

Development of Crash Modification Factors for Combined Treatments on Rural Two-lane Roads

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More than half (57 percent) of U.S. traffic fatalities occur after a driver crosses the edge or centerline of a roadway, among which two-thirds occur in rural areas (FHWA, 2015). Rumble strips (and rumble stripes) have been proven to be an effective means of reducing run-off-the-road crashes. They are primarily used to warn drivers when they have drifted from their lane. Wide paved shoulders and high friction surface treatment are also effective countermeasures for deterring run-off-the-road crashes.

In order to improve upon the safety performance of rural two-lane highways, the Missouri Department of Transportation (MoDOT) has deployed a combined treatment of shoulder rumble stripes, shoulder widening from no shoulder to 2 foot shoulder width and pavement resurfacing (combined RS-SW-PR treatment) to over 400 centerline miles of roadway segments within its jurisdiction. In an effort to objectively evaluate the safety performance of the treatment, MoDOT contracted with CH2M HILL to calculate the crash modification factors (CMFs) for the combined RS-SW-PR treatment for multiple designated crash severity levels and collision types.

The safety benefits for individual treatments of shoulder rumble stripes, shoulder widening, and pavement resurfacing have been documented in previous studies. However, no CMFs have been reported yet for the safety benefits these treatments in combination. Furthermore, it is not applicable to estimate the CMFs for the combined RS-SW-PR treatment by multiplying the CMFs for all individual treatments together directly since it is likely to result in an overestimation of the safety benefits.

The purpose of this technical memorandum is to document the calculation procedures and conclusions from the study. The contents of the memo include:

- Project Scope
- Data Provided by MoDOT
- CMF Development Procedure
- Study Assumptions
- Summary of Results
- Results Comparison
- Conclusions
- References

This technical memorandum is supplemented by appendices containing information about acronyms and abbreviations, and additional details on data collection and analysis assumptions. An electronic appendix will supplement the final version of this memo and contain relevant project documentation in electronic format including analysis spreadsheets.

Project Scope

The safety performance of the combined RS-SW-PR treatment for rural two-lane highway was evaluated by calculating CMFs and their standard errors utilizing an Empirical Bayesian (EB) before-after study procedure, as recommended in the Federal Highway Administration (FHWA) technical document *A Guide to Developing Quality Crash Modification Factors* (Gross et al, 2009). CMFs were calculated for multiple crash severity levels (K, A, BC, O, and their combinations) for total crashes and treatment targeted crash types including run-off-the-road and head-on (RRHO) crashes. In total, 20 CMFs and their standard errors were calculated.

No safety performance functions (SPF) were developed as part of this project. MoDOT previously calibrated the SPF for rural two-lane highways included in the Highway Safety Manual (HSM) (American Association of State Highway and Transportation Officials [AASHTO], 2010) with its jurisdiction-specific data, in a document titled *Calibration of the Highway Safety Manual for Missouri* (Sun et al, 2013). This calibrated SPF was used for calculating the predicted crash frequency. The SPF over-dispersion parameter in the HSM was used for estimating the expected crash frequency with the EB method.

Data Provided by MoDOT

MoDOT provided the following data used for calculating predicted, expected and observed crash frequency, the CMFs and standard errors in this study:

- Annual average daily traffic (AADT) for the roadway segments in the before and after periods
- Geometric characteristic data (segment length, lane width, and shoulder type) for the roadway segments
- Length and radius for the curve segments
- Grade for the roadway segments
- Driveway density (DD) and roadside hazard rating (RHR) data for the roadway segments
- Crash data for the roadway segments in the before and after periods
- Rumble stripe location and construction dates for the treatment

Descriptions of the utilization and incorporation of the MoDOT data are included in the ***Data Collection and Analysis Assumptions*** documentation in **Appendix B**. The data, which were provided electronically in ArcGIS databases and shapefiles and Microsoft Excel spreadsheets, are included in the electronic appendix with this technical memorandum.

CMF Development Procedure

The CMFs for the combined RS-SW-PR treatment were developed utilizing the steps illustrated by the flowchart in **Figure 1** and the procedures described below.

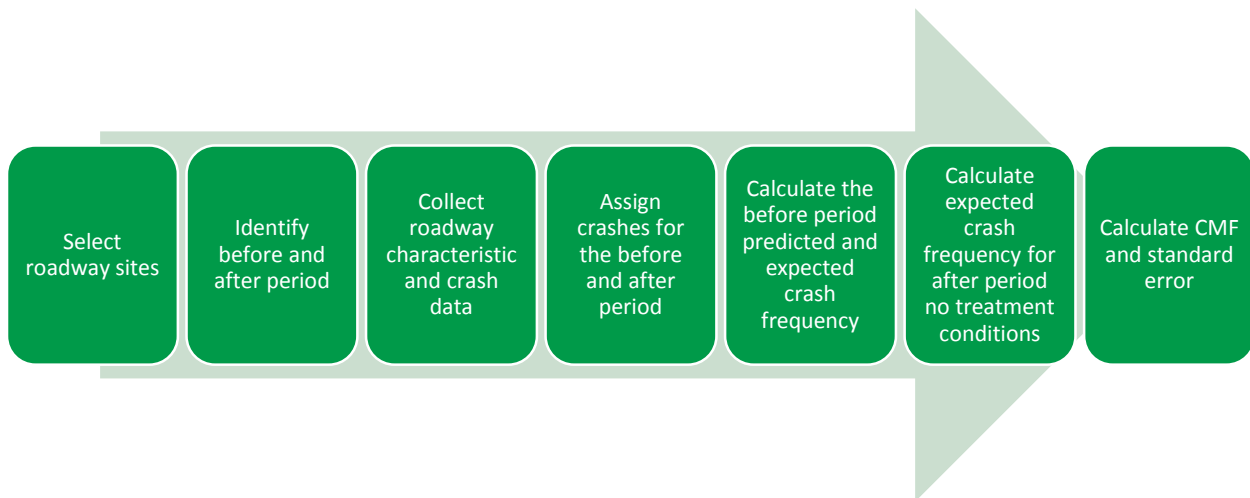


Figure 1. CMF Development Procedure Flow Chart
See below for procedure details

Step 1: Site Selection

A total of 65 rural two-lane undivided roadway segments that received the combined RS-SW-PR treatment in Missouri were considered for the study. These 65 segments were further divided into 177 homogeneous segments based on changes in lane width, shoulder width, shoulder type, grade level, etc. Four segments with lengths shorter than 0.1 mile and one segment with a relatively high AADT were excluded reducing the total number of homogeneous segments considered for the analysis to 172.

With the exclusion of the roadway segment that had a relatively high AADT of approximately 17,000 vehicles per day (VPD), the AADT range for the remaining 172 homogenous roadway segments was approximately 400 to 9,000 VPD. Given that the value of many CMFs are at least some function of AADT, the AADT range of 400 to 9,000 VPD should be considered a limiting factor when considering the applicability of the study results.

Step 2: Before and After Period Identification

For most roadway segments, the individual treatments that resulted in the combined RS-SW-PR treatment were not deployed simultaneously. To evaluate their comprehensive safety benefits, the before period was defined as time period before the earliest of the three construction dates provided in the MoDOT dataset, and the after period was defined as time period after the latest of the three construction dates provided in the MoDOT dataset. To avoid the possible impact of seasonal effects, all the before and after periods were selected on the basis of a full calendar year (from January to December).

The before and after period for each roadway segment were determined accordingly. A 3-year before period was identified for all roadway segments. Based on the final construction date, the after period for the roadway segments was identified, varying from 0 to 3 years based on available data. Available data were limited due to the provisional status of the MoDOT crash database for year 2014 and partial year 2015. With year 2013 identified as the most recent year possible in the after period, 97 roadway segments were identified as having reliable after period data. (27 roadway segments had 1 year after period crash data, 19 segments had 2 years after period crash data, and 51 segments had 3 years after period crash data.) These 97 segments were selected for this analysis. The other 75 roadway sites identified in Step 1 were excluded from the analysis since no after period crash data were available for them.

Step 3: Data Collection

To calculate the predicted and expected crash frequency for each roadway segment, data including roadway geometric characteristic data, traffic data, and crash data for the selected roadway segments were collected from different sources. Reliable data on curve superelevation variance (SV) was not available for the selected roadway segments. A SV value of less than 0.01 was applied based on HSM recommendation that a default value of less than 0.01 be applied when no SV values are available. It was also assumed that no street lighting and no automated speed enforcement were provided for the selected roadway segments based on data limitations and the fact that the selected sites are on rural facilities. *More comprehensive documentation of the assumptions made during the analysis is presented below in the **Study Assumptions** section and further detailed in **Appendix B** of this technical memorandum.*

Step 4: Before and After Period Observed Crash Assignment

Crash data for the roadway segments from 2000 to 2015 were provided by the MoDOT from their Transportation Management System (TMS). For each roadway segment, the number of crashes for the before and after period were counted separately. To calculate the CMFs for the study crash severity levels and collision types (K, A, BC, O, and their combinations for total crashes and RRHO crashes), the crashes for the before and after period were categorized by crash severity level and collision type.

Note: The before period observed crash assignment is utilized in the before period expected crash frequency calculation in Step 5. The after period observed crash assignment is utilized in the CMF calculation in Step 7.

Step 5: Calculation of Before Period Predicted and Expected Crash Frequency

For each roadway segment, the predicted crash frequency in the before period was calculated with the crash predictive models included in the HSM Chapter 10 (AASHTO, 2010). The predicted crash frequency under base conditions was calculated first using the segment length and AADT in Equation 10-6. All applicable CMFs were calculated to account for the non-base and base conditions for the sites. The predicted crash frequency for the roadway segment was determined by multiplying the predicted crash frequency under base conditions with all the applicable CMFs and the SPF local calibration factor.

Table 1 lists all the CMFs calculated in this study for the roadway sites' non-base and base conditions.

Table 1. CMFs Calculated for Predicted Crash Frequency Calculation

CMF Name	CMF Description	Base Condition	Source of Data Used in Analysis
CMF_{1r}	CMF for lane width	12 feet	MoDOT roadway segment data (GIS)
CMF_{2r}	CMF for shoulder width and type	6-foot paved shoulder	MoDOT roadway segment data (GIS)
CMF_{3r}	CMF for horizontal curve	Tangent roadway segment	MoDOT roadway curve data (GIS)
CMF_{4r}	CMF for horizontal curve SV	SV of less than 0.01	HSM default value for base condition
CMF_{5r}	CMF for grade	Level roadway	MoDOT roadway grade data (GIS)
CMF_{6r}	CMF for driveway density	Five driveways per mile	MoDOT database (Excel spreadsheet)
CMF_{7r}	CMF for centerline rumble strips	No centerline rumble strips	HSM default value for base condition
CMF_{8r}	CMF for passing lanes	No passing lanes	HSM default value for base condition

CMF_{9r}	CMF for two-way left-turn lanes	No two-way left-turn lanes	HSM default value for base condition
CMF_{10r}	CMF for roadside design	Roadside hazard rating of 3	MoDOT database (Excel spreadsheet)
CMF_{11r}	CMF for lighting	No lighting	HSM default value for base condition
CMF_{12r}	CMF for automated speed enforcement	No automated speed enforcement	HSM default value for base condition

For each roadway segment, the expected crash frequency in the before period was calculated by combining the predicted crash frequency and the observed crashes using the EB method, in accordance with HSM methodologies (AASHTO, 2010).

Note: The before period expected crash frequency is utilized in the after period expected crashes calculation in Step 6.

Step 6: Calculation of After Period (without treatment) Predicted and Expected Crash Frequency

The predicted crash frequency in the after period (without treatments) for each roadway segment was calculated with a similar procedure. The predicted crash frequency under base conditions was calculated first using the after period AADT and segment length. Then, all applicable CMFs were calculated to consider non-base conditions. The predicted crash frequency for the after period (without treatment) was determined by multiplying the predicted crash frequency under base conditions with all the applicable CMFs and the SPF local calibration factors.

The expected crashes in the after period (without treatment) for each roadway segment was calculated with HSM Equation (A-15) (AASHTO, 2010). Since no changes are made for the after period (without treatment) condition, the after period expected crashes can be determined by multiplying the before period expected crash frequency by the ratio of predicted crash frequency under base conditions in the after to the before period.

Note: The after period expected crash frequency is utilized in the CMF calculation in Step 7.

Step 7: Calculation of CMF and Standard Error

Based on the FHWA technical document *A Guide to Developing Quality Crash Modification Factors* (Gross et al, 2009), the CMF and standard error were determined using the following equations and utilizing the after period observed crash assignment from Step 4 and the after period (without treatment) expected crash frequency from Step 6:

$$\hat{\theta} = \frac{\frac{\lambda}{\pi}}{1 + \frac{Var(\pi)}{\pi^2}}$$

$$\hat{\sigma} = \frac{\hat{\theta} \times \sqrt{\frac{1}{\lambda} + \frac{Var(\pi)}{\pi^2}}}{1 + \frac{Var(\pi)}{\pi^2}}$$

Where

$\hat{\theta}$ = CMF for the designated treatment

λ = Observed crash frequency in the after period

π = Expected crash frequency in the after period (without treatments)

$\hat{\sigma}$ = Standard error of the CMF

Study Assumptions

The following assumptions were made for all roadway segments as part of the CMFs development:

- No shoulder (0 foot width) in the before period and 2 foot shoulder width in the after period
- The superelevation variance (SV), the superelevation rate contained in the AASHTO Green Book minus the actual superelevation of the curve, is less than 0.01
- No centerline rumble strips installed in before or after condition
- No passing lanes and two-way left-turn lanes (TWLTL)
- No street lighting
- No automated speed enforcement
- No changes in lane width from the before period to the after period
- No other changes from the before period to the after period except for the combined RS-SW-PR treatment analyzed in this study

Detailed descriptions for the study assumptions are included in the **Data Collection and Analysis Assumptions** documentation in **Appendix B**.

Summary of Results

Table 2 lists the calculated CMFs for the combined RS-SW-PR treatment. The CMFs for the study crash severity levels and collision types (K, A, BC, O, and their combinations for total crashes and RRHO crashes) range from 0.547 to 1.010. Generally, the CMFs for fatal and injury crashes are lower than that for non-injury crashes. This is an indication that the combined RS-SW-PR treatment is more effective for fatal and injury crashes. The lowest calculated CMF, which is for all fatal crashes, is 0.547. The highest CMF, which is for PDO RRHO crashes, is 1.010.

All but one crash severity level and collision type in this study had a CMF value less than 1.0. This indicates that the combined RS-SW-PR treatment generally has a positive safety effect, reducing the total crash frequency. The RRHO property damage only (PDO) is the only crash severity level and collision type with a CMF value over 1.0. One possible explanation for the increase in RRHO PDO crashes after the combined RS-SW-PR treatment is that the treatment actually converted some of the serious injury crashes into PDO crashes. This would be an indication that the combined RS-SW-PR treatment alleviates the severity of the crashes.

The standard error for most CMFs is less than 0.100, an indication of high quality in the developed CMFs (AASHTO, 2010). The highest standard error for CMF, 0.276, is for fatal RRHO crashes and may be due to low number of expected and observed fatal crashes. The lowest standard error for CMF, 0.054, is for total crashes.

Table 2. CMF Results for Combined RS-SW-PR Treatment on Rural Two-lane Roads

Crash Severity Level	Total Crashes		RRHO ^a	
	CMF	Standard Error	CMF	Standard Error
Fatal crash (K)	0.547	0.245	0.550	0.276
Disabling injury crash (A)	0.882	0.149	0.749	0.156
Minor injury crash (BC)	0.756	0.084	0.732	0.097
Property damage only crash (O)	0.984	0.070	1.010	0.096
KA crash	0.822	0.131	0.710	0.137
ABC crash	0.800	0.076	0.743	0.084
BCO crash	0.927^b	0.057	0.908	0.072
KABC crash	0.784	0.073	0.729	0.081
ABCO crash	0.930^b	0.055	0.891^b	0.067
Total crash (KABCO)	0.918^b	0.054	0.877^b	0.065

^a RRHO represents both run-off-the-road and head-on crashes based on the “on_off_roadway” and “two_veh_analysis” variables in the MoDOT crash database.

^b CMFs in bold have standard errors of approximately 0.05 and are more reliable than the reported CMFs in other studies.

Results Comparison

The safety performance of shoulder rumble strips (and rumble stripes), deployed alone or combined together with other safety treatments, have been widely investigated in numerous studies throughout the country. This study specifically evaluates the safety effects for the combined RS-SW-PR treatment on rural two-lane highways. Therefore, the following discussion is focused on CMFs for shoulder rumble strips (and rumble stripes), resurfacing and shoulder width, or their combined application, for rural highway segments. CMFs for similar treatments from other studies are summarized in **Table 3** below.

CMFs included in the HSM

The HSM (AASHTO, 2010) includes one CMF for rural highway shoulder rumble strips and one CMF for shoulder width, but no CMFs for resurfacing. The HSM doesn't provide CMFs for the combined treatments. For rural multilane divided highway, the shoulder rumble strip CMFs range from 0.78 to 0.90, depending on the crash severity levels and collision types. A CMF for total crash is provided for widening the shoulder from 0 to 2 feet. Depending on the AADT range, the CMF varies from 0.87 to 0.97. Refer to **Table 3** for additional details.

CMFs from the FHWA CMF Clearinghouse

Numerous CMFs on shoulder rumble strips (and rumble stripes), shoulder widening and resurfacing, either deployed alone or combined with other treatments, are available in the FHWA CMF clearinghouse. However, the CMF clearinghouse does not provide the CMFs for the combined RS-SW-PR treatment on rural two-lane highway. Two studies with safety treatments and facility type close to this study are discussed below.

National Cooperative Highway Research Program (NCHRP) Report 641 (Torbic et al, 2009) reports a CMF of 0.53 for fatal and injury run-off road crashes on rural two-lane undivided highway with the treatment as edgeline rumble strips for roadways with less than 5 feet shoulder. It should be noted that the CMF was developed using the regression cross-section study and not the EB before/after study.

A Missouri study by Potts (Potts et al, 2011) calculated the CMFs for the combined treatment of wider markings, shoulder rumble strips and resurfacing with EB method using data from Missouri and obtained a CMF of 0.77 for fatal and injury crashes and 0.74 for fatal and serious injury crashes. However, the CMFs are for rural principal arterial, freeway and expressway and not rural two-lane undivided highway.

CMFs from other published documents

Study results from 14 states published on the FHWA website (FHWA, 2015) show that shoulder rumble strips may reduce single-vehicle run-off road crashes by 14 to 80 percent on the freeway. Most results, however, report a reduction in the 30 to 40 percentage range. It should be noted that the CMF is only for shoulder rumble strips and not for the combined RS-SW-PR treatment investigated in this study. Furthermore, the CMFs are for freeways. No CMFs for similar treatments on rural two-lane highways are listed on the FHWA website.

Table 3. CMFs for Similar Treatments Documented in Other Studies

Treatment	Roadway Type	Crash Type and Severity	CMF	Standard Error
Shoulder rumble strip^a	Rural multilane divided highway	All types (all severities)	0.84	0.1
		All types (injury crashes)	0.83	0.2
		Single-vehicle run-off road crashes (all severities)	0.90	0.3
		Single-vehicle run-off road crashes (injury)	0.78	0.3
Widen shoulder from 0 to 2 feet^b	Rural two-lane undivided highway	All	0.87 to 0.97	N/A
Edgeline rumble strips with a shoulder width less than 5 feet^c	Rural two-lane undivided highway	Run-off road crashes (fatal and injury)	0.53	0.2339
Wider markings and shoulder rumble strips with resurfacing^d	Rural principal arterial, freeway and expressway	All types (fatal serious injury and minor injury)	0.77	0.051
		All types (fatal and serious injury)	0.74	0.088
Shoulder rumble strips and rumble stripes^e	Freeways	Single-vehicle run-off road crashes	0.60 to 0.70	N/A

^a CMF from the HSM (Table 13-44 on page 13-38)

^b CMF from the HSM (Table 13-7 on page 13-11)

^c <http://www.cmfclearinghouse.org/detail.cfm?facid=3401>

^d <http://www.cmfclearinghouse.org/detail.cfm?facid=4783>

^e http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/safety.cfm

Results Comparison

The CMFs from the studies with similar treatments discussed above are summarized with the results of this study in **Table 4** below. In general, the CMFs from this study are close to those from the Missouri study and those in the HSM. The greatest difference in CMF values was observed between this study and the results reported in NCHRP Report 641. The CMF standard error values for this study are close to those from the Missouri study and are lower than those reported in most other similar studies.

Table 4. Comparison on CMF from Different Studies

Crash severity and collision type	This study	Missouri Study	NCHRP 641	HSM
Run-off road (fatal and injury)	0.729 ^a		0.53	
Run-off road (all severities)	0.877 ^a			0.90
All types (fatal, serious injury and minor injury)	0.784	0.77		
All types (fatal and serious injury)	0.822	0.74		
All types (all severities)	0.918			0.84

^aThe CMF is for run-off road and head-on crashes.

It should be noted, once again, that the treatments and facility types differ from those in this study. The roadway type for most other studies is arterial, expressway or freeway and not rural two-lane undivided highway as in this study. Some of the other studies utilized naïve before/after study or regression cross-section study and not the EB observational before/after study; and therefore, may not be as reliable as the results from this study. While these other studies represent the best available information for results comparison, these factors ultimately make it difficult to directly compare the results from this study to those from other studies.

Conclusions

This study of the combined RS-SW-PR treatment provides a comprehensive set of CMFs for designated crash severity levels and collision types (K, A, BC, O, and their combinations for total crashes and RRHO crashes), resulting in 20 CMFs total. A summary of the results is listed in **Table 5** below. (*The full results were listed previously in Table 2 of this technical memorandum.*)

Generally, most of the CMFs are less than 1.000, an indication of the effectiveness of the combined RS-SW-PR treatment. The CMFs for RRHO crashes are lower than that for total crashes of the same severity level, which indicates that the combined RS-SW-PR treatment is more effective for the RRHO crashes. The lowest CMF, 0.547, is for total fatal crashes; while the highest CMF, 1.010, is for RRHO PDO crashes. The standard errors for most calculated CMFs are less than 0.100, an indication of high quality of the calculated CMFs. A number of CMFs have standard errors of approximately 0.05 and are more reliable than the reported CMFs in other studies. These CMFs are shown in bold in **Table 2** and **Table 5**.

Table 5. CMFs for the Combined RS-SW-PR Treatment on Rural Two-lane Roads

Crash Severity Level	Total Crashes	RRHO Crashes
Fatal crash (K)	0.547	0.550
Disabling injury crash (A)	0.882	0.749
Fatal and disabling injury crash (KA)	0.822	0.710
Minor injury crash (BC)	0.756	0.732
Property damage only crash (O)	0.984	1.010
Total crash (KABCO)	0.918^a	0.877^a

^aCMFs in bold have standard errors of approximately 0.05 and are more reliable than the reported CMFs in other studies.

In conclusion, this study calculated the CMFs for the various crash severity levels and collision types, quantifying the safety effects of combined RS-SW-PR treatment for rural two-lane highways in Missouri. Because of differences on treatment and roadway type, no direct comparison on CMFs between this study and other available studies can be made. However, the results appear to be consistent with the aggregate results of the most similar and comparable studies readily available. Furthermore, the CMFs

from this study are likely to be more reliable than that from previous studies based on smaller standard errors, the EB before/after study method adopted, the consideration of the combined treatment.

References

American Association of State Highway and Transportation Officials (AASHTO). 2010. Highway Safety Manual.

Federal Highway Administration (FHWA). 2015. Rumble Strips and Rumble Stripes. http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/safety.cfm. Accessed on July 2, 2015.

Gross, F., B. Persaud and C. Lyon. 2009. *A Guide on Develop Quality Crash Modification Factors*. US Department of Transportation, Federal Highway Administration.

Potts, I.B., D.W. Harwood, C.D. Bokenkroger, and M.M. Knoshaug. 2011. Benefit/Cost Evaluation of MoDOT's Total Striping and Delineation Program: Phase II. Missouri Department of Transportation, 2011.

Sun, C., H. Brown, P. Edara and B. Carlos. 2013. *Calibration of the Highway Safety Manual for Missouri*. University of Missouri, 2013.

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. 2009. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board, 2009.

Appendices

- A. Acronyms and Abbreviations
- B. Data Collection and Analysis Assumptions

Electronic Appendix (on Disc)

1. Technical Memorandum with Appendix A and Appendix B (PDF)
 - a. Appendix A – Acronyms and Abbreviations (PDF)
 - b. Appendix B – Data Collection and Analysis Assumptions (PDF)
2. Excel Spreadsheets
3. GIS Database

Appendix A

Acronyms and Abbreviations

APPENDIX A

Acronyms and Abbreviations

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABC	Incapacitating, non-incapacitating and possible injury crashes (crash severities)
ABCO	Incapacitating, non-incapacitating, possible injury and property damage only crashes (crash severities)
BC	Non-incapacitating and possible injury crashes (crash severities)
BCO	Non-incapacitating, possible injury and property damage only crashes (crash severities)
CMF	Crash Modification Factor. CMF represents the relative change in crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant).
DD	Driveway Density. DD represents the number of driveways per mile on both sides of the roadway combined.
EB	Empirical Bayesian. EB is a method used to combine observed crash frequency data for a given site with predicted crash frequency data from many similar sites to estimate its expected crash frequency.
FHWA	Federal Highway Administration
GIS	Geographical Information System
HSM	Highway Safety Manual
K	Fatal crashes (crash severity)
KA	Fatal and incapacitating crashes (crash severities)
KABC	Fatal, incapacitating, non-incapacitating and possible injury crashes (crash severities)
KABCO	Fatal, incapacitating, non-incapacitating, possible injury and property damage only crashes (crash severities)
MoDOT	Missouri Department of Transportation
NCHRP	National Cooperative Highway Research Program
O	Property damage only crashes (crash severity)
PDO	Property damage only crashes (crash severities)
RRHO	Run-off-the-road and head-on crashes (crash types).
RS-SW-PR	Shoulder rumble stripes, shoulder widening from no shoulder to 2 foot shoulder width and pavement resurfacing (combined treatment).
RHR	Roadside Hazard Rating. RHR is a rating system for the clear zone in conjunction with the roadside slope, roadside surface roughness, recoverability of the roadside, and other elements beyond the clear zone such as barriers or trees.
SPF	Safety Performance Function. An SPF is an equation used to estimate or predict the average crash frequency per year at a location as a function of traffic volume and in some cases roadway or intersection characteristics.
SV	Superelevation Variance. SV is the superelevation rate contained in the AASHTO Green Book minus the actual superelevation of the curve.

TMS	Transportation Management System
TWLTL	Two-Way Left-Turn Lane
VPD	Vehicles Per Day

Appendix B

Data Collection and Assumptions

Data Collection and Analysis Assumptions

This document includes additional details on the utilization and incorporation of MoDOT provided data and assumptions built into the CMF development procedure and analysis as part of the ***Development of Crash Modification Factors for Combined Treatments on Rural Two-lane Roads*** for MoDOT Job No. JOP3012. It should be considered in combination with the content of the technical memorandum.

The data provided by MoDOT, which was provided electronically in ArcGIS databases and shapefiles and Microsoft Excel spreadsheets, and the analysis spreadsheets are included in the electronic appendix of this technical memorandum.

Link the rumble stripe layer to roadway segment layer

There are 65 segments in the rumble stripe GIS layer and 177 segments in the segment GIS layer. A link was established between the two segment layers based on traffic way ID and beginning/ending stations for the segments. The results were saved in the following location:

File: MoDOTCMFDevelopment_WorkingData.xlsx, under the tab “LinkRumbleStripeToSegment”

The purpose for linking these two databases is to use the construction date/resurfacing date in the rumble stripe layer database to determine the before/after periods for different roadway segments.

AADT

MoDOT provided the database that includes AADTs from year 2004 to year 2013. However, the AADTs for year 2004 to 2006 are blank. An annual AADT increase rate of 1% was used to calculate the AADTs for missing years based on the available AADTs for the nearest year.

Shoulder width and type

MoDOT provided that shoulder width is 2 feet for all the segments in the after period. The shoulder width for all the sites in the before period is 0 feet (no shoulder).

The MoDOT roadway database indicates that the shoulder width for 5 roadway sites (5 in 172, or 3% in total) was 4 to 10 feet in the after period. The shoulder width for those sites in the after period was changed to 2 feet based on the information provided by MoDOT.

Shoulder type

Three different shoulder types are provided for the selected roadway sites:

- BM: bituminous material
- ERT: Earth
- SP: Superpave

The Highway Safety Manual defined the following four shoulder types:

- Paved
- Gravel
- Composite
- Turf

The shoulder type “BM” and “SP” were classified as “paved”, and “ERT” was classified as “composite”.

Link the segment and curve

There are 177 roadway segments and 1425 curves in total in their GIS layers. The total number of curves was reduced to 708 after removing duplicate curves and curves not on the segments. All the curves were linked to the related segments manually and the results were saved under the tab “LinkCurveToSegment” in the file “MoDOTCMFDevelopment_WorkingData.xlsx”.

The table may also be found in the file “MoDot_RumbleStripe.mxd”.

Superelevation

Superelevation value (variable “cross fall”) was provided for 229 locations. Among them, 189 superelevation values were assigned to 189 curves (one superelevation value for one curve). For the rest 40 superelevation values, no curves could be assigned.

After further coordination with MoDOT, it was confirmed that the superelevation value only represent the superelevation for the location and not the maximum superelevation for the curve segment. Therefore, the superelevation values were not be used in the CMF calculation and superelevation was assumed to be consistent with standard MoDOT design values.

Grade

Grade for roadway segments was determined with the following methods. The grade values for 1488 locations (cross sections) were assigned to the related roadway segments using the ArcGIS tool “Spatial Join”. For each segment, the average grade value for all cross sections is used to represent the grade for the roadway segment. The segments were classified into “level grade”, “moderate terrain” and “steep terrain” based on their average grade values, level grade, moderate terrain and steep terrain is defined by the Highway Safety Manual (HSM). The distribution of the grade values was as follows:

- Level grade ($\leq 3\%$): 1268 points
- Moderate terrain ($3\% < \text{grade} \leq 6\%$): 214 points
- Steep terrain ($\text{grade} > 6\%$): 6 points

The 6 locations with grade greater than 6% were distributed on 5 separate roadway segments. Only two locations (ID 220 and 359) were located on the same roadway segments. Therefore, no roadway segments will be classified as “steep terrain” category in the analysis.

No grade values were provided for 10 roadway segments. Based on the assumption from the MoDOT Inventory User Manual, the grades for these roadway segments are all 1.787% (level grade). A detailed look of those segments reveals that the grade category for those segments are consistent with that for adjacent roadway segments.

Before/after period for roadway segments

Three treatments, including rumble stripe, narrow shoulders and resurfacing, were applied to the roadway sites. The after period was determined based on the later date between the construction date (variable “Installation_dt”) and the surfacing date (variable “surface_date”) in order to ensure that all improvements were completed and that the safety effects of all three treatments could be considered.

Similarly, the before period was determined based on the length of time for construction, and the construction and resurfacing date (whichever is earlier) so that the before period did not include any period of time in which any of the safety treatments were in place.

Intersection and segment crashes

The intersection crashes and segment crashes are differentiated based on the variable “intersection_no”. All intersection crashes have a number assigned to this variable, while all segment

crashes have “0” or no value (blank). Of all the 9831 crashes, 6653 are segment crashes, and 6629 were assigned to the selected roadway segments. Only roadway segments are used in the study analysis.

Roadway data

The roadway database from MoDOT represents the status of the roadway segments before the application of the safety treatments. It is assumed that safety treatments for the roadway segments were limited to the following three categories and that no other improvements or changes occurred during before and after periods:

- Shoulder rumble stripe
- Shoulder widening from 0 to 2 feet
- Pavement resurfacing

Run-off-the-road crashes and head-on crashes

Per the guidance from MoDOT, the run-off-the-road crashes and head-on crashes were identified based on specific variables. Variable “on_off_roadway” was used to identify the run-off road crashes, while variable “two_veh_analysis” was used to identify the head-on crashes. A run-off-the-road crash is defined as a crash with variable “on_off_roadway” having a value of “2” in the MoDOT crash database. A head-on crash is defined as a crash with variable “two_veh_analysis” having a value of “60” in the MoDOT crash database. All the crashes that met either of the criteria were identified as the targeted crashes for the analysis.

Removal of roadway segments from the analysis

The 65 rumble stripe segments were divided into 177 shorter roadway segments to achieve homogeneous segments for crash frequency calculation. 4 of these roadway segments with length shorter than 0.1 miles were removed from the segment list. The AADTs for most segments were under 8,000. The AADT for one roadway segment (OID114_TID7806) was 17,223. The AADT is still below the maximum AADT (17,800) value based on HSM policy for rural 2-lane highways. However, AADT for this roadway segment is atypical for roadway segment AADTs in this study. For this reason, this segment was excluded from the analysis. The total number of segments reduced to 172.