
1	Click or tap here to enter text.
2	Click or tap here to enter text.
3	Click or tap here to enter text.
4	Click or tap here to enter text.
5	Click or tap here to enter text.

Project Notes: Please provide details on the project for which these CMFs were selected

County	
Area Type	
Facility Type	
Route	
Beginning MP	
Ending MP	
Brief Project Description	

Typical countermeasure cost: Please include a typical cost of the countermeasure being implemented. Multiple bullets are for a higher level of detail and are not necessary.

- COUNTERMEASURE ELEMENT $00000.00 Accuracy: Choose an item.
- COUNTERMEASURE ELEMENT $00000.00 Accuracy: Choose an item.
- COUNTERMEASURE ELEMENT $00000.00 Accuracy: Choose an item.

Appropriate application notes: Please cite the most recent edition of KYTC Specifications along with relevant sections for installation of the countermeasure.
Click or tap here to enter text.

Intersection related CMFs (If applicable): In some circumstances, a CMF may be vastly different when applied to intersections, thus, if the information is available, please attempt to fill out this template to the best of your ability.

Intersection Type	Crash Type				
	Choose an item.	Choose an item.	Choose an item.	Choose an item.	Choose an item.
All					
Signal 3-leg					
Stop 3-leg					
Yield 3-leg					
Signal 4-leg					
Stop 4-leg					
Yield 4-leg					

Additional Circumstances where CMFs are invalid: Describe practices in which these CMFs should not apply so as to clear up any confusion. For example, please note whether the countermeasure is installing or removing infrastructure such as guardrail.
Click or tap here to enter text.

References: Please cite all documents that were reviewed while analyzing the CMFs for this countermeasure. This may include the clearinghouse, the study from which the CMFs were developed, past projects, etc.
Click or tap here to enter text.