JOINT TRANSPORTATION
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AND PURDUE UNIVERSITY

Updating the Crash Modification Factors and Calibrating the IHSDM for Indiana

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SPR-4015 • Report Number: FHWA/IN/JTRP-2018/03 • DOI: 10.5703/1288284316646

RECOMMENDED CITATION

Tarko, A. P., Romero, M., Hall, T., & Sultana, A. (2018). *Updating the crash modification factors and calibrating the IHSDM for Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/03). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316646

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ACKNOWLEDGMENTS

The completion of this study was facilitated by the contributions of many people. The authors would like to thank Thomas Ford, Shuo Li, Louis Feagans, Abell Gelaye, George Kopcha, Katherine Smutzer, and John Wright from INDOT, Rick Drumm from the FHWA Indiana Division, and Laura Slusher from Indiana LTAP for their help throughout this project. The authors greatly appreciate the contributions of Jose Thomaz from the Purdue University Center for Road Safety for assisting in the data processing and preparation effort for this research.

JOINT TRANSPORTATION RESEARCH PROGRAM

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Print ISBN: 978-1-62260-495-1

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/IN/JTRP-2018/03	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Updating the Crash Modification Factors and Calibrating the IHSDM for Indiana	**5. Report Date** February 2018
	6. Performing Organization Code
7. Author(s) Andrew P. Tarko, Mario Romero, Thomas Hall, Afia Sultana	**8. Performing Organization Report No.** FHWA/IN/JTRP-2018/03
9. Performing Organization Name and Address Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051	**10. Work Unit No.**
	11. Contract or Grant No. SPR-4015
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	**13. Type of Report and Period Covered** Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

The Interactive Highway Safety Design Model (IHSDM) is a tool for assessing the safety impact of project-level design decisions by implementing the HSM crash prediction methodology. Safety Performance Functions (SPFs), Crash Modification Factors/Functions (CMFs), calibration factors, and crash proportions are utilized in predicting the number, severity, and type of crashes occurring on various types of roadway facilities. This study updated and expanded the set of CMFs applicable to Indiana conditions for various geometric, traffic, pavement, and other road characteristics. CMFs for 80 various road and control improvements for urban and rural segments, intersections, and interchanges. This report also presents the methodology of calibrating the IHSDM's predictive components based on local data and past research. This method jointly estimates the SPFs and CMFs to preserve the crash prediction consistency. SPFs, CMFs, and crash proportions were calibrated for Indiana rural two-lane segments, rural divided multilane segments, and urban/suburban arterial segments. Example calculations showed that some results were only slightly affected while others vary considerably. This finding confirms the need for calibrating the parameters in the IHSDM to local conditions.

17. Key Words road safety, IHSDM, design, CMF, SPF, HSM	**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 61	**22. Price**

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

UPDATING THE CRASH MODIFICATION FACTORS AND CALIBRATING THE IHSDM FOR INDIANA

Introduction

Reducing the number of severe injuries and fatalities on Indiana roads can be accomplished through comprehensive consideration of safety in transportation planning, design, management, and operations. To accomplish this goal, knowledge of the safety factors and countermeasures that may be applied to improve safety are needed, as well as tools for facilitating application of that knowledge. The main components of the safety knowledge are crash reduction factors (CRFs) and the associated crash modification factors (CMFs), which can be utilized to estimate the benefit cost ratio (BCR) and the net benefit (B-C) of safety projects in the planning, design, and management stages. There is a need to update the CRFs and CMFs applicable to Indiana conditions. This study addressed this concern by updating the CRFs/CMFs for various traffic, geometrics, and other improvements that may be applied in Indiana. Furthermore, the study calibrated the components of the Interactive Highway Safety Design Model (IHSDM) to better reflect Indiana conditions (FHWA, n.d.a).

Findings

A set of criteria was developed for determining the existing CRFs and CMFs that are most suitable for Indiana conditions. This research identified more than 80 safety countermeasures and their associated CRFs/CMFs for various geometric, traffic, pavement, and other characteristics. The identified CRFs/CMFs are applicable to different crash types and severities at urban and rural segments, intersections, and interchanges. CRFs and CMFs presented as functions were discretized for various levels of the change in safety in order to provide ease of implementation in Indiana.

Additionally, a comprehensive approach for calibrating the predictive components of the *Highway Safety Manual* (HSM) method was developed that fits within the constraints of the IHSDM. This included calibrating the tool's default parameters for SPFs and CMFs for rural and urban segments, as well as updating the default crash proportions to reflect Indiana conditions. In some cases, the Indiana parameters and crash proportions show similarities with their HSM counterparts. However, the results also show considerable differences that highlight the need for calibrating the crash prediction method for local conditions. The presented example studies show how the HSM default parameters may understate or overstate the safety performance of road facilities in comparison to using parameters developed specifically for Indiana.

Implementation

A comprehensive table of CRFs and CMFs that may be implemented in Indiana was presented. Furthermore, the study provides the Indiana specifications of the IHSDM CMFs, SPFs, and crash proportions, both in tabular form and in files that may be implemented directly in the software by the user.

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1. INTRODUCTION

1.1 Background

More than 30,000 people are killed annually in motor-vehicle crashes in the United States (BTS, 2017), or about one fatality every 17 minutes. The impact of these crashes is immense. The National Safety Council estimates that motor-vehicle crashes resulted in $430 billion in economic, personal, and societal costs in the United States for 2016 alone (NSC, 2017). Hence, it has become the long-term goal of cities, states, and the nation to greatly reduce or even eliminate the number of severe injuries and fatalities occurring in motor-vehicle crashes. Many of these programs fall under the umbrella of the "Towards Zero Deaths" vision promoted by the Federal Highway Administration (FHWA, n.d.b). As part of this initiative, the Indiana Department of Transportation (INDOT) has developed a *Strategic Highway Safety Plan* with the objective of identifying highway safety problems and implementing general strategies for reducing or eliminating the effect of these problems on the crash, injury, and fatality risk (INDOT, 2016).

Reducing the number of severe injuries and fatalities on Indiana roads can be accomplished through comprehensive consideration of safety in transportation planning, design, management, and operations. To accomplish this goal, knowledge of the safety factors and countermeasures which may be applied to improve safety are needed, as well as tools for facilitating application of that knowledge (AASHTO, 2010). Crash reduction factors (CRFs) are a key component of the safety knowledge which can be used to estimate the benefit cost ratio (BCR) and the net benefit (B-C) of safety projects in the planning, design, and management stages. Accurately predicting the safety effects of engineering countermeasures by determining the CRFs will improve the transportation decision-making process from the safety perspective (Herbel, Laing, & McGovern, 2010).

Tarko, Dey, and Romero (2015) conducted the last CRF study for Indiana in 2015. This study includes CRFs for geometric safety improvements on rural and urban road segments. However, there are CRFs for geometric and non-geometric safety improvements which are either outdated or not available for Indiana altogether. For these safety improvements, other regions with similar driving cultures and weather to Indiana have conducted recent CRF studies (AASHTO, 2010; FHWA & UNC HSRC, 2017). There is a need for updating out-of-date existing Indiana CRFs and increasing the size of the CRF database by adopting applicable CRFs for other regions similar to Indiana.

INDOT recently revisited scoping road improvement and design projects and advancing their development with a new emphasis on using a systemic approach and cost-effectiveness. A new design paradigm based on "practical design" was formulated and is now being implemented in Indiana. Safety consideration is a central component in this newly adopted approach. With this greater focus on safety, INDOT engineers and road designers are attempting to find improvement and design solutions which are budget-conscious while meeting a project's well-defined objectives. The goal is to build more and better roads within the limited budget.

This study generates results that are crucial for evaluating the safety effects of traffic control and road design decisions. One popular tool which may facilitate the implementation of these results is the Interactive Highway Safety Design Model (IHSDM), a tool developed by the FHWA which applies the *Highway Safety Manual* (HSM) crash prediction methodology. The IHSDM provides estimates of crash frequencies, types, and severity that can assist in identifying possible safety problems and evaluate the effects of various design improvements at the project-level. The tool can help justify the selection of one design improvement over another.

There are four main components of the HSM that are implemented through the IHSDM to predict crashes for different road facility types: (1) Safety performance functions (SPFs), (2) crash modification factors/functions (CMFs), (3) calibration factors, and (4) crash proportions. The predictive components must be calibrated in order to properly account for jurisdiction-specific conditions. However, the IHSDM imposes constraints which must be considered in the calibration of the HSM predictive method. The functional forms of the SPFs and CMFs (developed under certain base conditions) are fixed, may not be altered, and there are no provisions for adding new CMFs in the IHSDM. A comprehensive calibration method is needed which can facilitate the transfer of jurisdiction-specific CMFs to the IHSDM.

1.2 Scope of Work and Research Objectives

The scope of this project includes safety improvements implemented on INDOT-administered road elements (segments and intersections) in both rural and urban areas. The first objective of this study is to update the CRFs for various traffic, geometric, and other improvements which may be applied in Indiana. The comprehensive list of CRFs will be developed based on CRFs from Indiana and other applicable sources with conditions similar to Indiana. The other objective of this study is to calibrate the IHSDM tool for Indiana conditions. A new approach to this task will be proposed using all the available pieces of knowledge pertaining to Indiana while preserving consistency with the IHSDM, thus ensuring the integrity of the results. This will be done by implementing the results of the Indiana CMFs, whenever possible, into the IHSDM software through reconciliation with the default CMFs. This part of the study will also involve developing new Indiana SPFs that may be estimated in tandem with the CMFs and in a format compatible with the IHSDM. This study is expected to provide a method for supporting safety-related design and improvement decisions in Indiana.

1.3 Report Organization

This report is organized as follows:

- Chapter 1, Introduction
- Chapter 2, Existing Crash Reduction Factors Suitable for Indiana
- Chapter 3, Methodology for Calibrating the IHSDM
- Chapter 4, Calibration Data
- Chapter 5, Calibrating the IHSDM for Indiana
- Chapter 6, Summary and Conclusions
- Appendices

2. EXISTING CRASH REDUCTION FACTORS SUITABLE FOR INDIANA

2.1 Background

CRFs and the related CMFs provide a quantitative assessment of the impact on crash frequency for various types and severities of crashes. Whereas CRFs depict the percent change in crashes following the implementation of a countermeasure on a roadway facility, CMFs can be thought of as a multiplicative factor for determining the number of crashes after the implementation of the countermeasure (Scurry, n.d.). CMFs are related to CRFs through the relation shown in Equation 2.1:

$$CMF = 1 - \left(\frac{CRF}{100}\right) \tag{2.1}$$

A variety of methods have been utilized for determining CRFs/CMFs, including cross-sectional studies (for example, SPF regression models), before-and-after studies, and expert panels, among others (Wu, Lord, & Zou, 2015). In the case that a full SPF with all variables has been estimated, CMFs may be determined from the SPF coefficients as in Tarko et al. (2015). CMFs derived from before-and-after studies consider the safety performance before and after the application of one or more countermeasures at the considered sites (Wu et al., 2015). The empirical Bayes approach popularized by Hauer (1997) is one such method utilized in before-and-after studies to help account for the regression-to-the-mean effect (tending to cause an overestimation of the crash reduction potential) which may occur. In this research, studies that have used regression modeling, before-and-after studies, and other methods are consulted.

This chapter provides information on the existing CRFs and CMFs for various geometric, traffic, pavement, and other improvements that have been found to affect safety on roadway segments and intersections in urban and rural areas. The majority of the factors/functions were obtained from the Crash Modification Factors Clearinghouse, a continuously updated repository funded by the Federal Highway Administration and maintained by the University of North Carolina Highway Safety Research Center (FHWA & UNC HSRC, 2017). The Clearinghouse provides more than 5000 CRFs for both urban and rural areas in the United States, Canada, and internationally. Many of the safety improvements have multiple CRF values based on multiple studies, and there are also similar safety improvements which differ only by the wording in their names. Thus, it is necessary for the user to make a judgement call on which is most appropriate for their situation. Various criteria were used to identify the factors/functions most suitable for Indiana conditions. These criteria and a summary of the selected safety improvements and associated CRFs/CMFs are discussed in the sections that follow.

2.2 Criteria for Selecting CRFs/CMFs

Three criteria were utilized in determining CRFs suitable for segments and intersections in Indiana: the state or states where the CRF study was conducted, the star quality rating (from the CMF Clearinghouse), and the study timeframe. Based on these criteria, each CRF was classified in one of three criteria levels: first-tier, second-tier, or third-tier.

The first-tier criteria level includes Indiana and other nearby states that share a border and/or are expected to have similar environmental conditions and driving culture to Indiana (see Table 2.1). Additionally, CRFs in this level have a Clearinghouse star quality rating of 4 or 5 stars (out of a maximum 5 stars). A high star quality rating indicates a high-quality study design and estimation methodology, a large data sample from multiple years and sites, and data from a variety of states and geographies (FHWA & UNC HSRC, 2017). These CRFs also have limited standard error (as compared to the CRF value) and control for potential biases. Most studies with a high star quality rating use a well-established methodology such as the Empirical Bayes or Full Bayes to account for the regression-to-the-mean bias and enhance the estimation accuracy. Finally, only CRFs from studies in the past 10 years are included in the first-tier criteria level so as to reduce the influence of changing conditions and driving culture over time.

If a CRF does not meet one or more of the first-tier criteria, then it is considered for the second-tier criteria level.

TABLE 2.1
Summary of Criteria used for Determining Most Suitable Existing CRFs

Criteria level	States	CMF Clearinghouse star quality rating	Study timeframe
First-tier	IL, IN, IA, KY, MI, MO, OH, WI	4 or 5 stars	Past 10 years
Second-tier	AR, KS, MN, NE, NC, ND, OK, PA, SD, TN, VA, WV	3 or more stars	Past 15 years
Third-tier	Not meeting first- or second-tier criteria		

This level includes states outside of the first-tier states and which do not immediately border Indiana. The environmental conditions and driving culture in these states is expected to be somewhat different than Indiana. Additionally, the CRFs must meet a star quality rating of at least 3 stars and come from a study conducted within the past 15 years to be classified on the second-tier criteria level. If a study does not meet one or more of the first- or second-tier criteria, then it is considered to be part of the third-tier criteria level.

The main purpose for differentiating among the three tiers is to gather all the available CMFs so they can be readily available for practitioners. The tiers do not affect the use of the CMF selection from Appendix A.

2.3 Safety Improvements and CRFs

A total of 82 safety improvements were identified under 16 different categories (see Table 2.2). The categories of safety improvements included access management, alignment, highway lighting, intersection geometry, intersection traffic control, ITS and advanced technology, pavement, pedestrians, railroads, roadside, road diet, roadway delineation, segments, shoulder treatment, signs, and speed management.

For each safety countermeasure, the CRF and CMF values for urban and/or rural conditions, state(s) where the study was conducted, and applicable crash and roadway types were noted. The complete CRF/CMF table is contained in Appendix A. The categories of safety countermeasures and the CRF/CMF studies are detailed below.

A. Access Management

1. Install two-way left-turn lane (TWLTL). Persaud, Lyon, Eccles, Carter, et al. (2008) conducted a study evaluating the safety impacts of installing TWLTLs on two-lane roads in rural and urban areas in Arkansas, California, Illinois, and North Carolina. However, the safety impact was only found to be significant in the rural areas. The researchers developed CMFs for all crashes and injury crashes, as well as for rear-end crashes.
2. Replace TWLTL with raised median. Utilizing data from urban areas in Nevada, Mauga and Kaseko (2010) developed CMFs for the replacement of a TWLTL with a raised median on principal arterials, minor arterials, and collectors. CMFs were developed for total crashes, PDO crashes, and injury crashes. Furthermore, CMFs were estimated for rear-end, sideswipe, angle, and head-on crashes.
3. Driveway density. For driveway density in rural areas, a study was conducted by Fitzpatrick, Park, and Schneider (2008) using data from Texas. The researchers developed separate CMFs in the form of functions for all crashes on two-lane and four-lane highways. For urban areas, CMFs in the form of functions were developed by Mauga and Kaseko (2010) for roads classified as principal arterials, minor arterials, or collectors in Nevada. Separate sets of CMFs were developed for facilities with TWLTLs and for facilities with raised medians. The CMFs were provided for all crashes, PDO crashes, and injury crashes. In addition, CMFs were estimated for rear-end and right-angle crashes.

B. Alignment

1. Flatten crest of curve. Using data from Ohio, Hovey and Chowdhury (2005) developed CMFs for total and injury crashes occurring on rural arterials and collectors.
2. Reduce the average grade rate by X%. Tarko et al. (2015) presented CMFs for PDO and injury crashes on rural two-lane roads in Indiana. The average grade $\bar{G}$ along a segment of length L is calculated based on splitting the entire segment into grades and vertical curves:

$$\bar{G} = \frac{1}{2L}\left[L_1(G_1 + G_2) + L_2(G_2 + G_3) + \ldots + L_n(G_n + G_{n+1})\right]$$

   where: n is the total number of sub-segments that are grades or vertical curves, L is the entire segment length, L_i is the length of sub-segment i, G_i is the grade rate at the beginning of sub-segment i, and G_{n+1} is the grade rate at the end of the entire segment. The expression gives an exact result.
3. Reduce the average degree of curve by X degrees. CMFs for PDO and injury crashes on Indiana rural two-lane roads were presented by Tarko et al. (2015). The average degree of curve $\bar{D}$ along a segment of length L is calculated based on splitting the entire segment into tangents, spirals, and circular curves:

$$\bar{D} = \frac{1}{2L}\left[L_1(D_1 + D_2) + L_2(D_2 + D_3) + \ldots + L_n(D_n + D_{n+1})\right]$$

   where: n is the total number of sub-segments that are tangents, spirals, or circular curves, L is the entire segment length, L_i is the length of sub-segment i, D_i is the degree of curve at the beginning of sub-segment i, D_{n+1} is the degree of curve at the end of the entire segment. Although the degree of curve on a tangent is zero, these sub-segments are included in the equation to preserve the simplicity and consistency of the expression. The expression gives an exact result.

C. Highway Lighting

1. Install lighting on a roadway segment. Harkey et al. (2008) presented CMFs for roadway lighting on segments, including for all crashes and injury crashes occurring during the nighttime.
2. Install lighting at a signalized intersection. Bullough, Donnell, and Rea (2013) examined the impact that lighting has on crashes at signalized intersections in Minnesota. Separate CMFs were developed for all crashes in rural and urban areas occurring during the daytime and nighttime.
3. Install lighting at a stop-controlled intersection. Bullough et al. (2013) also researched the effects of installing lighting at stop-controlled intersections located in rural and urban locations in Minnesota.
4. Install lighting at an interchange. CMFs were estimated for total and injury crashes on arterial and collector roads in Ohio by Hovey and Chowdhury (2005).

D. Intersection Geometry

1. Add a left-turn lane on one major approach to a signalized intersection. Harwood et al. (2003) provided separate CMF values for three- and four-leg intersections in both rural and urban areas utilizing a broad dataset containing states from throughout the country.

TABLE 2.2
Summary of Identified Safety Countermeasures

Category	Countermeasure
Access management	Install two-way left-turn lane (TWLTL) Replace TWLTL with raised median Reduce driveway density by X driveways per mile
Alignment	Flatten crest of curve Reduce the average grade rate by X% Reduce the average degree of curve by X degrees
Highway lighting	Install lighting on a roadway segment Install lighting at a signalized intersection Install lighting at a stop-controlled intersection Install lighting at an interchange
Intersection geometry	Add a left-turn lane on one major approach to a signalized intersection Add a left-turn lane on one major approach to an unsignalized intersection Add a right-turn lane on one major approach to a signalized intersection Add a right-turn lane on one major approach to an unsignalized intersection Convert diamond interchange to diverging diamond interchange (DDI) Convert intersection on low-speed road to a roundabout Convert intersection on high-speed road to a roundabout Convert intersection to a single-lane roundabout Convert intersection to a multilane roundabout Convert two-way stop-controlled intersection to a roundabout Convert all-way stop-controlled intersection to a roundabout Convert signalized intersection to a roundabout Convert a non-controlled or yield-controlled intersection to a roundabout Convert two-way stop-controlled intersection to J-turn intersection Improve left-turn lane offset to create positive offset Improve intersection sight distance
Intersection traffic control	Change left-turn phasing on one approach from permitted to protected/permitted phasing Change left-turn phasing on more than one approach from permitted to protected/permitted phasing Change left-turn phasing from permitted or permitted/protected to protected-only phasing Supplement left-turn phasing from at least one permitted approach with flashing yellow arrow Change left-turn phasing from protected/permitted to flashing yellow arrow Change left-turn phasing from protected to flashing yellow arrow Convert two-way stop control to all-way stop control Improve signal visibility Increase yellow change interval (1.0 seconds) Increase all-red clearance interval (average of 1.1 seconds) Increase yellow interval (average of 0.8 seconds) and add all-red interval (average of 1.2 seconds) Install transverse rumble strips on approaches to stop-controlled intersection Install new traffic signal at previously stop-controlled intersection Replace standard stop sign with flashing LED stop sign Retime signal change intervals to Institute of Transportation Engineers (ITE) standards
ITS and advanced technology	Install actuated advance intersection warning system at high-speed intersection Install changeable horizontal curve speed warning signs Install variable speed limit signs Install "Vehicle Entering When Flashing" (VEWF) system with advance post mounted signs on major approach and loops on minor approach
Pavement	Improve pavement condition from poor (critical condition index below 60) to good (critical condition index above 70)

TABLE 2.2
(Continued)

Category	Countermeasure
Pedestrians	Construct pedestrian bridge or tunnel Install High intensity Activated crossWalK (HAWK) at intersection Install sidewalk
Railroads	Build grade-separated crossing Eliminate railroad crossing Install gates at crossings with signs Upgrade signs to flashing lights
Roadside	Increase median width from 10 feet to X feet Install guardrail Install cable median barrier (high-tensioned) on depressed median of 50 feet wide or wider Install concrete median barrier Change in sideslope from 1V:3H to 1V:4H Change in sideslope from 1V:4H to 1V:6H Remove or relocate fixed objects outside of clear zone
Road diet	Re-stripe four-lane undivided road to three-lane (with TWLTL)
Roadway delineation	Add no passing striping Install centerline rumble strips Install shoulder rumble strips Install centerline plus shoulder rumble strips Install edgeline pavement markings on curves Install edgeline pavement markings on tangent sections Install raised pavement markers
Segments	Increase in number of through lanes by X lanes Convert two-lane roadway to four-lane divided roadway Convert 12 foot lanes and 6 foot shoulders to X foot lanes and Y foot shoulders Extend on-ramp acceleration lane by 30 meters (about 100 feet) Extend off-ramp deceleration lane by 30 meters (about 100 feet) Install passing relief lane Increase lane width by X feet
Shoulder treatment	Increase right shoulder width by X feet Increase left/inside shoulder width by X feet
Signs	Install chevron signs on horizontal curves Increase retroreflectivity of stop signs Install flashing beacons at stop-controlled intersections
Speed management	Change posted speed by X mph Set appropriate speed limit

2. Add a left-turn lane on one major approach to an unsignalized intersection. CMF values from the Harwood et al. (2003) study were also given for three- and four-leg unsignalized intersections.
3. Add a right-turn lane on one major approach to a signalized intersection. A CMF value was estimated by Harwood et al. (2003) for four-leg intersections in urban areas.
4. Add a right-turn lane on one major approach to an unsignalized intersection. A CMF value was estimated by Harwood et al. (2003) for four-leg intersections in rural areas.
5. Convert diamond interchange to diverging diamond interchange (DDI). Utilizing data from Kentucky, Missouri, New York, and Tennessee, Hummer et al. (2016) developed CMFs for total, injury, angle, rear-end, sideswipe, and single-vehicle crashes in urban areas.
6. Convert intersection on low-speed road to a roundabout. Utilizing data from Wisconsin, Qin, Bill, Chitturi, and Noyce (2013) calculated CMF values for intersection conversions on low-speed roads (posted speeds less than 45 mph on all approaches). The values were determined for all crashes and injury crashes and applicable for either urban or rural areas.
7. Convert intersection on high-speed road to a roundabout. The same study by Qin, Bill, et al. (2013) also determined CMF values for intersection conversions where at least one of the approaches was high-speed (speeds of 45 mph or greater).
8. Convert intersection to a single-lane roundabout. Qin, Bill, et al. (2013) estimated CMFs for all crashes and injury crashes for intersection conversions to a single-lane roundabout.
9. Convert intersection to a multilane roundabout. Qin, Bill, et al. (2013) estimated CMFs for all crashes and injury crashes for intersection conversions to a multilane roundabout.
10. Convert two-way stop-controlled intersection to a roundabout. Rodegerdts et al. (2007) and Qin, Bill et al. (2013) estimated CMFs applicable for urban and rural conversions of two-way stop-controlled intersections to roundabouts. The former study used data from a variety of states spread across the US, while the latter used data from Wisconsin. The CMFs were developed for total and injury crashes.
11. Convert all-way stop-controlled intersection to a roundabout. Rodegerdts et al. (2007) and Qin, Bill, et al. (2013) developed CMFs for total and injury crashes, applicable for urban and rural conversions of all-way stop-controlled intersections to roundabouts.
12. Convert signalized intersection to a roundabout. Rodegerdts et al. (2007), Gross, Lyon, Persaud, and Srinivasan (2013), and Qin, Bill, et al. (2013) employed data from across the US to evaluate the impact of converting signalized intersections to roundabouts. The Rodegerdts et al. (2007) and Qin, Bill, et al. (2013) studies were developed for total and injury crashes in urban and rural areas, while the Gross et al. (2013) study was applicable for total and injury crashes in urban areas.
13. Convert a non-controlled or yield-controlled intersection to a roundabout. Qin, Bill, et al. (2013) utilized urban and rural Wisconsin data to determine CMFs for total and injury crashes following the conversion of non-controlled or yield-controlled intersections to roundabouts.
14. Convert two-way stop-controlled intersection to J-turn intersection. CMFs were estimated by Edara, Sun, and Breslow (2014) for total and injury crashes following the installation of J-turn intersections located on rural four-lane divided, high-speed roads in Missouri.
15. Improve left-turn lane offset to create positive offset. Persaud, Lyon, Eccles, Lefler, and Gross (2009) estimated CMFs for total, injury, left-turn, and rear-end crashes using data from four-leg intersections in Wisconsin.
16. Improve intersection sight distance. Gan, Shen, and Rodriguez (2005) provided CMFs for intersection sight distance improvements. CMFs were given for total, right-angle, left-turn, and sideswipe crashes. Depending on the type of crash, the CMFs were developed based on data from Alaska, Arizona, California, Iowa, Kentucky, Minnesota, and Missouri.

E. Intersection Traffic Control

1. Change left-turn phasing on one approach from permitted to protected/permitted phasing. Utilizing North Carolina and Canadian data, Srinivasan et al. (2011) developed CMFs for urban total, injury, left-turn, and rear-end crashes at four-leg signalized intersections.
2. Change left-turn phasing on more than one approach from permitted to protected/permitted phasing. Srinivasan et al. (2011) developed CMFs total, injury, left-turn, and rear-end crashes at urban four-leg signalized intersections.
3. Change left-turn phasing from permitted or permitted/protected to protected-only phasing. Utilizing data from North Carolina, Harkey et al. (2008) provided CMFs for total and left-turn crashes for urban signalized intersections.
4. Supplement left-turn phasing from at least one permitted approach with flashing yellow arrow. Srinivasan et al. (2011) used data from urban four-leg signalized intersections in North Carolina, Oregon, and Washington to estimate CMFs for total and left-turn crashes.
5. Change left-turn phasing from protected/permitted to flashing yellow arrow. Srinivasan et al. (2011) developed CMFs for total and left-turn crashes occurring at four-leg signalized intersections in urban areas.
6. Change left-turn phasing from protected to flashing yellow arrow. CMFs were developed for total and left-turn crashes at urban four-leg signalized intersections by Srinivasan et al. (2011).
7. Convert two-way stop control to all-way stop control. Simpson and Hummer (2010) developed CMFs for the total, injury, frontal impact, and ran stop sign crash types at four-leg intersections in North Carolina.
8. Improve signal visibility. El-Basyouny, Sayed, El Esawey, and Pump (2012) estimated CMFs for the application of a variety of signal improvements at Canadian four-leg intersections in urban areas. The CMFs were developed for daytime and nighttime PDO and injury crashes.
9. Increase yellow change interval (1.0 seconds). CMFs were estimated by Srinivasan et al. (2011) using data from urban three- and four-leg signalized intersections in California and Maryland. The CMFs were provided for total, injury, rear-end, and angle crashes.
10. Increase all-red clearance interval (average of 1.1 seconds). The study by Srinivasan et al. (2011) was consulted. CMFs were developed for total, injury, rear-end, and angle crashes at urban three- and four-leg signalized intersections.
11. Increase yellow interval (average of 0.8 seconds) and add all-red interval (average of 1.2 seconds). In the study by Srinivasan et al. (2011), the authors estimated the CMFs

for total, injury, rear-end, and angle crashes at urban three- and four-leg signalized intersections.

12. Install transverse rumble strips on approaches to stop-controlled intersection. Using data from Iowa and Minnesota, Srinivasan et al. (2010) developed CMFs for total crashes and different crash severity levels at rural three-leg and four-leg intersections (located on major collector roads).
13. Install new traffic signal at previously stop-controlled intersection. CMFs were provided by McGee, Taori, and Persaud (2003) for urban areas (using California, Florida, Maryland, Virginia, Wisconsin, and Canadian data) and by Harkey et al. (2008) for rural areas (using California and Minnesota data). The urban CMFs were given separately for total injury, right-angle injury, and rear-end injury crashes at three-leg and four-leg intersections. The rural CMFs were given for total, right-angle, rear-end, and left-turn crashes, applicable for three-leg or four-leg intersections.
14. Replace standard stop sign with flashing LED stop sign. A study by Davis, Hourdos, and Xiong (2014) involved the estimation of a CMF for right-angle crashes on two-lane Minnesota roads in which a flashing LED stop sign had been installed.
15. Retime signal change intervals to the Institute of Transportation Engineers (ITE) standards. Retting, Chapline, and Williams (2002) developed CMFs for urban four-leg signalized intersections using data from New York. Separate CMFs were developed for the overall total and injury crashes, as well as total and injury crashes of the following types: rear-end, right-angle, and vehicle/bicycle and vehicle/pedestrian.

F. ITS and Advanced Technology

1. Install actuated advance intersection warning system at high-speed intersection. Using data from Nebraska, Appiah, Naik, Wojtal, and Rilett (2011) developed CMFs for total, injury, rear-end, and right-angle crashes applicable to intersections where the major road was a high-speed four-lane divided highway.
2. Install changeable horizontal curve speed warning signs. Hallmark, Hawkins, and Smadi (2015) developed a CMF for total crashes on rural two-lane roads using data from a number of states spread across the country.
3. Install variable speed limit signs. A CMF was estimated for total crashes by Bham et al. (2010) using data from urban principal arterial interstates in Missouri.
4. Install “Vehicle Entering When Flashing” (VEWF) system with advance post mounted signs on major approach and loops on minor approach. Simpson and Troy (2013) estimated CMFs for total, injury, and target crashes (angle, head-on, left-turn, and right-turn) occurring on North Carolina highways with mainline approach speeds of 35–55 mph.

G. Pavement

1. Improve pavement condition from poor (critical condition index below 60) to good (critical condition index above 70). Zeng, Fontaine, and Smith (2014) estimated CMFs for total crashes and for injury crashes on rural two-lane roads in Virginia.

H. Pedestrians

1. Construct pedestrian bridge or tunnel. Gan et al. (2005) provided a CMF for pedestrian-related crashes in urban areas based on data from Alaska, Arizona, Kentucky, and Missouri.
2. Install High intensity Activated crossWalK (HAWK) at intersection. Fitzpatrick and Park (2010) developed CMFs for total, severe injury, and pedestrian-related crashes in urban areas utilizing Arizona data. The analyzed sites were for crosswalks crossing four- to six-lane roads.
3. Install sidewalk. Gan et al. (2005) provided an urban CMF for pedestrian-related crashes based on data from Alaska, Arizona, Kentucky, Missouri, and Oklahoma.

I. Railroads

1. Build grade-separated crossing. Based on results from Iowa, Gan et al. (2005) provided a CMF for total crashes that may be expected after a grade-separated railroad crossing has been built.
2. Eliminate railroad crossing. Additionally, Gan et al. (2005) provided a CMF for total crashes for the elimination of a railroad crossing.
3. Install gates at crossings with signs. Park and Saccomanno (2005) utilized data from Canada to estimate a CMF applicable to total crashes on arterials, collectors, and local roads.
4. Upgrade signs to flashing lights. The same study by Park and Saccomanno (2005) estimated a CMF for total crashes on arterials, collectors, and local roads based on the Canadian data.

J. Roadside

1. Increase median width. Stamatiadis, Pigman, Sacksteder, Ruff, and Lord (2009) developed CMFs for increasing the median width on rural four-lane divided highways using data from California, Kentucky, and Minnesota.
2. Install guardrail. Gan et al. (2005) provided CMFs for total, minor injury, severe injury, and run-off-the-road crashes based on data from Arizona, Iowa, Indiana, Kentucky, and Missouri.
3. Install cable median barrier (high-tensioned) on depressed median of 50 feet wide or wider. Villwock, Blond, and Tarko (2009) developed CMFs for rural principal arterial interstates in Indiana. CMF values were provided for multiple-vehicle, opposite direction crashes and for single-vehicle crashes.
4. Install concrete median barrier. Tarko, Villwock, and Blond (2008) estimated CMFs for single-vehicle and multiple-vehicle crashes on rural interstates using an extensive dataset from states across the country, including Indiana.
5. Change in sideslope from 1V:3H to 1V:4H. Elvik and Vaa (2004) provided CMFs for PDO and injury crashes in rural areas.
6. Change in sideslope from 1V:4H to 1V:6H. Elvik and Vaa (2004) provided CMFs for PDO and injury crashes in rural areas.
7. Remove or relocate fixed objects outside of clear zone. Hovey and Chowdhury (2005) estimated CMFs for total and injury crashes on arterials and collectors in Ohio.

K. Road Diet

1. Re-stripe four-lane undivided road to three-lane (with TWLTL). Using data from California, Iowa, and Washington, Harkey et al. (2008) developed a CMF applicable to total crashes occurring on minor arterials in urban areas.

L. Roadway Delineation

1. Add no passing striping. The CMFs for no passing striping came from a study by Gan et al. (2005). The authors provided a CMF for total crashes on rural roads based on data from Montana. Furthermore, CMFs for head-on and sideswipe crashes on rural roads (based on Kentucky and Missouri data) were given in the report.
2. Install centerline rumble strips. CMFs for the installation of centerline rumble strips were developed for rural and urban two-lane roads in a study by Torbic et al. (2009). The authors used data from a variety of states spread across the county. The CMFs were for total and injury crashes on the rural roads, as well for total and injury target crashes (head-on and opposite-direction sideswipe). For urban roads, the significant CMFs were for total and injury target crashes.
3. Install shoulder rumble strips. The same study by Torbic et al. (2009) was consulted for CMFs associated with the installation of shoulder rumble strips on rural two-lane roads and rural freeways. Data from Minnesota, Missouri, and Pennsylvania was used for estimating the CMFs, which were provided for both total and injury single-vehicle run-off-the-road crashes.
4. Install centerline plus shoulder rumble strips. Kay et al. (2015) and Lyon, Persaud, and Eccles (2015) developed rural CMFs for the installation of centerline rumble strips in combination with shoulder rumble strips. Using data from Michigan, Kay et al. (2015) developed a CMF for total crashes on two-lane roads. The study by Lyon et al. (2015) utilized data from Kentucky, Missouri, and Pennsylvania to develop CMFs for total, injury, head-on, run-off-the-road, and opposite-direction sideswipe crashes.
5. Install edgeline pavement marking on curves. Tsyganov, Warrenchuk, and Machemehl (2009) estimated CMFs for edgeline installations on curves for rural two-lane roads. Using data from Texas, the CMFs were developed for total, run-off-the-road, and speed-related (nighttime) crashes.
6. Install edgeline pavement markings on tangent sections. Similarly, Tsyganov et al. (2009) developed CMFs for edgeline installations on tangent sections of rural two-lane roads. CMFs were provided for total, run-off-the-road, and speed-related (nighttime) crashes.
7. Install raised pavement markers. Bahar et al. (2004) estimated CMFs for total nighttime crashes on rural two-lane highways and four-lane freeways. Data from the two-lane facilities was obtained from Illinois, New Jersey, New York, and Pennsylvania, while data from the four-lane facilities was obtained from Missouri, New York, Pennsylvania, and Wisconsin. Separate CMFs were provided based on the road's AADT and the curve radius (R => 1640 feet or R < 1640 feet) for two-lane highways and based solely on the road's AADT for four-lane freeways.

Note: To apply this countermeasure to a two-lane highway segment with multiple curves, the segment would need to be subdivided into the part(s) of the segment with R => 1640 feet (which includes tangent sections) and the part(s) of the segment with R < 1640 feet. The separate CMFs for the different curve radii R may be applied to these distinct parts.

M. Segments

1. Increase in number of through lanes. Based on Indiana conditions, Tarko et al. (2015) presented CMFs for PDO and injury crashes for urban multilane roadway segments.
2. Convert two-lane roadway to four-lane divided roadway. Using Florida data, Ahmed, Abdel-Aty, and Park (2015) developed CMFs for urban and rural total, PDO, and injury crashes, applicable for the conversion of a two-lane roadway to a four-lane divided roadway.
3. Change in lane and shoulder width from 12 foot lane width and 6 foot shoulder width. CMFs for the effect of changing the lane and shoulder width from base conditions of 12 foot lane width and 6 foot shoulder width were developed by Gross, Jovanis, Eccles, and Chen (2009) using data from rural two-lane roadways in Pennsylvania. The CMFs were applicable for run-off-the-road, head-on, and sideswipe crashes. Furthermore, Le and Porter (2013) developed CMFs for lane and shoulder width combinations using data from urban and suburban arterials in Illinois. The researchers provided the CMFs as functions for injury crashes.
4. Extend on-ramp acceleration lane by 30 meters (about 100 feet) at grade-separated junction. Elvik and Vaa (2004) presented a CMF for total crashes. The CMF applied only to lanes up to 200 meters (656 feet) in length.
5. Extend off-ramp deceleration lane by 30 meters (about 100 feet) at grade-separated junction. A CMF for total crashes was given by Elvik and Vaa (2004), applicable for lanes up to 200 meets (656 feet) in length.
6. Install passing relief lane. Bagdade et al. (2012) estimated CMFs for rural two-lane roads using Michigan data. The researchers determined CMFs for total, injury, target (head-on, rear-end, run-off-the-road, and sideswipe), peak month (June, July, and August) and off-peak month crashes for passing relief lanes between 1.0 and 2.9 miles long.
7. Increase in lane width. Tarko et al. (2015) developed CMFs for PDO and injury crashes for urban and rural two-lane and multilane roadway segments, using data from Indiana.

N. Shoulder Treatment

1. Increase right shoulder width. Based on data from Indiana, Tarko et al. (2015) developed CMFs for urban and rural two-lane and multilane facilities. The urban CMFs were for PDO crashes on two-lane and multilane roads, and the rural CMFs were for PDO and injury crashes on two-lane roads and injury crashes on multilane roads.
2. Increase left/inside shoulder width. Tarko et al. (2015) provided CMFs for injury crashes on urban multilane roads and PDO and injury crashes on rural multilane roads in Indiana.

O. Signs

1. Install chevron signs on horizontal curves. Srinivasan et al. (2009) developed CMFs for rural total, injury,

lane departure, nighttime, and nighttime lane departure crashes utilizing data from Washington State.

2. Increase retroreflectivity of stop signs. Persaud, Lyon, Eccles, Lefler, and Amjadi (2008) estimated CMFs for total, injury, right-angle, rear-end, daytime, and nighttime crashes for stop-controlled intersections in Connecticut and South Carolina, which included both three- and four-leg intersections.
3. Install flashing beacons at stop-controlled intersections. Srinivasan et al. (2008) determined CMFs for total crashes in rural and urban areas utilizing data from two-lane highways in North Carolina and South Carolina.

P. Speed Management

1. Change posted speed limit. CMFs for lowering or raising the posted speed limit in various increments were estimated by Parker (1997) using data from twenty-two states across the US.
2. Set appropriate speed limit. A CMF value for total crashes was provided by Gan et al. (2005) based on Kentucky, Missouri, and Montana data.

3. METHODOLOGY FOR CALIBRATING THE IHSDM

3.1 Background

Among the main components of the HSM predictive method, SPFs play perhaps the greatest role in predicting crashes. Calibration efforts focusing on updating the HSM SPFs have been conducted by researchers for several states, including Kansas (Lubliner, 2011; Lubliner & Schrock, 2012), Missouri (Sun, Brown, Edara, Claros, & Nam, 2013), Oregon (Dixon, Monsere, Xie, & Gladhill, 2012), South Dakota (Qin, Rahman Shaon, & Chen, 2016), Utah (Brimley, Saito, & Schultz, 2012), and Virginia (Kweon, Lim, Turpin, & Read, 2014). Some researchers have also developed jurisdiction-specific SPFs that have additional variables beyond the base HSM exposure variables, including the following: shoulder width, presence of rumble strips, speed limit, truck percentages, and regional variables (Brimley et al., 2012; Qin et al., 2016). More accurate results may be possible by developing the SPFs with the full functional form rather than adding CMFs separately to the base SPF. However, it is not possible to modify the SPF structure in the IHSDM, so calibration must be consistent with the constraints of the software.

CMFs comprise the second component of the HSM predictive method. The HSM CMFs are compiled from a variety of sources which do not necessarily have the same base conditions. National and international studies have found that the HSM CMFs may not be suitable for their particular area (Abdel-Aty et al., 2014; Sacchi, Persaud, & Bassani, 2012). These results indicate the need for calibrating not only the SPFs but also the CMFs to local conditions. The IHSDM expresses CMFs in various forms that differ across the CMFs and may be inconsistent with the format used by others in past studies. In order to facilitate transferring the past research results to the IHSDM, a calibration procedure should be able to deal with these differences.

Calibration factors are the third component of the HSM predictive method. Numerous researchers have updated the calibration factors for their respective jurisdictions (Banihashemi, 2011; Fitzpatrick, Schneider, & Carvell, 2006; Mehta, & Lou, 2013; Persaud, Lord, & Palmisano, 2002; Shin, Lee, & Dadvar, 2014; Sun, Magri, Shirazi, Gillella, & Li, 2011; Xie, Gladhill, Dixon, & Monsere, 2011). Researchers have found that calibration factors may vary not only across different parts of a region, but also based on geometric characteristics (for instance, tangent versus horizontal curve segments) (Fitzpatrick, Schneider, et al., 2006). Mehta and Lou (2013) proposed an approach that involves calibration factor estimation as a special case of SPF estimation. The authors also developed an area-specific SPF (including AADT, segment length, lane width, and speed limit) which they found to outperform the adjusted base SPFs with calibration factors.

Finally, other researchers have examined the applicability of the IHSDM within and outside of the US, as well as its calibration scope (Bansen & Passetti, 2005; Dominguez-Lira, Castro, Pardillo-Mayora, & Gascón-Varón, 2010; Donnell, Gross, Stodart, & Opiela, 2009; Koorey, 2010; Marchionna, Perco, & Falconetti, 2012; Martinelli, La Torre, & Vadi, 2009). Donnell et al. (2009) provided recommendations on the need to expand the capabilities of the IHSDM's design consistency module to consider low-speed, complex alignments. Koorey (2010) incorporated crash proportions data from New Zealand's rural two-lane highways to predict crashes using the IHSDM, finding it to provide superior "local calibration" than by using sub-national calibration parameters. Bansen and Passetti (2005) used the IHSDM in evaluating the impacts of various geometric design alternatives on a 23-mile long corridor. The authors discussed the intensive data needs of the IHSDM, for this reason suggesting that its use may be better suited to the design community where data is more readily available.

There has been a substantial amount of work directed towards calibrating the HSM for regional/state conditions. The majority of previous studies focused on calibrating the SPFs. Separate estimation of SPFs and CMFs is questionable. Furthermore, the previous literature highlighted some of the constraints of implementing the HSM predictive method in the IHSDM. A methodology is needed that estimates the SPFs and CMFs and allows incorporation of CMFs from past research into a form compatible with the IHSDM.

3.2 Methodological Framework

To meet the identified void in the IHSDM calibration methodology, a comprehensive approach to calibrating the components of the HSM predictive method is proposed here that regards the structure of the IHSDM. First, the CMFs in their IHSDM format are adjusted to the local data and past results. Then, those CMFs are converted to an overall CMF and incorporated in the comprehensive safety model as an offset variable to estimate the expected crash frequency. This method preserves the crash prediction consistency, and the step to estimate the calibration parameter is eliminated.

Chapters 10 and 11 of the HSM (AASHTO, 2010) present the general form of the crash prediction model for rural two-lane and rural multilane roadway facilities. The model is presented here in Equation 3.1. The model form is similar for urban/suburban arterials, with the addition of terms for vehicle-pedestrian and vehicle-bicycle collisions.

$$N_p = N_{spf} \cdot (CMF_1 \cdot CMF_2 \cdot \ldots \cdot CMF_x) \cdot C \qquad (3.1)$$

where:

N_p is the predicted average crash frequency for an individual roadway facility for a specific year,

N_{spf} is the predicted average crash frequency under base conditions for an individual roadway facility,

$CMF_1, CMF_2, \ldots, CMF_x$ are the HSM crash modification factors for road features x, and

C is the calibration factor for roadway facilities of a specific type to account for the discrepancy between the actual safety in a specific jurisdiction or geographical areas and its prediction.

The first step in the methodology involves reconciling the HSM CMFs in IHSDM format with those obtained from local data and past results. In this step, CMFs for local conditions must have the same base conditions b as the HSM CMFs. Let the local CMF for road feature x and containing other confounding variables y (for example, AADT) be given as $CMF_{local}(x,y,b)$. The corresponding HSM CMF for road feature x, confounding variables z, and parameters β can be represented as $CMF_{HSM}(x,z,\beta,b)$. The β parameters of the HSM CMF may be adjusted so as to minimize the overall discrepancy between the factors, where $i=1 \ldots m$ applies to observations in the sample used for fitting the CMFs:

$$\min_{\{\beta\}} \sum_{i=1}^{m} \left[CMF_{local}(x_i,y_i,b) - CMF_{HSM}(x_i,z_i,\beta,b)\right]^2 \qquad (3.2)$$

The obtained adjusted parameter values, $\hat{\beta}$, may be entered into the IHSDM for the CMF being considered. The same procedure is repeated for each CMF from $j=1 \ldots n$ contained in the IHSDM and for which a corresponding local CMF is available. CMFs that are a part of the IHSDM, but for which local CMFs are not available utilize the HSM CMFs with default β parameters. The overall CMF_{All} including adjusted parameters $\hat{\beta}$ is calculated with Equation 3.3 for each observation in the sample to be used to calibrate the SPF:

$$CMF_{All} = \Pi_{j=1}^{n} CMF_{HSM}(x_j,z_j,\hat{\beta}_j,b_j) \qquad (3.3)$$

In the second step, CMF_{All} is incorporated as an offset variable in the estimation of the calibrated SPF for local conditions. The SPF is shown here for roadway segments.

$$SPF = e^{\alpha_0} \cdot AADT^{\alpha_1} \cdot L^{\alpha_2} \cdot CMF_{All} \cdot e^{\varepsilon} \qquad (3.4)$$

where:

SPF is the safety performance function calibrated for local conditions,

$AADT$ is the annual average daily traffic (veh/day),

L is the segment length (mi.),

$\alpha_0, \alpha_1, \alpha_2$ are the parameter estimates based on local data, and

e^{ε} is the error term that follows gamma distribution with mean equal to 1 and variance equal to the overdispersion.

The format of the SPF is consistent with that of the IHSDM for rural multilane divided segments, and the α parameters may be entered directly into the IHSDM. For rural two-lane undivided segments, the SPF must be rearranged slightly after estimation so that its format is compatible with the IHSDM.

4. CALIBRATION DATA

The highway facilities examined in this research include rural two-lane undivided segments, rural multilane divided segments, and urban/suburban arterial segments. The data available for these segments included three years (2013–2015) of crash data, road geometrics, and traffic volumes. Police-reported crashes were retrieved through the Automated Reporting Information Exchange System (ARIES) crash portal. The road geometrics and traffic volumes came from records maintained by the Indiana Department of Transportation (INDOT). The calibration procedure could not be completed for the intersections as the minor approach AADT data is not available in the current data portal.

For rural two-lane undivided segments, the total annual crash frequency had a mean of 1.84 and a standard deviation of 3.08, with a maximum of 72 crashes. Segment lengths vary from relatively short (0.02 mi.) to around a mile (0.99 mi.), with an average segment length of 0.65 mi. Only tangent segments were used to model the crash data and CMF calibration. The mean corridor AADT was 3623 veh/day for two-lane. The Indiana average is lower than the HSM base condition for lane width and shoulder width. Developing jurisdiction-specific SPFs with a very small sample size may yield impractical results and undermine safety effects. Therefore, all the data from Indiana rural two-lane undivided segments has been used to develop the SPF and calibrating CMF parameters for use in the IHSDM. Table 4.1 shows the summary statistics of the crash, geometric, and traffic data for rural two-lane undivided segments. The table also presents the HSM base conditions for different geometric variables.

The HSM recommends to update the default proportions for severity levels and collision types based on local data for a particular jurisdiction as part of the calibration process. The related crash percentage is 100.00% for Indiana, since Indiana roadway segments consist of only the crashes that are defined as related

TABLE 4.1
Summary of Crash Data, Road Geometrics, and Traffic Volumes for Rural Two-Lane Undivided Segments

Data type	Average	Min	Max	Std. dev.	HSM base condition
Crashes (3 years)	1.84	0	72	3.08	–
AADT (veh/day)	3623	60	17460	2638	–
Segment length (mi.)	0.65	0.02	0.99	0.21	–
Lane width (ft)	11.30	8.5	13	1.01	12
Shoulder width (ft)	3.94	0	13	2.56	6
Number of segments				5774	

TABLE 4.2
Indiana and HSM Crash Severity Distribution on Rural Two-Lane Undivided Segments (All Values in Percent)

Crash severity level	Indiana	HSM default
Fatal	1.06	1.3
Incapacitating Injury	5.09	5.4
Nonincapacitating injury	10.30	10.9
Possible injury	1.34	14.5
Total fatal plus injury	17.79	32.1
Property damage only	82.20	67.9
Total	*100*	*100*

TABLE 4.3
Indiana and HSM Collision Type Distribution for Rural Two-Lane Undivided Segments (All Values in Percent)

	Fatal and injury		PDO		Total	
Crash Types	**Indiana**	**HSM**	**Indiana**	**HSM**	**Indiana**	**HSM**
Single Vehicle						
Collision with animal	4.81	3.8	45.77	18.4	38.48	12.1
Collision with bicycle	0.48	0.4	0.02	0.1	0.10	0.2
Collision with pedestrian	0.90	0.7	0.05	0.1	0.20	0.3
Overturned	7.08	3.7	2.50	1.5	3.32	2.5
Ran off road	44.48	54.5	21.16	50.5	25.31	52.1
Other single-vehicle crash	1.32	0.7	4.84	2.9	4.21	2.1
Total single-vehicle crashes	*59.06*	*63.8*	*74.34*	*73.5*	*71.62*	*69.3*
Multiple Vehicle						
Angle collision	6.02	10.1	2.32	7.2	2.98	8.5
Head-on collision	8.45	3.4	0.81	0.3	2.17	1.6
Rear-end collision	14.47	16.5	9.08	12.2	10.04	14.2
Sideswipe collision	7.45	3.8	5.13	3.8	5.55	3.7
Other multi-vehicle collision	4.54	2.6	8.31	3.0	7.64	2.7
Total multiple-vehicle crashes	*40.94*	*36.4*	*25.66*	*26.5*	*28.38*	*30.7*
Total crashes	**100**	**100**	**100**	**100**	**100**	**100**

crashes in the HSM. Table 4.2 and Table 4.3 provide the Indiana percentages for crash severity and collision types for rural two-lane undivided segments. These tables are used to separate the crash frequencies into components by severity level and collision type. The tables also present the HSM's default percentages for severity levels and collision types. Table 4.2 shows that the percentage of possible injury crashes in Indiana is very low compared to the HSM default. The definition of possible injury is subject to the interpretation of the police officer, and this could be the primary reason for the notable difference. The Indiana crash percentages also can be found in Appendix B.

As shown in Table 4.4, the total annual crash frequency had a mean of 3.21 and a standard deviation of 4.67, with a maximum of 48 crashes on rural multilane divided segments. The mean corridor AADT was 11,969 veh/day for multilane divided segments. Segment lengths vary from relatively short (0.04 mi.) to around a mile (0.99 mi.), with an average segment length of 0.64 mi.

TABLE 4.4
Summary of Crash Data, Road Geometrics, and Traffic Volumes for Rural Multilane Divided Segments

Data type	Average	Min	Max	Std. dev.	HSM base condition
Crashes (3 years)	3.21	0	48	4.67	–
AADT (veh/day)	11969	2220	29390	6275	–
Segment length (mi.)	0.64	0.04	0.99	0.20	–
Lane width (ft)	11.91	11	13	0.30	12
Shoulder width (ft)	9.54	0	14	2.47	8
Median width (ft)	48.83	3	100	13.84	30
Number of segments			782		

TABLE 4.5
Indiana and HSM Crashes by Collision Type and Crash Severity Level for Rural Multilane Divided Segments (All Values in Percent)

	Total		Fatal and injury		Fatal and injury*		PDO	
Collision type	Indiana	HSM	Indiana	HSM	Indiana	HSM	Indiana	HSM
Head-on	0.68	0.6	1.55	1.3	1.47	1.8	0.46	0.2
Sideswipe	7.23	4.3	6.02	2.7	6.11	2.2	7.52	5.3
Rear-end	17.84	11.6	29.13	16.3	28.42	11.4	15.14	8.8
Angle	4.76	4.3	10.68	4.8	10.53	4.5	3.34	4.1
Single	64.58	76.8	49.52	72.7	50.32	77.8	68.18	79.2
Other	4.91	2.4	3.11	2.2	3.16	2.3	5.34	2.4

*Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

TABLE 4.6
Summary of Crash Data, Road Geometrics, and Traffic Volumes for Urban/Suburban Arterial Segments

Data type	Average	Min	Max	Std. dev.	HSM base condition
Multiple-vehicle non-driveway crashes	2.45	0	215	11.02	–
Single-vehicle crashes	1.53	0	27	2.90	–
AADT (veh/day)	16045	790	72700	10360	–
Segment length (mi.)	0.56	0.03	0.99	0.23	–
Lane width (ft)	11.51	9	13	1.25	12
Shoulder width (ft)	4.83	0	13	3.91	8
Median width (ft)	29.76	2	100	20.55	15
Number of segments				820	

The Indiana average is slightly lower than the HSM base condition for lane width but higher for shoulder width and median width. Developing jurisdiction-specific SPFs with a very small sample size may yield impractical results and undermine safety effects. Therefore, all the data from Indiana multilane segments has been used to develop the SPF and calibrating CMF parameters for use in the IHSDM. Table 4.4 shows the summary statistics of the crash, geometric, and traffic data for rural multilane divided segments. The HSM base conditions for different geometric variables are also provided.

The Indiana related crash percentage is 100.00%, the same as for rural two-lane undivided segments. Indiana percentages by collision type and severity on rural multilane divided segments are presented in Table 4.5. Furthermore, the table presents the HSM's default percentages for collision types and severity levels. Appendix B also contains the Indiana crash percentages for rural multilane divided segments.

Multiple-vehicle non-driveway collisions are more frequent than the single-vehicle crashes on urban/suburban arterial segments. The mean corridor AADT was 16,045 veh/day for urban/suburban arterial segments. Segment lengths vary from relatively short (0.03 mi.) to around a mile (0.99 mi.), with an average segment length of 0.56 mi. The Indiana average is lower than the HSM base condition for lane width and shoulder width but higher for median width. Table 4.6 shows the summary statistics of the crash, geometric, and traffic data for urban/suburban arterial segments, as well as the HSM's base condition for different geometric variables.

Table 4.7 provides the Indiana percentages for multiple-vehicle non-driveway crashes on urban/suburban arterial segments. This table is used to separate the

TABLE 4.7
Indiana Crash Distributions for Urban/Suburban Arterial Segments (All Values in Percent)

		Multiple-vehicle non-driveway crashes						
Facility type	**Severity**	**Rear-end**	**Head-on**	**Angle**	**Sideswipe same direction**	**Sideswipe opposite direction**	**Other**	**Total**
Two-lane undivided	KABC	51.00	13.00	17.00	3.00	2.00	14.00	100
arterials (2U)	PDO	45.95	1.65	11.26	14.71	2.85	23.57	100
Four-lane undivided	KABC	50.88	7.02	26.32	5.26	0.00	10.53	100
arterials (4U)	PDO	41.86	0.47	12.09	16.28	2.33	26.98	100
Four-lane divided	KABC	65.74	3.90	12.81	7.80	0.56	9.19	100
arterials (4D)	PDO	48.88	2.58	8.66	22.55	1.39	15.94	100

crash frequencies into components by severity level and collision type. Appendix B also contains the Indiana crash percentages for urban/suburban arterial segments.

5. CALIBRATING THE IHSDM FOR INDIANA

To preserve the IHSDM structure, the calibration process presented in this report involves fitting the HSM CMF's to local data or CMFs and calibrating the SPFs to data with the already fitted CMFs included as offset variables. All these calibrated CMF and SPF parameters and updated crash distributions and proportions must be entered in the IHSDM Administration Tool. Appendix C presents the updated IHSDM Administration Tool with the Indiana configuration. Table 5.1 presents the CMFs that could be calibrated for the various facility types based on the available Indiana data.

Indiana CMFs were obtained from a report by Tarko et al. (2015), and these CMFs were reconciled with the HSM CMFs to better reflect current Indiana conditions in the IHSDM tool. Note that the Indiana CMFs have an exponential form and are based on the difference between the actual lane width or shoulder width and the corresponding HSM base condition. Whereas the HSM CMFs are based on the AADT and other cofounding variables for different geometric features. Table 5.2 shows the Indiana and HSM CMFs for lane width and shoulder width.

where:

LW and *SW* are the lane width and shoulder width (both in ft), respectively,

LW_{bt}, SW_{bt}, LW_{bm}, and SW_{bm}, are the HSM base conditions for lane width on rural two-lane undivided segments (12 ft), shoulder width on rural two-lane undivided segments (6 ft), lane width on rural multilane divided segments (12 ft), and shoulder width on rural multilane divided segments (8 ft), respectively,

CMF_{RA} is the CMF for related crash types (run-off-road, head-on, and sideswipe crashes),

p_{RA} is the proportion of total crashes which are related crashes, and

a, b, c, d are parameters.

It should be noted that CMF_{RA} is presented based on three different AADT levels for lane and shoulder width on rural two-lane undivided segments and for lane width on rural multilane divided segments. These AADT levels are as follows: low if AADT<400, moderate if 400≤AADT≤2000, and high if AADT>2000. For the low and high AADT categories, the *b* and *c* parameters have default values of 0 and the equation includes only parameter *a*. The majority of Indiana's rural two-lane undivided segments and all of the multilane undivided segments fall within the high AADT category. For the moderate AADT category, the *a* and *b* parameters may be fitted by minimizing the sum of squared discrepancies in Equation 3.2. Since the Indiana CMFs are not dependent on AADT, the optimization process fitted only the *a* parameter while setting the *b* parameter (associated with the AADT in CMF_{RA}) to zero.

TABLE 5.1
Available CMFs from Indiana for Various Facility Types

Facility type	**CMF**
Rural two-lane undivided segments	Lane width Shoulder width
Rural multilane divided segments	Lane width Shoulder width

The form of the Indiana CMFs are such that they are compatible with the HSM base condition. Hence, the CMF equation that associates total and related crashes for Indiana may be written as shown in Equation 5.1. In the equation, the proportion of total crashes which are related crashes for Indiana is given as $p_{Ind}{\cdot}p_{Ind}$ is represented as 1 since Indiana roadway segments consist of only the crashes that are defined as related crashes in the HSM.

$$CMF_{Ind} = (CMF_{RA} - 1.0) \cdot p_{Ind} + 1.0 \qquad (5.1)$$

This equation may be solved for CMF_{RA} and rewritten with the Indiana CMF substituted into the equation:

$$CMF_{RA} = \frac{e^{\beta_W (W - W_b)} - 1}{p_{Ind}} + 1 \qquad (5.2)$$

where:

β_W is the Indiana coefficient for lane width or shoulder width,

TABLE 5.2
CMFs from Indiana and the HSM for different facility types

Variable	Indiana	HSM
Rural two-lane undivided segments		
Lane width	$CMF_{Ind}=e^{-0.08125(LW-LW_{bt})}$	$CMF_{HSM}=(CMF_{RA}-1.0)\cdot p_{RA}+1.0$, where $CMF_{RA}=a+(b\cdot 10^{c}\cdot(AADT-d))$
Shoulder width	$CMF_{Ind}=e^{-0.0256(SW-SW_{bt})}$	$CMF_{HSM}=(CMF_{RA}-1.0)\cdot p_{RA}+1.0$, where $CMF_{RA}=a+(b\cdot 10^{c}\cdot(AADT-d))$
Rural multilane divided segments		
Lane width	$CMF=e^{-0.2164(LW-LW_{bm})}$	$CMF=(CMF_{RA}-1.0)\cdot p_{RA}+1.0$, where $CMF_{RA}=a+(b\cdot 10^{c}\cdot(AADT-d))$
Shoulder width	$CMF=e^{-0.0412(SW-SW_{bm})}$	$CMF=$ 1.18 for SW = 0 ft ... CMF = 1.00 for $SW \geq$ 8 ft

TABLE 5.3
Calibrated and Default CMF_{RA} for Lane Width on Rural Two-Lane Undivided Segments

		Default CMF_{RA}		
Lane width (ft)	**Calibrated CMF_{RA}**	**<400 AADT**	**400 to 2000 AADT**	**>2000 AADT**
9	1.28	1.05	(1.05–1.50)	1.50
10	1.18	1.02	(1.02–1.30)	1.30
11	1.08	1.01	(1.01–1.05)	1.05
12	1.00	1.00	1.00	1.00

TABLE 5.4
Calibrated and Default CMF_{RA} for Shoulder Width on Rural Two-Lane Undivided Segments

		Default CMF_{RA}		
Shoulder width (ft)	**Calibrated CMF_{RA}**	**<400 AADT**	**400 to 2000 AADT**	**>2000 AADT**
0	1.17	1.10	(1.10–1.50)	1.50
2	1.11	1.07	(1.07–1.30)	1.30
4	1.05	1.02	(1.02–1.15)	1.15
6	1.00	1.00	1.00	1.00
8 or more	0.95	0.98	(0.98–0.87)	0.87

W is the lane width or shoulder width (ft), and
W_b is the HSM base condition for lane width or shoulder width (ft).

The calibrated and default values of the CMFs for lane width and shoulder width are presented in the sections for rural two-lane undivided segments and rural multilane divided segments. The next sections also presents the calibrated SPFs for different facility types.

5.1 Rural Two-Lane Undivided Segments

5.1.1 CMF Calibration

The calibrated and default values of CMF_{RA} for lane width are presented in Table 5.3 for rural two-lane undivided segments. The calibrated and default CMF_{RA} for lane width on rural two-lane undivided segments are relatively similar.

Table 5.4 presents the calibrated and default values of CMF_{RA} for shoulder width on rural two-lane undivided segments. The calibrated values of CMF_{RA} for shoulder width are within the range of the default values across all shoulder widths.

5.1.2 SPF Calibration

Equation 3.3 may be utilized to calculate the overall CMF_{All} for rural two-lane undivided segments based on the calibrated CMFs for Indiana conditions. As calculated in Equation 3.4, the SPF's for these road facilities predict crashes using AADT and segment length as exposure and CMF_{All} as the offset variable. SPF modeling was done with generalized linear modeling using the SAS GENMOD procedure (SAS Institute Inc., 2009). Table 5.5 presents the SPFs for total crashes on rural two-lane undivided segments. Note that the exposure

TABLE 5.5

Safety Performance Function for on Rural Two-Lane Undivided Segments Total Crashes using $\mathrm{CMF_{ALL}}$ as an Offset Variable

Parameter	Estimate	Std. Error	t-statistic	p-value
Intercept	-6.711	0.188	-35.77	<.0001
AADT	0.814	0.023	35.09	<.0001
Length L (mi.)	0.886	0.046	19.46	<.0001
Dispersion	0.985	0.034	28.63	
Offset Variable			CMF_{ALL}	
AIC			19581	
Pearson chi-square/DF			1.41	

TABLE 5.6

Comparison of the Safety Performance Function Parameters for Rural Two-Lane Undivided Segments—Total Crashes

Facility type	Calibrated SPF	Default SPF
Segments	$AADT^{0.814} \times Length^{0.886} \times 365 \times 10^{-6} \times e^{1.204} \times CMF$	$AADT^{1} \times Length^{1} \times 365 \times 10^{-6} \times e^{-0.312}$

TABLE 5.7

Predicted Crashes for Rural Two-Lane Undivided Segment using Calibrated and Default Parameters

State Road 49	Calibrated Parameters	Default Parameters
Total crashes (3 years)	3.18	3.37
Fatal and injury (FI) crashes	0.57	1.08
Property damage only (PDO) crashes	2.61	2.29

TABLE 5.8

Calibrated and Default $\mathrm{CMF_{RA}}$ for Lane Width on Rural Multilane Divided Segments

		Default CMF_{RA}		
Lane width (ft)	Calibrated CMF_{RA}	<400 AADT	400 to 2000 AADT	>2000 AADT
9	1.91	1.03	(1.03–1.25)	1.25
10	1.54	1.01	(1.01–1.15)	1.15
11	1.24	1.01	(1.01–1.03)	1.03
12	1.00	1.00	1.00	1.00

variables are statistically significant for this facility type.

The model structure of the safety performance function for the rural two-lane undivided segments must be rearranged (as shown in Table 5.6) slightly so that it is consistent with the format of the IHSDM and can be implemented in the tool.

5.1.3 Example Case

A segment of State Road 49 in Northwest Indiana was examined. This 2000-foot segment had an AADT of 10,350, lane width of 11 feet, and shoulder width of 5 feet. Table 5.7 provides a comparison of the crash prediction results using the calibrated and default parameters.

For the selected roadway segment, the predicted number of total crashes was slightly lower when using the calibrated parameters versus the default parameters. When splitting the crashes by severity, however, it can be seen that using the default parameters led to an overstated number of FI crashes and an understated number of PDO crashes.

5.2 Rural Multilane Divided Segments

5.2.1 CMF Calibration

Table 5.8 presents the calibrated and default CMF_{RA} for lane width on rural multilane divided segments. It is interesting to note that the calibrated and default CMF_{RA} for lane width on rural multilane divided segments are considerably different. This result shows the importance of calibrating the default values to region-specific values. Although the calibrated CMF values are not sensitive to the AADT due to the lack of Indiana data to preserve this differentiation, the considerable difference between the calibrated and default results prompts for applying simple but correct models instead of more elaborated models that are not supported by local data. The presented example illustrates a practical strategy of simplifying a model if necessary due to the lack of data while following the IHSDM overall structure and making the results still implementable via the IHSDM.

TABLE 5.9
Calibrated and Default CMF for Shoulder Width on Rural Multilane Divided Segments

Shoulder width (ft)	Calibrated *CMF*	Default *CMF*
0	1.39	1.18
2	1.28	1.13
4	1.17	1.09
6	1.08	1.04
8 or more	1.00	1.00

Table 5.9 presents the calibrated and default *CMF* for shoulder width on rural multilane divided segments. The calibrated *CMF* values for shoulder width are higher than the default values. In this case, the CMF values may be directly replaced with the Indiana CMF values in the IHSDM since the base conditions are consistent.

5.2.2 SPF Calibration

Table 5.10 presents the safety performance model results for total crashes on rural multilane divided segments. For rural multilane divided segments, this model structure assumes the SPF format of the IHSDM, and the estimated parameters may be entered directly into the software.

Table 5.11 summarizes the results for KABC and KAB crash severities on rural multilane divided segments. Note that the exposure variables are also statistically significant for different severity types.

Table 5.12 summarizes the calibrated and default SPFs for total, KABC and KAB crashes rural multilane

TABLE 5.10
Safety Performance Function for Rural Multilane Divided Segments-Total Crashes using $\mathrm{CMF_{ALL}}$ as an Offset Variable

Parameter	Estimate	Std E	t-statistic	p-value
Intercept	-10.074	0.749	-13.43	<.0001
AADT	1.139	0.080	14.11	<.0001
Length *L* (mi.)	0.749	0.110	6.81	<.0001
Dispersion	1.083	0.086	12.58	
Offset Variable	CMF_{ALL}			
AIC	3359			
Pearson chi-square/DF	1.05			

TABLE 5.11
Safety Performance Functions for Rural Multilane Divided Segments—KABC and KAB Crashes using $\mathrm{CMF_{ALL}}$ as an Offset Variable

	Rural Multilane Divided KABC				Rural Multilane Divided KAB			
Parameter	Estimate	Std E	t-statistic	p-value	Estimate	Std E	t-statistic	p-value
Intercept	-12.736	1.096	-11.62	<.0001	-12.717	1.106	-11.49	<.0001
AADT	1.238	0.116	10.68	<.0001	1.230	0.117	10.52	<.0001
Length *L* (mi.)	0.608	0.169	3.60	<.0003	0.669	0.172	3.88	0.0001
Dispersion	0.806	0.148	5.43		0.708	0.144	4.49	
Offset Variable	CMF_{ALL}				CMF_{ALL}			
AIC	1527				1454			
Pearson chi-square/DF	1.05				1.04			

TABLE 5.12
Comparison of the SPF Parameters for Rural Multilane Divided Segments—Total Crashes

Severity level	Calibrated SPFs	Default SPFs
Total crashes	$exp(-10.074+1.139\times ln(AADT)+0.749\times ln(Length))\times \mathrm{CMF}$	$exp(-9.025+1.049\times ln(AADT)+ln(Length))$
KABC crashes	$exp(-12.736+1.238\times ln(AADT)+0.608\times ln(Length))\times \mathrm{CMF}$	$exp(-8.837+0.958\times ln(AADT)+ln(Length))$
KAB crashes	$exp(-12.717+1.230\times ln(AADT)+0.669\times ln(Length))\times \mathrm{CMF}$	$exp(-8.505+0.874\times ln(AADT)+ln(Length))$

divided segments. The parameter estimates for different severity levels reveal that there is a significant difference between the calibrated and default SPFs.

5.2.3 Example Case

A segment of US Highway 30 in Northeast Indiana was examined. This 3060-foot segment had an AADT of 17,220, lane width of 11 feet, shoulder width of 7 feet, and median width of 40 feet. The crash prediction results obtained by utilizing the calibrated and default parameters are shown in Table 5.13.

The predicted number of total crashes was greater when using the calibrated parameters versus the default parameters. Similarly as for the rural two-lane undivided segment, it can be seen that using the default parameters overstated the number of FI crashes while understating the number of PDO crashes.

TABLE 5.13
Predicted Crashes for Rural Multilane Divided Segments using Calibrated and Default Parameters

US Highway 30	Calibrated parameters	Default parameters
Total crashes (3 years)	7.17	5.96
Fatal and injury (FI) crashes	1.41	2.96
Property damage only (PDO) crashes	5.76	3.00

5.3 Urban/Suburban Arterial Segments

The SPF's for urban/suburban arterial segments predict crashes using AADT and segment length as exposure and CMF_{All} as the offset variable. Due to the unavailability of the minor road AADT data, the SPF calibration could not be conducted for urban/suburban intersections. Also, the HSM-specified CMF variables were not available in the Indiana data, therefore all CMFs were assumed to have default values as the base condition. Urban/suburban arterial segment SPFs are developed based on five different geometry cases, three levels of severity and collision types. The next section presents all the calibrated SPFs within the data constraints.

5.3.1 SPF Calibration

Table 5.14 presents the safety performance model results for multiple-vehicle non-driveway total crashes, PDO and FI crashes on two-lane undivided roads. Safety performance model results for multiple-vehicle non-driveway total crashes, PDO and FI crashes on four-lane undivided roads are shown in Table 5.15. Finally, safety performance model results are depicted in Table 5.16 for Multiple-vehicle non-driveway total crashes, PDO and FI crashes on four-lane divided roads.

Table 5.17 presents the safety performance model results for single-vehicle non-driveway total crashes, PDO and FI crashes on two-lane undivided roads. Finally, Table 5.18 presents the safety performance model results for single-vehicle non-driveway total crashes, PDO crashes, and FI crashes on four-lane divided roads.

Table 5.19 summarizes the calibrated and default SPFs for total, KABC, and KAB multiple-vehicle non-driveway crashes on different types of urban/suburban arterial segments. The parameter estimates for different severity levels reveal that there is a significant difference between the calibrated and default SPFs for Indiana.

Calibrated and default SPFs for total, KABC, and KAB single-vehicle crashes on different types of urban/suburban arterial segments are presented side by side in Table 5.20 for comparison. The parameter estimates for different severity levels and facility configurations show that there is a significant difference between the calibrated and default SPFs for Indiana.

TABLE 5.14
Safety Performance Functions for Multiple-Vehicle Non-Driveway Crashes on Urban/Suburban Two-Lane Undivided Segments

Parameter		Estimate	Std E	t-statistic	p-value
Total Crashes	Intercept	-13.357	1.384	-9.65	<.0001
	AADT	1.452	0.151	9.62	<.0001
	Length L (mi.)	0.307	0.096	3.21	0.0013
	Dispersion	1.813	0.209	8.68	
PDO Crashes	Intercept	-14.117	1.546	-9.13	<.0001
	AADT	1.502	0.168	8.93	<.0001
	Length L (mi.)	0.287	0.104	2.77	0.0055
	Dispersion	2.110	0.265	7.95	
FI Crashes	Intercept	-13.864	1.989	-6.97	<.0001
	AADT	1.366	0.216	6.33	<.0001
	Length L (mi.)	0.437	0.153	2.86	0.0042
	Dispersion	2.240	0.465	4.82	
Number of Observations			377		

TABLE 5.15

Safety Performance Functions for Multiple-Vehicle Non-Driveway Crashes on Urban/Suburban Four-Lane Undivided Segments

Parameter		Estimate	Std E	t-statistic	p-value
Total Crashes	Intercept	-16.691	4.598	-3.63	0.0003
	AADT	1.811	0.475	3.82	0.0001
	Length *L* (mi.)	0.658	0.221	2.98	0.0029
	Dispersion	1.901	0.462	4.12	
PDO Crashes	Intercept	-19.510	5.230	-3.73	0.0002
	AADT	2.087	0.543	3.84	0.0001
	Length *L* (mi.)	0.747	0.251	2.98	0.0029
	Dispersion	2.013	0.518	3.89	
FI Crashes	Intercept	-14.163	4.839	-2.93	0.0034
	AADT	1.401	0.497	2.82	0.0048
	Length *L* (mi.)	0.689	0.241	2.86	0.0043
	Dispersion	1.343	0.613	2.19	
Number of Observations			77		

TABLE 5.16

Safety Performance Functions for Multiple-Vehicle Non-Driveway Crashes on Urban/Suburban Four-Lane Divided Segments

Parameter		Estimate	Std E	t-statistic	p-value
Total Crashes	Intercept	-9.896	1.393	-3.63	<.0001
	AADT	1.093	0.140	3.82	<.0001
	Length *L* (mi.)	0.664	0.107	2.98	<.0001
	Dispersion	2.145	0.200	4.12	
PDO Crashes	Intercept	-10.105	1.441	-9.13	<.0001
	AADT	1.092	0.144	8.93	<.0001
	Length *L* (mi.)	0.677	0.113	2.77	<.0001
	Dispersion	2.337	0.230	7.95	
FI Crashes	Intercept	-11.124	1.900	-6.97	<.0001
	AADT	1.054	0.189	6.33	<.0001
	Length *L* (mi.)	0.594	0.134	2.86	<.0001
	Dispersion	2.163	0.318	4.82	
Number of Observations			366		

TABLE 5.17

Safety Performance Functions for Single-Vehicle Non-Driveway Crashes on Urban/Suburban Two-Lane Undivided Segments

Parameter		Estimate	Std E	t-statistic	p-value
Total Crashes	Intercept	-2.624	1.066	-2.46	0.0139
	AADT	0.300	0.117	2.56	0.0106
	Length *L* (mi.)	0.980	0.117	8.37	<.0001
	Dispersion	1.156	0.171	6.74	
PDO Crashes	Intercept	-2.051	1.152	-1.78	0.0750
	AADT	0.217	0.127	1.71	0.0865
	Length *L* (mi.)	0.979	0.125	7.86	<.0001
	Dispersion	1.214	0.192	6.33	
FI Crashes	Intercept	-9.934	1.856	-5.35	<.0001
	AADT	0.896	0.200	4.49	<.0001
	Length *L* (mi.)	0.994	0.216	4.61	<.0001
	Dispersion	0.576	0.324	1.78	
Number of Observations			377		

TABLE 5.18

Safety Performance Functions for Single-Vehicle Non-Driveway Crashes on Urban/Suburban Four-Lane Divided Segments

Parameter		Estimate	Std E	t-statistic	p-value
Total Crashes	Intercept	-7.583	1.164	-6.52	<.0001
	AADT	0.824	0.116	7.11	<.0001
	Length L (mi.)	1.184	0.105	11.30	<.0001
	Dispersion	1.051	0.136	7.71	
PDO Crashes	Intercept	-7.217	1.231	-5.86	<.0001
	AADT	0.776	0.123	6.33	<.0001
	Length L (mi.)	1.272	0.116	11.01	<.0001
	Dispersion	1.132	0.153	7.41	
FI Crashes	Intercept	-12.905	1.758	-7.34	<.0001
	AADT	1.143	0.171	6.70	<.0001
	Length L (mi.)	0.862	0.155	5.58	<.0001
	Dispersion	0.244	0.180	1.36	
Number of Observations			366		

TABLE 5.19

Safety Performance Functions for Multiple-Vehicle Non-Driveway Crashes on Urban/Suburban Arterial Segments

Facility type		Calibrated SPFs	Default SPFs
Two-lane undivided arterials (2U)	Total	$exp(-13.357+1.452\times ln(AADT)+0.307\times ln(Length))*\text{CMF}$	$exp(-15.22+1.68\times ln(AADT)+ln(Length))$
	KABC	$exp(-14.117+1.502\times ln(AADT)+0.287\times ln(Length))*\text{CMF}$	$exp(-16.22+1.66\times ln(AADT)+ln(Length))$
	PDO	$exp(-13.864+1.366\times ln(AADT)+0.437\times ln(Length))*\text{CMF}$	$exp(-15.62+1.37\times ln(AADT)+ln(Length))$
Four-lane undivided arterials (4U)	Total	$exp(-16.691+1.811\times ln(AADT)+0.658\times ln(Length))*\text{CMF}$	$exp(-11.63+1.33\times ln(AADT)+ln(Length))$
	KABC	$exp(-19.510+2.087\times ln(AADT)+0.747\times ln(Length))*\text{CMF}$	$exp(-12.08+1.25\times ln(AADT)+ln(Length))$
	PDO	$exp(-14.163+1.401\times ln(AADT)+0.689\times ln(Length))*\text{CMF}$	$exp(-12.53+1.38\times ln(AADT)+ln(Length))$
Four-lane divided arterials (4D)	Total	$exp(-9.896+1.093\times ln(AADT)+0.664\times ln(Length))*\text{CMF}$	$exp(-12.34+1.36\times ln(AADT)+ln(Length))$
	KABC	$exp(-10.105+1.092\times ln(AADT)+0.677\times ln(Length))*\text{CMF}$	$exp(-12.76+1.28\times ln(AADT)+ln(Length))$
	PDO	$exp(-11.124+1.054\times ln(AADT)+0.594\times ln(Length))*\text{CMF}$	$exp(-12.81+1.38\times ln(AADT)+ln(Length))$

TABLE 5.20

Safety Performance Functions for Single-Vehicle Crashes on Urban/Suburban Arterial Segments

Facility type		Calibrated SPFs	Default SPFs
Two-lane undivided arterials (2U)	Total	$exp(-2.624+0.300\times ln(AADT)+0.980\times ln(Length))*\text{CMF}$	$exp(-5.47+0.56\times ln(AADT)+ln(Length))$
	KABC	$exp(-2.051+0.217\times ln(AADT)+0.979\times ln(Length))*\text{CMF}$	$exp(-3.96+0.23\times ln(AADT)+ln(Length))$
	PDO	$exp(-9.934+0.896\times ln(AADT)+0.994\times ln(Length))*\text{CMF}$	$exp(-6.51+0.64\times ln(AADT)+ln(Length))$
Four-lane divided arterials (4D)	Total	$exp(-7.583+0.824\times ln(AADT)+1.184\times ln(Length))*\text{CMF}$	$exp(-5.05+0.47\times ln(AADT)+ln(Length))$
	KABC	$exp(-7.217+0.776\times ln(AADT)+1.272\times ln(Length))*\text{CMF}$	$exp(-8.71+0.66\times ln(AADT)+ln(Length))$
	PDO	$exp(-12.905+1.143\times ln(AADT)+0.862\times ln(Length))*\text{CMF}$	$exp(-5.04+0.45\times ln(AADT)+ln(Length))$

6. SUMMARY AND CONCLUSIONS

Safety of Indiana road facilities may be enhanced through the consideration of safety countermeasures in the transportation planning, design, management, and operations stages. Implementation of the safety knowledge may be facilitated through the IHSDM, a tool which may be utilized to assess the safety impact of project-level design decisions by implementing the HSM crash prediction methodology. SPFs, CMFs, calibration factors, and crash proportions are utilized in predicting the number, severity, and type of crashes occurring on various types of roadway facilities. The crash prediction method must be calibrated in order to accurately assess the impact of design decisions for Indiana conditions.

In this report, a comprehensive approach to calibrating the HSM predictive method within the constraints of the IHSDM is presented. First, the parameters of the tool's default CMFs are calibrated so that they are consistent with the CMFs from past research and local data. Second, the method jointly estimates the SPFs and CMFs, thus preserving crash prediction consistency. Proper calibration of the CMFs and SPFs eliminates the necessity of calibration factors. The developed methodology allows users to utilize the IHSDM to determine the safety impacts of road designs while incorporating local data and past results in forms which may differ from the IHSDM.

This study also updated and expanded the database of CRFs applicable to Indiana conditions for various geometric, traffic, pavement, and other characteristics of Indiana road facilities. CRFs/CMFs for various types and severities of crashes were identified for around 80 safety countermeasures applied on urban and rural segments, intersections, and interchanges. Most of these CRFs/CMFs were available as values, and those provided as functions were discretized for various levels of the change in safety. This comprehensive CRFs/CMFs database is helpful to get the quick notion about the benefit of a selected countermeasure outside IHSDM analysis.

For the comprehensive analysis of a selected countermeasure or design changes in the IHSDM, the results of the developed methodology are implemented in the tool to reflect local Indiana conditions. Calibrated SPF and CMF parameters, as well as crash proportions were included in IHSDM for rural two-lane undivided segments, rural multilane divided segments, and urban/suburban arterial segments. The application of these calibrated parameters was demonstrated for Indiana rural two-lane undivided segments and rural multilane divided segments.

The calibrated CMF_{RA} values for lane width on rural two-lane undivided segments are relatively similar to the default CMF_{RA}. On the other hand, the calibrated CMF_{RA} values are considerably higher than the defaults for rural multilane divided segments. The calibrated CMF_{RA} for shoulder width on rural two-lane undivided segments are within the range of defaults for all shoulder widths. On the other hand, the calibrated CMF for shoulder width on rural multilane divided segments are higher than the defaults. The total CMF_{All} is determined based on the individual CMFs and is included as an offset variable in the SPF to predict crashes, along with the AADT and segment length as exposure.

Finally, example studies were performed to compare the predictive performance of the IHSDM using the calibrated and default Indiana parameters for both facility types. Although the predicted total crashes was marginally lower when using the calibrated versus default parameters on the rural two-lane undivided segment, using the default parameters overstated the FI crashes while understating the PDO crashes. For the rural multilane divided segment, the predicted number of total crashes was greater with the calibrated Indiana parameters as compared to the default parameters. Again, the calculations with the default parameters overstated the FI crashes while understating the PDO crashes, this time to a greater extent than for rural two-lane undivided segments. This comparison indicated that, at least in Indiana, the calibration resulted in considerably different crash estimates than based on the default parameters for the studied segments.

The findings from this report highlight the need for calibrating the parameters in the IHSDM to local conditions. In order to preserve the integrity of the presented method, SPFs should be calibrated every 2 to 3 years to accommodate changes in the traffic and/or changes in road conditions. Furthermore, CMFs should be updated as new studies are conducted for Indiana or other nearby states. Such an effort may be conducted as a part of a research project conducted under the assistance of Purdue University and/or INDOT's Research and Development Division.

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APPENDIX A. CRASH REDUCTION FACTORS AND CRASH MODIFICATION FACTORS SUITABLE FOR INDIANA

This appendix presents the CRFs/CMFs for safety countermeasures that were identified as being the most suitable for Indiana based on the criteria presented in Chapter 2. Table A.1 contains 82 safety countermeasures spanning 16 different categories. For each countermeasure, the applicable area type (urban and/or rural), facility type, and CRF/CMF values for various crash types and severities are presented. Finally, the state(s) where each study was conducted and the corresponding reference are provided in the table.

TABLE A.1
CRFs and CMFs Most Suitable for Indiana

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Access management	Install two-way left-turn lane (TWLTL)	Rural	Two-lane highways	Total	36.0	0.640	AR, CA, IL, NC (29)
				KABC	34.8	0.652	
				Rear-end	46.8	0.532	
Access management	Replace TWLTL with raised median	Urban	Principal arterials; minor arterials; collectors	Total	23	0.77	NV (24)
				PDO	33	0.67	
				KABC	21	0.79	
				Rear-end	19	0.81	
				Sideswipe	21	0.79	
				Angle	36	0.64	
				Head-on	47	0.53	
Access management	Reduce driveway density by 1 driveway per mile*	Rural	Two-lane highways	Total	2.3	0.977	TX (11)
			Four-lane highways	Total	0.4	0.996	
Access management	Reduce driveway density by 2 driveways per mile*	Rural	Two-lane highways	Total	4.5	0.955	TX (11)
			Four-lane highways	Total	0.7	0.993	
Access management	Reduce driveway density by 3 driveways per mile*	Rural	Two-lane highways	Total	6.7	0.933	TX (11)
			Four-lane highways	Total	1.1	0.989	
Access management	Reduce driveway density by 5 driveways per mile*	Urban	Principal arterials, minor arterials, or collectors with raised medians	Total	4.7	0.953	NV (24)
				PDO	3.5	0.965	
				KABC	2.9	0.971	
				Rear-end	1.5	0.985	
				Angle	4.3	0.957	
			Principal arterials, minor arterials, or collectors with TWLTLs	Total	4.4	0.956	
				PDO	4.6	0.954	
				KABC	1.3	0.987	
				Rear-end	3.8	0.962	
				Angle	4.1	0.959	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Access management	Reduce driveway density by 10 driveways per mile*	Urban	Principal arterials, minor arterials, or collectors with raised medians	Total	9.2	0.908	NV (24)
				PDO	6.9	0.931	
				KABC	5.7	0.943	
				Rear-end	3.0	0.970	
				Angle	8.3	0.917	
			Principal arterials, minor arterials, or collectors with TWLTLs	Total	8.6	0.914	
				PDO	9.0	0.910	
				KABC	2.6	0.974	
				Rear-end	7.4	0.926	
				Angle	8.1	0.919	
Access management	Reduce driveway density by 15 driveways per mile*	Urban	Principal arterials, minor arterials, or collectors with raised medians	Total	13.4	0.866	NV (24)
				PDO	10.1	0.899	
				KABC	8.5	0.915	
				Rear-end	4.4	0.956	
				Angle	12.2	0.878	
			Principal arterials, minor arterials, or collectors with TWLTLs	Total	12.6	0.874	
				PDO	13.2	0.868	
				KABC	3.8	0.962	
				Rear-end	10.9	0.891	
				Angle	11.8	0.882	
Access management	Reduce driveway density by 20 driveways per mile*	Urban	Principal arterials, minor arterials, or collectors with raised medians	Total	17.5	0.825	NV (24)
				PDO	13.2	0.868	
				KABC	11.1	0.889	
				Rear-end	5.8	0.942	
				Angle	16.0	0.840	
			Principal arterials, minor arterials, or collectors with TWLTLs	Total	16.5	0.835	
				PDO	17.1	0.829	
				KABC	5.1	0.949	
				Rear-end	14.3	0.857	
				Angle	15.5	0.845	
Alignment	Flatten crest of curve	Rural	Arterials, collectors	Total	19.6	0.804	OH (19)
				KABC	51.2	0.488	
Alignment	Reduce the average grade rate by 1%*	Rural	Two-lane roads	PDO	2.0	0.980	IN (42)
				KABC	1.9	0.981	
Alignment	Reduce the average grade rate by 2%*	Rural	Two-lane roads	PDO	4.0	0.960	IN (42)
				KABC	3.8	0.962	
Alignment	Reduce the average grade rate by 3%*	Rural	Two-lane roads	PDO	6.0	0.940	IN (42)
				KABC	5.7	0.943	
Alignment	Reduce the average grade rate by 4%*	Rural	Two-lane roads	PDO	7.9	0.921	IN (42)
				KABC	7.5	0.925	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Alignment	Reduce the average grade rate by 5%*	Rural	Two-lane roads	PDO	9.7	0.903	IN (42)
				KABC	9.3	0.907	
Alignment	Reduce the average degree of curve by 1 degree*	Rural	Two-lane roads	PDO	1.9	0.981	IN (42)
				KABC	2.9	0.971	
Alignment	Reduce the average degree of curve by 2 degrees*	Rural	Two-lane roads	PDO	3.8	0.962	IN (42)
				KABC	5.7	0.943	
Alignment	Reduce the average degree of curve by 3 degrees*	Rural	Two-lane roads	PDO	5.7	0.943	IN (42)
				KABC	8.4	0.916	
Alignment	Reduce the average degree of curve by 4 degrees*	Rural	Two-lane roads	PDO	7.5	0.925	IN (42)
				KABC	11.1	0.889	
Alignment	Reduce the average degree of curve by 5 degrees*	Rural	Two-lane roads	PDO	9.3	0.907	IN (42)
				KABC	13.6	0.864	
Highway lighting	Install lighting on a roadway segment	Urban and rural	Not specified	Nighttime	20.0	0.800	Not specified (17)
				Nighttime KABC	29.0	0.710	
Highway lighting	Install lighting at a signalized intersection	Urban	Not specified	Daytime	-3.0	1.030	MN (6)
				Nighttime	3.0	0.970	
		Rural	Not specified	Daytime	2.0	0.980	
				Nighttime	2.0	0.980	
Highway lighting	Install lighting at a stop-controlled intersection	Urban	Not specified	Daytime	-5.0	1.050	MN (6)
				Nighttime	9.0	0.910	
		Rural	Not specified	Daytime	-9.0	1.090	
				Nighttime	-7.0	1.070	
Highway lighting	Install lighting at an interchange	Urban and rural	Arterials, collectors	Total	50.4	0.496	OH (19)
				KABC	26.0	0.740	
Intersection geometry	Add a left-turn lane on one major approach to a signalized intersection	Urban	Three-leg intersections	Total	7.0	0.930	IA, IL, LA, MN, NE, NC, OR, VA (18)
			Four-leg intersections	Total	10.0	0.900	
		Rural	Three-leg intersections	Total	15.0	0.850	
			Four-leg intersections	Total	18.0	0.820	
Intersection geometry	Add a left-turn lane on one major approach to an unsignalized intersection	Urban	Three-leg intersections	Total	33.0	0.670	IA, IL, LA, MN, NE, NC, OR, VA (18)
			Four-leg intersections	Total	27.0	0.730	
		Rural	Three-leg intersections	Total	44.0	0.560	
			Four-leg intersections	Total	28.0	0.720	
Intersection geometry	Add a right-turn lane on one major approach to a signalized intersection	Urban	Four-leg intersections	Total	4.0	0.960	IA, IL, LA, MN, NE, NC, OR, VA (18)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Intersection geometry	Add a right-turn lane on one major approach to an unsignalized intersection	Rural	Four-leg intersections	Total	14.0	0.860	IA, IL, LA, MN, NE, NC, OR, VA (18)
Intersection geometry	Convert diamond interchange to diverging diamond interchange (DDI)	Urban	Principal arterial, other freeways and expressways	Total	33	0.67	KY, MO, NY, TN (20)
				Injury	41	0.59	
				Angle	67	0.33	
				Rear-end	36	0.64	
				Sideswipe	-27	1.27	
				Single-vehicle	24	0.76	
Intersection geometry	Convert intersection on low-speed road to a roundabout	Urban and rural	Intersections where all approaches are low-speed (less than 45 mph)	Total	-9.9	1.099	WI (31)
				KABC	52.7	0.473	
Intersection geometry	Convert intersection on high-speed road to a roundabout	Urban and rural	Intersections where at least one approach is high-speed (45 mph or greater)	Total	34.1	0.659	WI (31)
				KABC	49.4	0.506	
Intersection geometry	Convert intersection to a single-lane roundabout	Urban and rural	Intersections with low- and high-speed approaches	Total	36.0	0.640	WI (31)
				KABC	18.2	0.818	
Intersection geometry	Convert intersection to a multilane roundabout	Urban and rural	Intersections with low- and high-speed approaches	Total	-6.2	1.062	WI (31)
				KABC	63.3	0.367	
Intersection geometry	Convert two-way stop-controlled intersection to a roundabout	Urban	Intersections on two- or four-lane roads	Total	27.0	0.730	CA, CO, CT, FL, KS, MD, ME, MI, MO, MS, NV, OR, SC, UT, VT, WA WI (31,33)
				KABC	58.1	0.419	
		Rural	Intersections on two- or four-lane roads	Total	48.2	0.518	
				KABC	61.2	0.388	
Intersection geometry	Convert all-way stop-controlled intersection to a roundabout	Urban and rural	Intersections on two- or four-lane roads	Total	-7.4	1.074	CA, CO, CT, FL, KS, MD, ME, MI, MO, MS, NV, OR, SC, UT, VT, WA WI (31,33)
				KABC	8.7	0.913	
Intersection geometry	Convert signalized intersection to a roundabout	Urban	Intersections on two- or four-lane roads	Total	12.4	0.876	CA, CO, CT, FL, IN, KS, MD, ME, MI, MO, MS, NC, NV, NY, OR, SC, UT, VT, WA, WI (15,31,33)
				KABC	66.1	0.339	
		Rural	Intersections on two- or four-lane roads	Total	26.2	0.738	
				KABC	71.5	0.285	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Intersection geometry	Convert a non-controlled or yield-controlled intersection to a roundabout	Urban and rural	Intersections on two- or four-lane roads	Total	-24.2	1.242	WI (31)
				KABC	100.0	0.000	
Intersection geometry	Convert two-way stop-controlled intersection to J-turn intersection	Rural	Intersections of four-lane divided, high-speed roads and minor roads	Total	34.8	0.652	MO (8)
				KABC	53.7	0.463	
Intersection geometry	Improve left-turn lane offset to create positive offset	Urban and rural	Four-leg intersections	Total	33.8	0.662	WI (30)
				KABC	35.6	0.644	
				Left-turn	38.0	0.620	
				Rear-end	31.7	0.683	
Intersection geometry	Improve intersection sight distance	Urban and rural	Not specified	Total	33.0	0.670	Based on AK, AZ, CA, IA, KY, MO (13)
				Right-angle	21.0	0.790	Based on AZ, MO, MN (13)
				Left-turn	13.0	0.870	Based on AZ, MO (13)
				Sideswipe	43.0	0.570	Based on AK, MO (13)
Intersection traffic control	Change left-turn phasing on one approach from permitted to protected/permitted phasing	Urban	Four-leg intersections	Total	-8.1	1.081	NC, Toronto (39)
				KABC	0.5	0.995	
				Left-turn	7.5	0.925	
				Rear-end	-9.4	1.094	
Intersection traffic control	Change left-turn phasing on more than one approach from permitted to protected/permitted phasing	Urban	Four-leg intersections	Total	4.2	0.958	NC, Toronto (39)
				KABC	8.6	0.914	
				Left-turn	21.3	0.787	
				Rear-end	-5.0	1.050	
Intersection traffic control	Change left-turn phasing from permitted or permitted/protected to protected-only phasing	Urban	Signalized intersections	Total	1	0.99	NC (17)
				Left-turn	99	0.01	
Intersection traffic control	Supplement left-turn phasing from at least one permitted approach with flashing yellow arrow	Urban	Four-leg intersections	Total	24.7	0.753	NC, OR, WA (39)
				Left-turn	36.5	0.635	
Intersection traffic control	Change left-turn phasing from protected/permitted to flashing yellow arrow	Urban	Four-leg intersections	Total	7.8	0.922	NC, OR, WA (39)
				Left-turn	19.4	0.806	
Intersection traffic control	Change left-turn phasing from protected to flashing yellow arrow	Urban	Four-leg intersections	Total	-33.8	1.338	NC, OR, WA (39)
				Left-turn	-124.2	2.242	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Intersection traffic control	Convert two-way stop control to all-way stop control	Urban and rural	Four-leg intersections	Total	68	0.32	NC (34)
				KABC	77	0.23	
				Frontal impact	75	0.25	
				Ran stop sign	15	0.85	
Intersection traffic control	Improve signal visibility	Urban	Four-leg intersections on three- to four-lane roads	Daytime PDO	9.9	0.901	British Columbia (9)
				Daytime KABC	-0.4	1.004	
				Nighttime PDO	13.3	0.867	
				Nighttime KABC	9.8	0.902	
Intersection traffic control	Increase yellow change interval (1.0 seconds)	Urban	Three- and four-leg intersections	Total	-14.1	1.141	CA, MD (39)
				KABC	-7.3	1.073	
				Rear-end	6.6	0.934	
				Angle	-7.6	1.076	
Intersection traffic control	Increase all-red clearance interval (average of 1.1 seconds)	Urban	Three- and four-leg intersections	Total	20.2	0.798	CA, MD (39)
				KABC	13.7	0.863	
				Rear-end	19.6	0.804	
				Angle	3.4	0.966	
Intersection traffic control	Increase yellow interval (average of 0.8 seconds) and add all-red interval (average of 1.2 seconds)	Urban	Three- and four-leg intersections	Total	1.0	0.990	CA, MD (39)
				KABC	-2.0	1.020	
				Rear-end	-11.7	1.117	
				Angle	3.9	0.961	
Intersection traffic control	Install transverse rumble strips on approaches to stop-controlled intersection	Rural	Three-leg intersections on major collectors	Total	-22.3	1.223	IA, MN (38)
				PDO	-28.4	1.284	
				KA	59	0.41	
			Four-leg intersections on major collectors	Total	-6.6	1.066	
				PDO	-13.8	1.138	
				KA	34.8	0.652	
Intersection traffic control	Install new traffic signal at previously stop-controlled intersection	Urban	Three-leg intersections	KABC	14	0.86	CA, FL, MD, VA, WI, Toronto (25)
				Right-angle KABC	34	0.66	
				Rear-end KABC	-50	1.50	
			Four-leg intersections	KABC	23	0.77	
				Right-angle KABC	67	0.33	
				Rear-end KABC	-38	1.38	
		Rural	Three- and four-leg intersections	Total	44	0.56	CA, MN (17)
				Right-angle	77	0.23	
				Rear-end	-58	1.58	
				Left-turn	60	0.40	
Intersection traffic control	Replace standard stop sign with flashing LED stop sign	Urban and rural	Two-lane highways	Right-angle	41.5	0.585	MN (7)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Intersection traffic control	Retime signal change intervals to Institute of Transportation Engineers (ITE) standards	Urban	Four-leg intersections	Total	8	0.92	NY (32)
				KABC	12	0.88	
				Rear-end	-12	1.12	
				Rear-end KABC	-8	1.08	
				Angle	4	0.96	
				Angle KABC	-6	1.06	
				Vehicle/bicycle and vehicle/pedestrian	37	0.63	
				Vehicle/bicycle and vehicle/pedestrian KABC	37	0.63	
ITS and advanced technology	Install actuated advance intersection warning system at high-speed intersection	Urban and rural	Four-lane high-speed divided highways (major road)	Total	8.2	0.918	NE (2)
				KABC	11.3	0.887	
				Rear-end	1.2	0.988	
				Right-angle	43.6	0.564	
ITS and advanced technology	Install changeable horizontal curve speed warning signs	Rural	Two-lane highways	Total	5.0	0.950	AZ, FL, IA, OH, OR, TX, WA (16)
ITS and advanced technology	Install variable speed limit signs	Urban	Principal arterial interstates	Total	8.0	0.920	MO (5)
ITS and advanced technology	Install "Vehicle Entering When Flashing" (VEWF) system with advance post mounted signs on major approach and loops on minor approach	Urban and rural	Highways with 35–55 mph mainline approach speeds	Total	32	0.68	NC (35)
				KABC	27	0.73	
				Target (angle, head-on, left-turn, and right-turn)	32	0.68	
Pavement	Improve pavement condition from poor (critical condition index below 60) to good (critical condition index above 70)	Rural	Two-lane highways	Total	-3.0	1.030	VA (46)
				KABC	26.0	0.740	
Pedestrians	Construct pedestrian bridge or tunnel	Urban	Not specified	Pedestrian	86	0.14	Based on AK, AZ, KY, MO (13)
Pedestrians	Install High intensity Activated crossWalK (HAWK) at intersection	Urban	Crossings of four- to six-lane roads	Total	29	0.71	AZ (12)
				KA	15	0.85	
				Pedestrian	69	0.31	
Pedestrians	Install sidewalk	Urban	Not specified	Pedestrian	74	0.26	Based on AK, AZ, KY, MO, OK (13)
Railroads	Build grade-separated crossing	Urban and rural	Not specified	Total	39	0.61	Based on IA (13)
Railroads	Eliminate railroad crossing	Urban and rural	Not specified	Total	75	0.25	Based on IA (13)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Railroads	Install gates at crossings with signs	Urban and rural	Arterials, collectors, local roads	Total	93	0.07	Canada (26)
Railroads	Upgrade signs to flashing lights	Urban and rural	Arterials, collectors, local roads	Total	77	0.23	Canada (26)
Roadside	Increase median width from 10 feet to 20 feet	Rural	Four-lane divided highways	Multiple vehicle	9	0.91	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 30 feet	Rural	Four-lane divided highways	Multiple vehicle	17	0.83	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 40 feet	Rural	Four-lane divided highways	Multiple vehicle	25	0.75	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 50 feet	Rural	Four-lane divided highways	Multiple vehicle	32	0.68	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 60 feet	Rural	Four-lane divided highways	Multiple vehicle	38	0.62	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 70 feet	Rural	Four-lane divided highways	Multiple vehicle	43	0.57	CA, KY, MN (40)
Roadside	Increase median width from 10 feet to 80 feet	Rural	Four-lane divided highways	Multiple vehicle	49	0.51	CA, KY, MN (40)
Roadside	Install guardrail	Urban and rural	Not specified	Total BC KA Run-off-the-road	11 40 65 30	0.89 0.60 0.35 0.70	Based on AZ, IA, IN, KY, MO (13)
Roadside	Install cable median barrier (high-tensioned) on depressed median of 50 feet wide or wider	Rural	Principal arterial interstates	Multiple-vehicle, opposite direction (cross median, frontal and opposing direction sideswipe, head-on) Single-vehicle crashes (fixed object, run-off-the-road)	96 -72	0.04 1.72	IN (45)
Roadside	Install concrete median barrier	Rural	Interstates	Single-vehicle Multiple-vehicle, same direction Multiple-vehicle opposite direction	-120 20 100	2.20 0.80 0.00	CO, IL, IN, MO, NY, OH, OR, WA (41)
Roadside	Change in sideslope from 1V:3H to 1V:4H	Rural	Not specified	PDO KABC	29 42	0.71 0.58	Not specified (10)
Roadside	Change in sideslope from 1V:4H to 1V:6H	Rural	Not specified	PDO KABC	24 22	0.76 0.78	Not specified (10)
Roadside	Remove or relocate fixed objects outside of clear zone	Urban and rural	Arterials, collectors	Total KABC	38.2 38.1	0.618 0.619	OH (19)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Road diet	Re-stripe four-lane undivided road to three-lane (with TWLTL)	Urban	Minor arterials	Total	29	0.71	CA, IA, WA (17)
Roadway delineation	Add no passing striping	Rural	Not specified	Total	53	0.47	Based on MT (13)
				Head-on	40	0.60	Based on KY, MO (13)
				Sideswipe	40	0.60	
Roadway delineation	Install centerline rumble strips	Urban	Two-lane roads	Target (head-on, opposite-direction sideswipe)	40	0.60	CA, CO, DE, MD, MN, OR, PA, WA (43)
				Target KABC	64	0.36	
		Rural	Two-lane roads	Total	9	0.91	
				KABC	12	0.88	
				Target	30	0.70	
				Target KABC	44	0.56	
Roadway delineation	Install shoulder rumble strips	Rural	Two-lane roads	Run-off-the-road	15	0.85	MN, MO, PA (43)
				Run-off-the-road KABC	29	0.71	
			Freeways	Run-off-the-road	11	0.89	
				Run-off-the-road KABC	16	0.84	
Roadway delineation	Install centerline plus shoulder rumble strips	Rural	Two-lane roads	Total	18.6	0.814	KY, MI, MO, PA (21,23)
				KABC	22.9	0.771	
				Head-on	36.8	0.632	
				Run-off-the-road	25.8	0.742	
				Opposite-direction sideswipe	23.3	0.767	
Roadway delineation	Install edgeline pavement markings on curves	Rural	Two-lane highways	Total	25.9	0.741	TX (44)
				Run-off-the-road	11.0	0.890	
				Speed-related (nighttime)	3.7	0.963	
Roadway delineation	Install edgeline pavement markings on tangent sections	Rural	Two-lane highways	Total	6.1	0.939	TX (44)
				Run-off-the-road	13.4	0.866	
				Speed-related (nighttime)	3.4	0.966	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Roadway delineation	Install raised pavement markers	Rural	Two-lane highways with AADT 0–5000, curve radius $R \geq 1640$ ft	Nighttime	-16	1.16	IL, NJ, NY, PA (4)
			Two-lane highways with AADT 5001–15000, curve radius $R \geq 1640$ ft	Nighttime	1	0.99	
			Two-lane highways with AADT 15001–20000, curve radius $R \geq 1640$ ft	Nighttime	24	0.76	
			Two-lane highways with AADT 0–5000, curve radius $R < 1640$ ft	Nighttime	-43	1.43	
			Two-lane highways with AADT 5001–15000, curve radius $R < 1640$ ft	Nighttime	-26	1.26	
			Two-lane highways with AADT 15001–20000, curve radius $R < 1640$ ft	Nighttime	-3	1.03	
			Four-lane freeways with AADT ≤ 20000	Nighttime	-13	1.13	MO, NY, PA, WI (4)
			Four-lane freeways with AADT 20001–60000	Nighttime	6	0.94	
			Four-lane freeways with AADT > 60000	Nighttime	33	0.67	
Segments	Increase in number of through lanes by 1 lane*	Urban	Multilane	PDO	61.3	0.387	IN (42)
				KABC	66.5	0.335	
Segments	Convert two-lane roadway to four-lane divided roadway	Urban	Before: Two-lane roadway	Total	65.9	0.341	FL (1)
			After: Four-lane divided roadway	PDO	64.9	0.351	
				KABC	63.3	0.367	
		Rural	Before: Two-lane roadway	Total	28.8	0.712	
			After: Four-lane divided roadway	PDO	30.9	0.691	
				KABC	45.1	0.549	
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 7 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	10	0.90	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 8 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	62	0.38	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 5 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	13	0.87	PA (14)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 6 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	16	0.84	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 7 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-96	1.96	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 4 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-4	1.04	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 5 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-6	1.06	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 6 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	25	0.75	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 3 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-11	1.11	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 4 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-14	1.14	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 5 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-22	1.22	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 2 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-16	1.16	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 3 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-19	1.19	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 4 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-20	1.20	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 1 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-85	1.85	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 2 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-12	1.12	PA (14)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 3 foot shoulders	Rural	Two-lane highways	Run-off-the-road, head-on, sideswipe	-13	1.13	PA (14)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 0 foot shoulders*	Urban	Urban and suburban arterials	Total	-42.7	1.427	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 1 foot shoulders*	Urban	Urban and suburban arterials	Total	-34.5	1.345	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 2 foot shoulders*	Urban	Urban and suburban arterials	Total	-26.7	1.267	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 3 foot shoulders*	Urban	Urban and suburban arterials	Total	-19.4	1.194	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 4 foot shoulders*	Urban	Urban and suburban arterials	Total	-12.6	1.126	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 5 foot shoulders*	Urban	Urban and suburban arterials	Total	-6.1	1.061	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 7 foot shoulders*	Urban	Urban and suburban arterials	Total	5.8	0.942	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 8 foot shoulders*	Urban	Urban and suburban arterials	Total	11.2	0.888	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 9 foot shoulders*	Urban	Urban and suburban arterials	Total	16.3	0.837	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 12 foot lanes and 10 foot shoulders*	Urban	Urban and suburban arterials	Total	21.1	0.789	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 0 foot shoulders*	Urban	Urban and suburban arterials	Total	-270.5	3.705	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 1 foot shoulders*	Urban	Urban and suburban arterials	Total	-248.4	3.484	IL (22)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 2 foot shoulders*	Urban	Urban and suburban arterials	Total	-227.6	3.276	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 3 foot shoulders*	Urban	Urban and suburban arterials	Total	-208	3.08	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 4 foot shoulders*	Urban	Urban and suburban arterials	Total	-189.6	2.896	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 5 foot shoulders*	Urban	Urban and suburban arterials	Total	-172.3	2.723	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 6 foot shoulders*	Urban	Urban and suburban arterials	Total	-156	2.56	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 7 foot shoulders*	Urban	Urban and suburban arterials	Total	-140.7	2.407	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 8 foot shoulders*	Urban	Urban and suburban arterials	Total	-126.3	2.263	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 9 foot shoulders*	Urban	Urban and suburban arterials	Total	-112.8	2.128	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 10 foot lanes and 10 foot shoulders*	Urban	Urban and suburban arterials	Total	-100.1	2.001	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 0 foot shoulders*	Urban	Urban and suburban arterials	Total	-14.2	1.142	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 1 foot shoulders*	Urban	Urban and suburban arterials	Total	-10.4	1.104	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 2 foot shoulders*	Urban	Urban and suburban arterials	Total	-6.8	1.068	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 3 foot shoulders*	Urban	Urban and suburban arterials	Total	-3.3	1.033	IL (22)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 4 foot shoulders*	Urban	Urban and suburban arterials	Total	0.1	0.999	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 5 foot shoulders*	Urban	Urban and suburban arterials	Total	3.4	0.966	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 6 foot shoulders*	Urban	Urban and suburban arterials	Total	6.6	0.934	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 7 foot shoulders*	Urban	Urban and suburban arterials	Total	9.7	0.903	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 8 foot shoulders*	Urban	Urban and suburban arterials	Total	12.6	0.874	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 9 foot shoulders*	Urban	Urban and suburban arterials	Total	15.5	0.845	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 11 foot lanes and 10 foot shoulders*	Urban	Urban and suburban arterials	Total	18.3	0.817	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 0 foot shoulders*	Urban	Urban and suburban arterials	Total	-23.8	1.238	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 1 foot shoulders*	Urban	Urban and suburban arterials	Total	-16.8	1.168	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 2 foot shoulders*	Urban	Urban and suburban arterials	Total	-10.1	1.101	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 3 foot shoulders*	Urban	Urban and suburban arterials	Total	-3.8	1.038	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 4 foot shoulders*	Urban	Urban and suburban arterials	Total	2.1	0.979	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 5 foot shoulders*	Urban	Urban and suburban arterials	Total	7.6	0.924	IL (22)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 6 foot shoulders*	Urban	Urban and suburban arterials	Total	12.9	0.871	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 7 foot shoulders*	Urban	Urban and suburban arterials	Total	17.9	0.821	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 8 foot shoulders*	Urban	Urban and suburban arterials	Total	22.5	0.775	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 9 foot shoulders*	Urban	Urban and suburban arterials	Total	26.9	0.731	IL (22)
Segments	Convert 12 foot lanes and 6 foot shoulders to 13 foot lanes and 10 foot shoulders*	Urban	Urban and suburban arterials	Total	31.1	0.689	IL (22)
Segments	Extend on-ramp acceleration lane by 30 meters (about 100 feet)	Urban and rural	Grade-separated junctions	Total	11	0.89	Not specified (10)
Segments	Extend off-ramp deceleration lane by 30 meters (about 100 feet)	Urban and rural	Grade-separated junctions	Total	7	0.93	Not specified (10)
Segments	Install passing relief lane	Rural	Two-lane highways	Total	33	0.67	MI (3)
				KABC	29	0.71	
				Target (head-on, rear-end, run-off-the-road, sideswipe)	47	0.53	
				Peak month (June, July, August)	46	0.54	
				Off-peak month	28	0.72	
Segments	Increase lane width by 1 foot*	Urban	Two-lane roads	PDO	6.6	0.934	IN (42)
				KABC	14.2	0.858	
			Multilane roads	PDO	2.0	0.980	
				KABC	14.1	0.859	
		Rural	Two-lane roads	PDO	8.2	0.918	
				KABC	7.4	0.926	
			Multilane roads	PDO	17.7	0.823	
				KABC	21.2	0.788	
Segments	Increase lane width by 2 feet*	Urban	Two-lane roads	PDO	12.7	0.873	IN (42)
				KABC	26.3	0.737	
			Multilane roads	PDO	4.0	0.960	
				KABC	26.2	0.738	
		Rural	Two-lane roads	PDO	15.7	0.843	
				KABC	14.3	0.857	
			Multilane roads	PDO	32.2	0.678	
				KABC	37.9	0.621	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Segments	Increase lane width by 3 feet*	Urban	Two-lane roads	PDO	18.4	0.816	IN (42)
				KABC	36.8	0.632	
			Multilane roads	PDO	6.0	0.940	
				KABC	36.6	0.634	
		Rural	Two-lane roads	PDO	22.6	0.774	
				KABC	20.7	0.793	
			Multilane roads	PDO	44.2	0.558	
				KABC	51.1	0.489	
Segments	Increase lane width by 4 feet*	Urban	Two-lane roads	PDO	23.8	0.762	IN (42)
				KABC	45.7	0.543	
			Multilane roads	PDO	7.9	0.921	
				KABC	45.6	0.544	
		Rural	Two-lane roads	PDO	28.9	0.711	
				KABC	26.6	0.734	
			Multilane roads	PDO	54.0	0.460	
				KABC	61.5	0.385	
Shoulder treatment	Increase right shoulder width by 1 foot*	Urban	Two-lane roads	PDO	1.7	0.983	IN (42)
			Multilane roads	PDO	1.6	0.984	
		Rural	Two-lane roads	PDO	2.3	0.977	
				KABC	2.8	0.972	
			Multilane roads	KABC	4.0	0.960	
Shoulder treatment	Increase right shoulder width by 2 feet*	Urban	Two-lane roads	PDO	3.5	0.965	IN (42)
			Multilane roads	PDO	3.1	0.969	
		Rural	Two-lane roads	PDO	4.6	0.954	
				KABC	5.4	0.946	
			Multilane roads	KABC	7.9	0.921	
Shoulder treatment	Increase right shoulder width by 3 feet*	Urban	Two-lane roads	PDO	5.1	0.949	IN (42)
			Multilane roads	PDO	4.7	0.953	
		Rural	Two-lane roads	PDO	6.8	0.932	
				KABC	8.0	0.920	
			Multilane roads	KABC	11.6	0.884	
Shoulder treatment	Increase right shoulder width by 4 feet*	Urban	Two-lane roads	PDO	6.8	0.932	IN (42)
			Multilane roads	PDO	6.2	0.938	
		Rural	Two-lane roads	PDO	8.9	0.911	
				KABC	10.6	0.894	
			Multilane roads	KABC	15.2	0.848	
Shoulder treatment	Increase left/inside shoulder width by 1 foot*	Urban	Multilane roads	KABC	18.5	0.815	IN (42)
		Rural	Multilane roads	PDO	4.3	0.957	
				KABC	6.7	0.933	

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Shoulder treatment	Increase left/inside shoulder width by 2 feet*	Urban	Multilane roads	KABC	33.6	0.664	IN (42)
		Rural	Multilane roads	PDO	8.5	0.915	
				KABC	13.0	0.870	
Shoulder treatment	Increase left/inside shoulder width by 3 feet*	Urban	Multilane roads	KABC	45.9	0.541	IN (42)
		Rural	Multilane roads	PDO	12.4	0.876	
				KABC	18.9	0.811	
Shoulder treatment	Increase left/inside shoulder width by 4 feet*	Urban	Multilane roads	KABC	56.0	0.440	IN (42)
		Rural	Multilane roads	PDO	16.2	0.838	
				KABC	24.3	0.757	
Signs	Install chevron signs on horizontal curves	Rural	Two-lane highways	Total	4.3	0.957	WA (37)
				KABC	16.4	0.836	
				Lane departure	5.9	0.941	
				Nighttime	24.5	0.755	
				Nighttime lane departure	22.1	0.779	
Signs	Increase retroreflectivity of stop signs	Urban and rural	Three- and four-leg stop-controlled intersections	Total	1.2	0.988	CT, SC (28)
				KABC	6.7	0.933	
				Right-angle	-1.2	1.012	
				Rear-end	-2.2	1.022	
				Nighttime	4.4	0.956	
				Daytime	-0.1	1.001	
Signs	Install flashing beacons at stop-controlled intersections	Urban	Two-lane highways	Angle	-12	1.12	NC, SC (36)
		Rural	Two-lane highways	Angle	16	0.84	
Speed management	Lower posted speed by 15–20 mph	Urban and rural	Nonlimited access highways	Total	6	0.94	AZ, CA, CO, CT, DE, ID, IL, IN, ME, MD, MA, MI, MS, NE, NJ, NM, OH, OK, TN, TX, VA, WV (27)
Speed management	Lower posted speed by 10 mph	Urban and rural	Nonlimited access highways	Total	4	0.96	AZ, CA, CO, CT, DE, ID, IL, IN, ME, MD, MA, MI, MS, NE, NJ, NM, OH, OK, TN, TX, VA, WV (27)

TABLE A.1
(Continued)

Category	Countermeasure	Area type	Facility type	Crash type	CRF	CMF	States and (reference number)
Speed management	Lower posted speed by 5 mph	Urban and rural	Nonlimited access highways	Total	-17	1.17	AZ, CA, CO, CT, DE, ID, IL, IN, ME, MD, MA, MI, MS, NE, NJ, NM, OH, OK, TN, TX, VA, WV (27)
Speed management	Raise posted speed by 5 mph	Urban and rural	Nonlimited access highways	Total	8	0.92	AZ, CA, CO, CT, DE, ID, IL, IN, ME, MD, MA, MI, MS, NE, NJ, NM, OH, OK, TN, TX, VA, WV (27)
Speed management	Raise posted speed by 10–15 mph	Urban and rural	Nonlimited access highways	Total	15	0.85	AZ, CA, CO, CT, DE, ID, IL, IN, ME, MD, MA, MI, MS, NE, NJ, NM, OH, OK, TN, TX, VA, WV (27)
Speed management	Set appropriate speed limit	Urban and rural	Not specified	Total	28	0.72	Based on KY, MO, MT (13)

*CRF/CMF given in the form of a function in the CMF Clearinghouse or in the report/paper. For this table, the CRFs/CMFs have been discretized for various levels of the safety countermeasure. The user is referred to the source (provided by the reference number) for the original functional form.

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APPENDIX B. CALIBRATED CMF, SPF, AND CRASH PERCENTAGES IMPLEMENTED IN THE IHSDM

This appendix summarizes the calibrated CMF and SPF parameters, as well as the updated crash percentages, which may be entered into the user interface of the IHSDM Administration Tool to reflect Indiana conditions. Table B.1 presents the calibrated CMF_{RA} (associated with related crash types) for lane width and shoulder width on rural two-lane undivided segments and for lane width on rural multilane divided segments. Furthermore, Table B.2 gives the calibrated CMF for shoulder width on rural multilane divided segments. Table B.3 provides the calibrated SPFs for all the rural and urban/suburban segment types under consideration. Table B.4 and Table B.5 give the general crash distributions and crash type percentages, respectively, for rural two-lane undivided segments. The crash type percentages are split be severity level for rural multilane divided segments in Table B.6; similarly, Table B.7 provides the crash percentages by severity level for multiple-vehicle non-driveway crashes on urban/suburban arterial segments.

TABLE B.1
Calibrated CMF_{RA} for Lane Width and Shoulder Width on Rural Two-Lane Undivided Segments and Rural Multilane Divided Segments

Countermeasure	Width in feet	Rural two-lane undivided	Rural multilane divided
Lane width	9	1.28	1.91
	10	1.18	1.54
	11	1.08	1.24
	12	1	1
Shoulder width	0	1.17	–
	2	1.11	–
	4	1.05	–
	6	1	–
	8 or more	0.95	–

TABLE B.2
Calibrated CMF for Shoulder Width on Rural Multilane Divided Segments

Shoulder width	Calibrated CMF
0	1.39
2	1.28
4	1.17
6	1.08
8 or more	1

TABLE B.4
Indiana General Crash Distributions for Rural Two-Lane Undivided Segments (All Values in Percent)

Crash severity level	Indiana
Related crash percentage	100.00
Fatal	1.06
Incapacitating injury	5.09
Nonincapacitating injury	10.30
Possible injury	1.34

TABLE B.3
Calibrated SPFs for Rural and Urban/Suburban Segments

Area	Facility Type	Number of Vehicles	Crash Type	Intercept	AADT	Length *L* (mi.)	Dispersion
Rural	Two-lane undivided	All	Total	1.204*	0.814	0.886	0.985
Rural	Multilane divided	All	Total	-10.074	1.139	0.749	1.083
Rural	Multilane divided	All	KABC	-12.736	1.238	0.608	0.806
Rural	Multilane divided	All	KAB	-12.717	1.230	0.669	0.708
Urban/suburban	Two-lane undivided	Multiple	Total	-13.357	1.452	0.307	1.813
Urban/suburban	Two-lane undivided	Multiple	PDO	-14.117	1.502	0.287	2.110
Urban/suburban	Two-lane undivided	Multiple	KABC	-13.864	1.366	0.437	2.240
Urban/suburban	Four-lane undivided	Multiple	Total	-16.691	1.811	0.658	1.901
Urban/suburban	Four-lane undivided	Multiple	PDO	-19.510	2.087	0.747	2.013
Urban/suburban	Four-lane undivided	Multiple	KABC	-14.163	1.401	0.689	1.343
Urban/suburban	Four-lane divided	Multiple	Total	-9.896	1.093	0.664	2.145
Urban/suburban	Four-lane divided	Multiple	PDO	-10.105	1.092	0.677	2.337
Urban/suburban	Four-lane divided	Multiple	KABC	-11.124	1.054	0.594	2.163
Urban/suburban	Two-lane undivided	Single	Total	-2.624	0.300	0.980	1.156
Urban/suburban	Two-lane undivided	Single	PDO	-2.051	0.217	0.979	1.214
Urban/suburban	Two-lane undivided	Single	KABC	-9.934	0.896	0.994	0.576
Urban/suburban	Four-lane divided	Single	Total	-7.583	0.824	1.184	1.051
Urban/suburban	Four-lane divided	Single	PDO	-7.217	0.776	1.272	1.132
Urban/suburban	Four-lane divided	Single	KABC	-12.905	1.143	0.862	0.244

*Check Section 5.1.2 for explanation

TABLE B.5
Indiana Crash Type Percentages for Rural Two-Lane Undivided Segments

Crash types	Fatal and injury	PDO	Total
Single vehicle			
Collision with animal	4.81	45.77	38.48
Collision with bicycle	0.48	0.02	0.10
Collision with pedestrian	0.90	0.05	0.20
Overturned	7.08	2.50	3.32
Ran off road	44.48	21.16	25.31
Other single-vehicle crash	1.32	4.84	4.21
Multiple vehicle			
Angle collision	6.02	2.32	2.98
Head-on collision	8.45	0.81	2.17
Rear-end collision	14.47	9.08	10.04
Sideswipe collision	7.45	5.13	5.55
Other multi-vehicle collision	4.54	8.31	7.64

Note: Related crash percentage for rural multilane divided segments: 100.00%

TABLE B.6
Indiana Crash Type Percentages by Severity Level for Rural Multilane Divided Segments

Collision type	Total	Fatal and injury	Fatal and injury*	PDO
Head-on	0.675	1.553	1.474	0.464
Sideswipe	7.234	6.019	6.105	7.524
Rear-end	17.841	29.126	28.421	15.142
Angle	4.760	10.680	10.526	3.344
Single	64.580	49.515	50.316	68.184
Other	4.910	3.107	3.158	5.341

*Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

TABLE B.7
Indiana Crash Type Percentages by Severity Level for Multiple-Vehicle Non-Driveway Crashes on Urban/Suburban Arterial Segments

Facility type	Severity	Rear-end	Head-on	Angle	Sideswipe same direction	Sideswipe opposite direction	Other
Two-lane undivided arterials (2U)	KABC	51.00	13.00	17.00	3.00	2.00	14.00
	PDO	45.95	1.65	11.26	14.71	2.85	23.57
Four-lane undivided arterials (4U)	KABC	50.88	7.02	26.32	5.26	0.00	10.53
	PDO	41.86	0.47	12.09	16.28	2.33	26.98
Four-lane divided arterials (4D)	KABC	65.74	3.90	12.81	7.80	0.56	9.19
	PDO	48.88	2.58	8.66	22.55	1.39	15.94

APPENDIX C. IMPLEMETING THE CALIBRATED INDIANA PARAMETERS IN THE IHSDM

The SPFs, CMFs, and crash proportions included in the HSM predictive method have been calibrated for Indiana conditions. These components may be incorporated in the IHSDM using the Administration Tool, shown in Figure C.1. The crash proportions are implemented under the "Crash Distribution Data Sets" module, while the SPF and CMF parameters are implemented under the "Model Data Sets" module.

This appendix illustrates how the Indiana-specific parameters may be implemented in the IHSDM Administration Tool and how this configuration is selected for use in the IHSDM crash prediction tool. The step-by-step procedures are detailed here for two cases. The first case involves transferring the prepared files containing the Indiana configuration to the Administration Tool interface. This case is applicable if the Administration Tool is in the default configuration (in other words, the HSM default is the only configuration available in the tool). In the second case, the user inputs the Indiana-specific parameters directly into the Administration Tool. This case is applicable if the Administration Tool is not in the default configuration (there are user-specified custom configurations already entered in the tool in addition to the HSM default).

Case 1—Transferring the Indiana Configuration Files to the Administration Tool

Step 1: Locate and copy the files with the Indiana configuration. Two files that contain the Indiana configuration have been prepared, one that includes the updated crash proportions and the other which has the parameters of the SPFs and CMFs. These files are named "config.cd.cpm.local_1" and "config.md.cpm.local_1," respectively, as shown in Figure C.2. They are available as supplements to this report and can be downloaded at https://doi.org/10.5703/1288284316646.

Step 2: Navigate to the IHSDM configuration folder. As displayed in Figure C.3, in this case, the folder is located in the C: drive under the following path: C: > IHSDM2017 > config

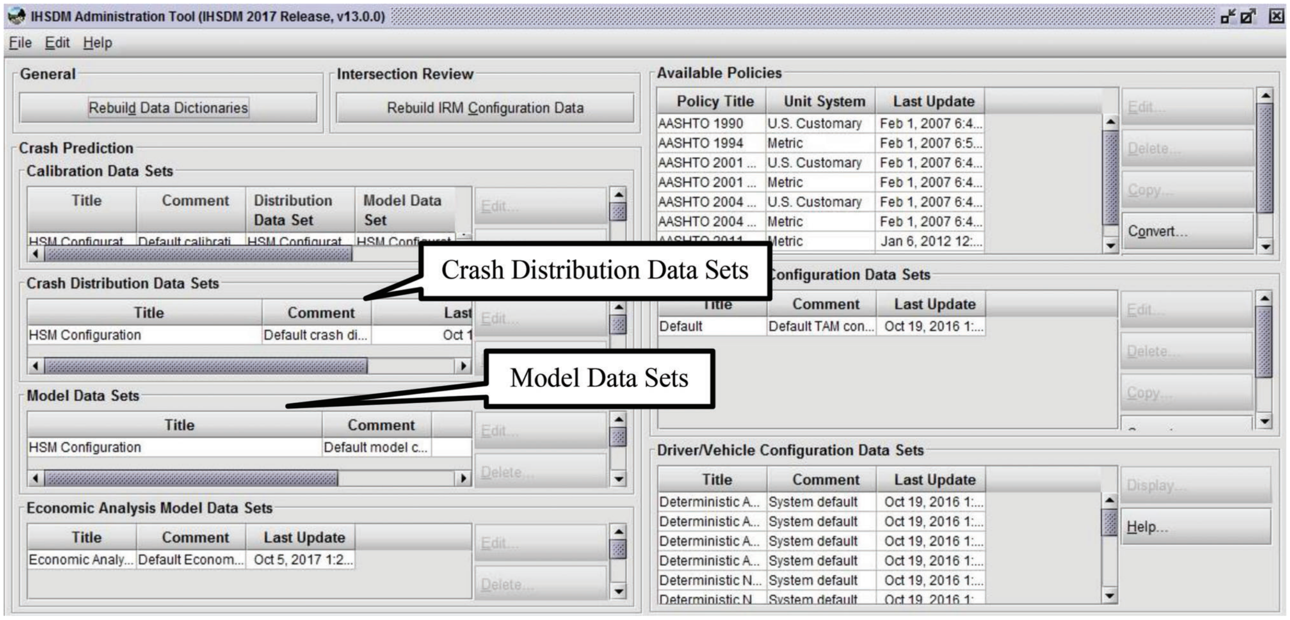
Step 3: Paste the files with the Indiana configuration in the IHSDM configuration folder. This step is shown in Figure C.4. The configuration folder may then be closed.

Step 4: Open the IHSDM Administration Tool from the Start menu (Figure C.5). The software should open with both the default HSM configuration and Indiana configuration appearing under the "Crash Distribution Data Sets" and "Model Data Sets" (Figure C.6).

Step 5: Save backup copies of the Indiana configuration files. In order for the Indiana configuration to work properly and be compatible with any other custom configurations that the user may decide to add later, backup copies of the Indiana configuration files should be saved. Under the "Crash Distribution Data Sets" module, select the Indiana configuration and click the "Edit" button as displayed in Figure C.7.

The following dialogue box appears (Figure C.8). No changes need to be made in this box, as the appropriate Indiana crash proportions have already been entered. Simply click "Ok."

Even though no changes were made in the configuration, a backup configuration file was automatically created,



Title	Comment	Distribution Data Set	Model Data Set
HSM Configurat	Default calibrati	HSM Configurat	HSM Configurat

Title	Comment	Last
HSM Configuration	Default crash di...	Oct 1

Title	Comment
HSM Configuration	Default model c...

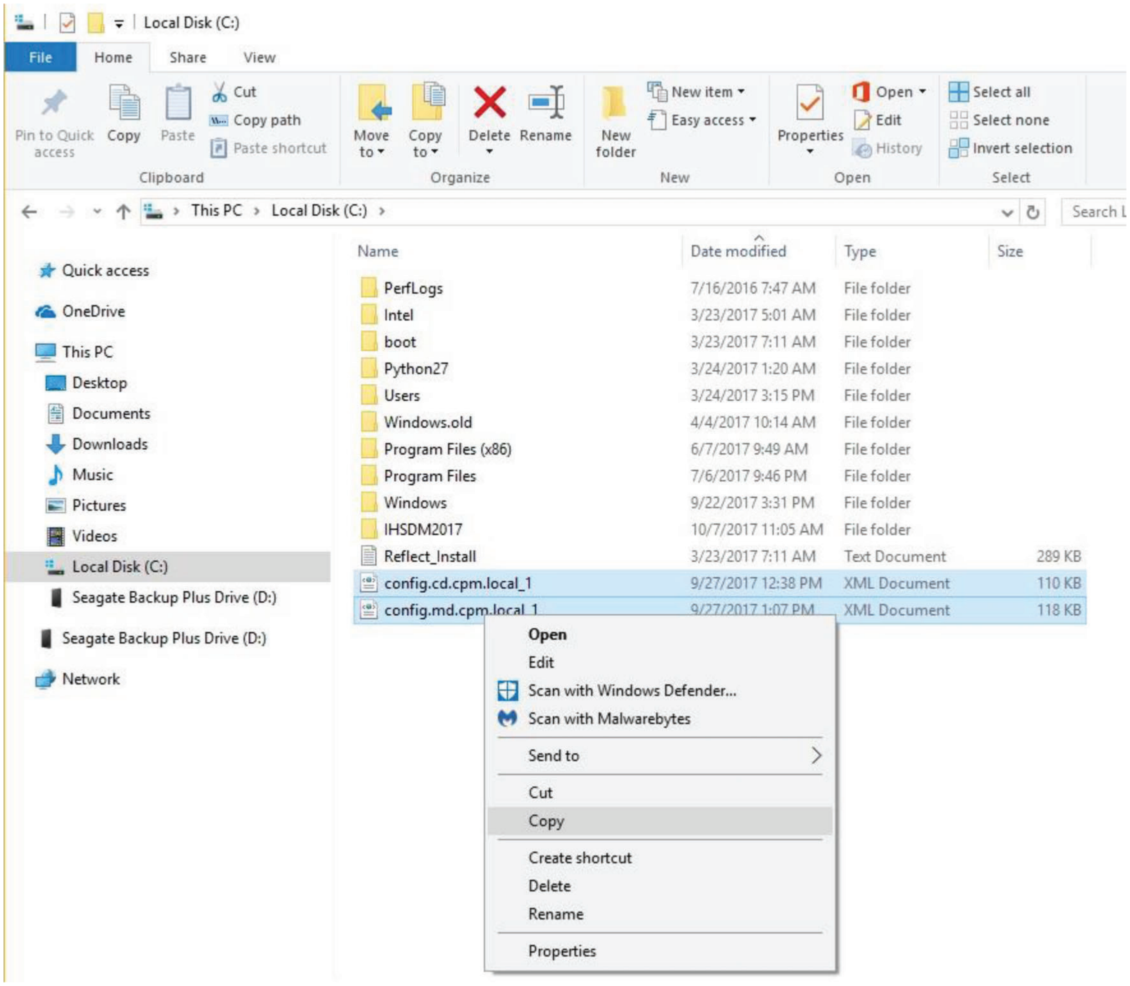
Title	Comment	Last Update
Economic Analy...	Default Econom...	Oct 5, 2017 1:2...

Policy Title	Unit System	Last Update
AASHTO 1990	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 1994	Metric	Feb 1, 2007 6:5...
AASHTO 2001 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2001 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2004 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2004 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2011	Metric	Jan 6, 2012 12:...

Title	Comment	Last Update
Default	Default TAM con...	Oct 19, 2016 1:...

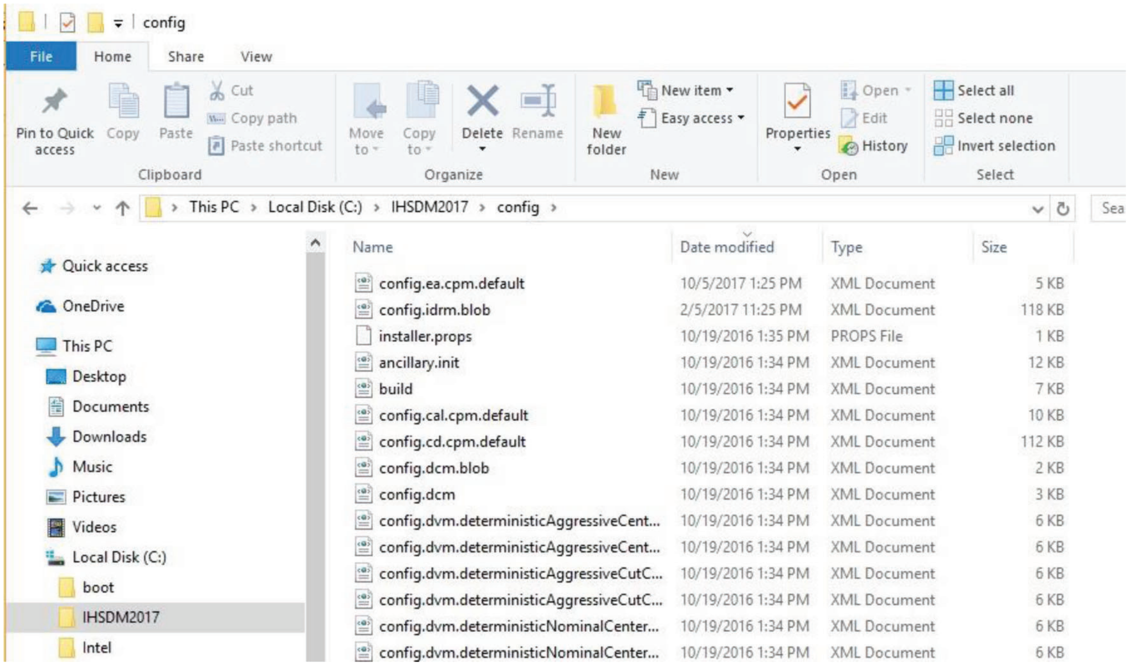
Title	Comment	Last Update
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...

Figure C.1 IHSDM Administration Tool.



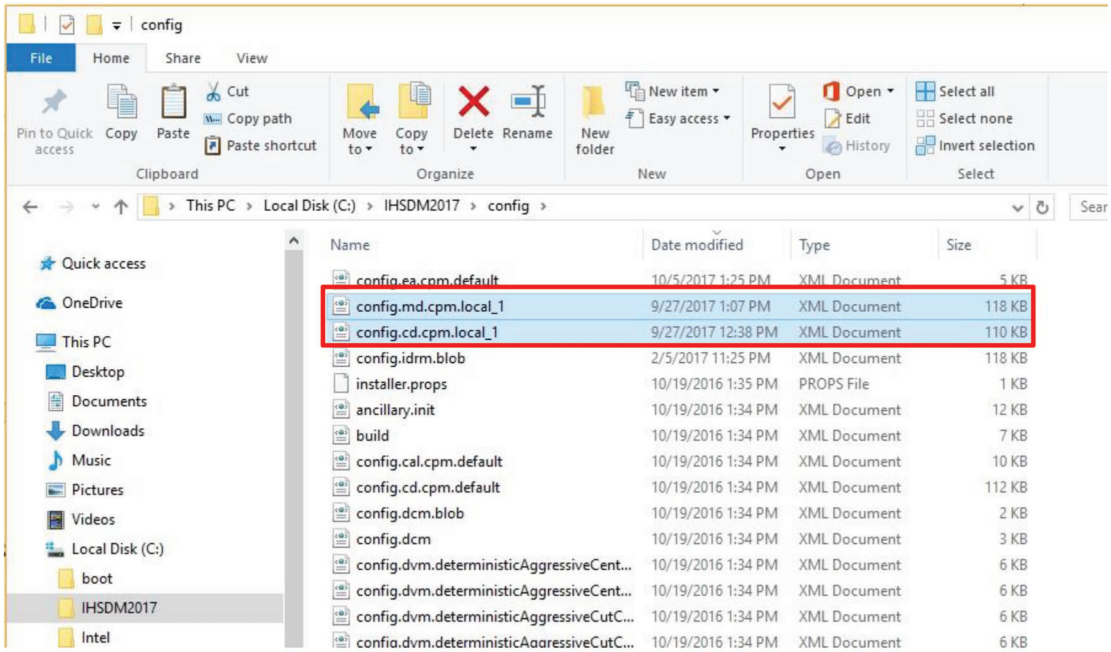
Name	Date modified	Type	Size
PerfLogs	7/16/2016 7:47 AM	File folder	
Intel	3/23/2017 5:01 AM	File folder	
boot	3/23/2017 7:11 AM	File folder	
Python27	3/24/2017 1:20 AM	File folder	
Users	3/24/2017 3:15 PM	File folder	
Windows.old	4/4/2017 10:14 AM	File folder	
Program Files (x86)	6/7/2017 9:49 AM	File folder	
Program Files	7/6/2017 9:46 PM	File folder	
Windows	9/22/2017 3:31 PM	File folder	
IHSDM2017	10/7/2017 11:05 AM	File folder	
Reflect_Install	3/23/2017 7:11 AM	Text Document	289 KB
config.cd.cpm.local_1	9/27/2017 12:38 PM	XML Document	110 KB
config.md.cpm.local_1	9/27/2017 1:07 PM	XML Document	118 KB

Figure C.2 Files with calibrated, Indiana-specific parameters.



Name	Date modified	Type	Size
config.ea.cpm.default	10/5/2017 1:25 PM	XML Document	5 KB
config.idrm.blob	2/5/2017 11:25 PM	XML Document	118 KB
installer.props	10/19/2016 1:35 PM	PROPS File	1 KB
ancillary.init	10/19/2016 1:34 PM	XML Document	12 KB
build	10/19/2016 1:34 PM	XML Document	7 KB
config.cal.cpm.default	10/19/2016 1:34 PM	XML Document	10 KB
config.cd.cpm.default	10/19/2016 1:34 PM	XML Document	112 KB
config.dcm.blob	10/19/2016 1:34 PM	XML Document	2 KB
config.dcm	10/19/2016 1:34 PM	XML Document	3 KB
config.dvm.deterministicAggressiveCent...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCent...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCutC...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCutC...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicNominalCenter...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicNominalCenter...	10/19/2016 1:34 PM	XML Document	6 KB

Figure C.3 IHSDM configuration folder.



Name	Date modified	Type	Size
config.ea.cpm.default	10/5/2017 1:25 PM	XML Document	5 KB
config.md.cpm.local_1	9/27/2017 1:07 PM	XML Document	118 KB
config.cd.cpm.local_1	9/27/2017 12:38 PM	XML Document	110 KB
config.idrm.blob	2/5/2017 11:25 PM	XML Document	118 KB
installer.props	10/19/2016 1:35 PM	PROPS File	1 KB
ancillary.init	10/19/2016 1:34 PM	XML Document	12 KB
build	10/19/2016 1:34 PM	XML Document	7 KB
config.cal.cpm.default	10/19/2016 1:34 PM	XML Document	10 KB
config.cd.cpm.default	10/19/2016 1:34 PM	XML Document	112 KB
config.dcm.blob	10/19/2016 1:34 PM	XML Document	2 KB
config.dcm	10/19/2016 1:34 PM	XML Document	3 KB
config.dvm.deterministicAggressiveCent...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCent...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCutC...	10/19/2016 1:34 PM	XML Document	6 KB
config.dvm.deterministicAggressiveCutC...	10/19/2016 1:34 PM	XML Document	6 KB

Figure C.4 Indiana configuration files in the IHSDM configuration folder.

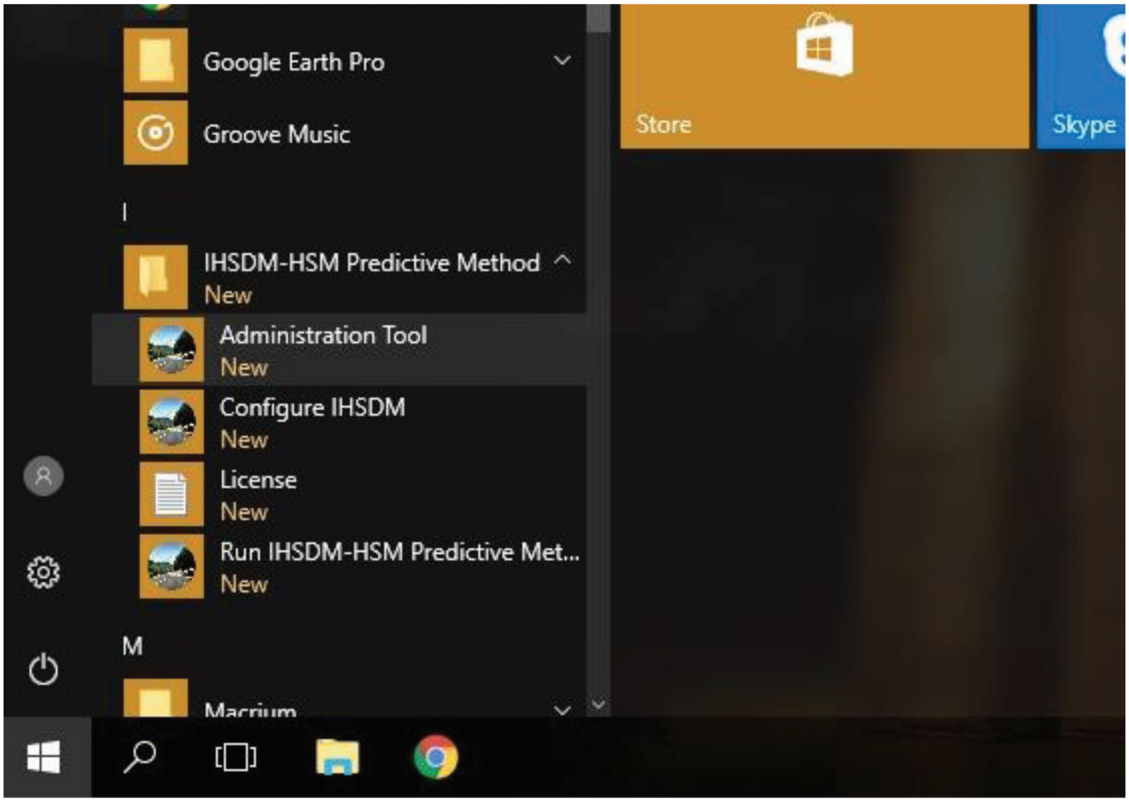
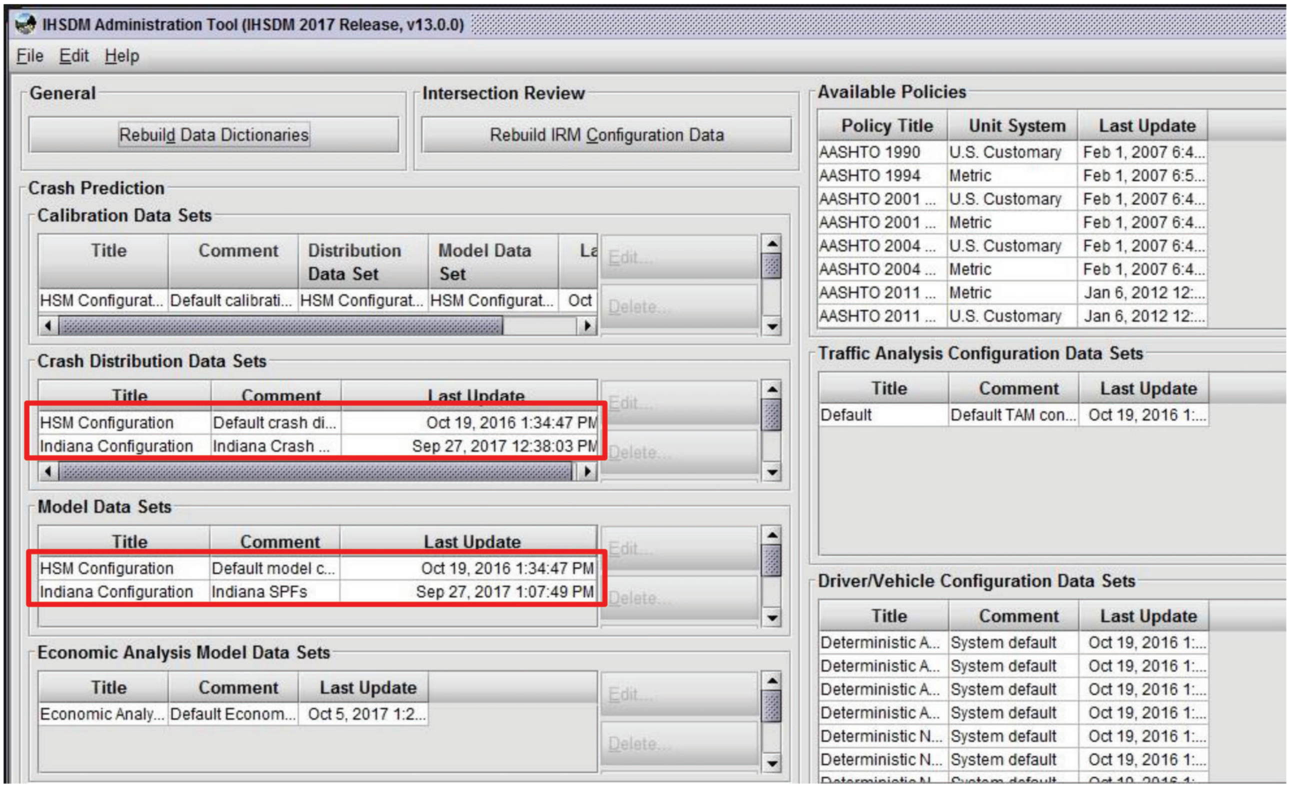


Figure C.5 Opening the IHSDM Administration Tool.



Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	La
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Indiana Configuration	Indiana Crash ...	Sep 27, 2017 12:38:03 PM

Model Data Sets

Title	Comment	Last Update
HSM Configuration	Default model c...	Oct 19, 2016 1:34:47 PM
Indiana Configuration	Indiana SPFs	Sep 27, 2017 1:07:49 PM

Economic Analysis Model Data Sets

Title	Comment	Last Update
Economic Analy...	Default Econom...	Oct 5, 2017 1:2...

Available Policies

Policy Title	Unit System	Last Update
AASHTO 1990	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 1994	Metric	Feb 1, 2007 6:5...
AASHTO 2001 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2001 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2004 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2004 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2011 ...	Metric	Jan 6, 2012 12:...
AASHTO 2011 ...	U.S. Customary	Jan 6, 2012 12:...

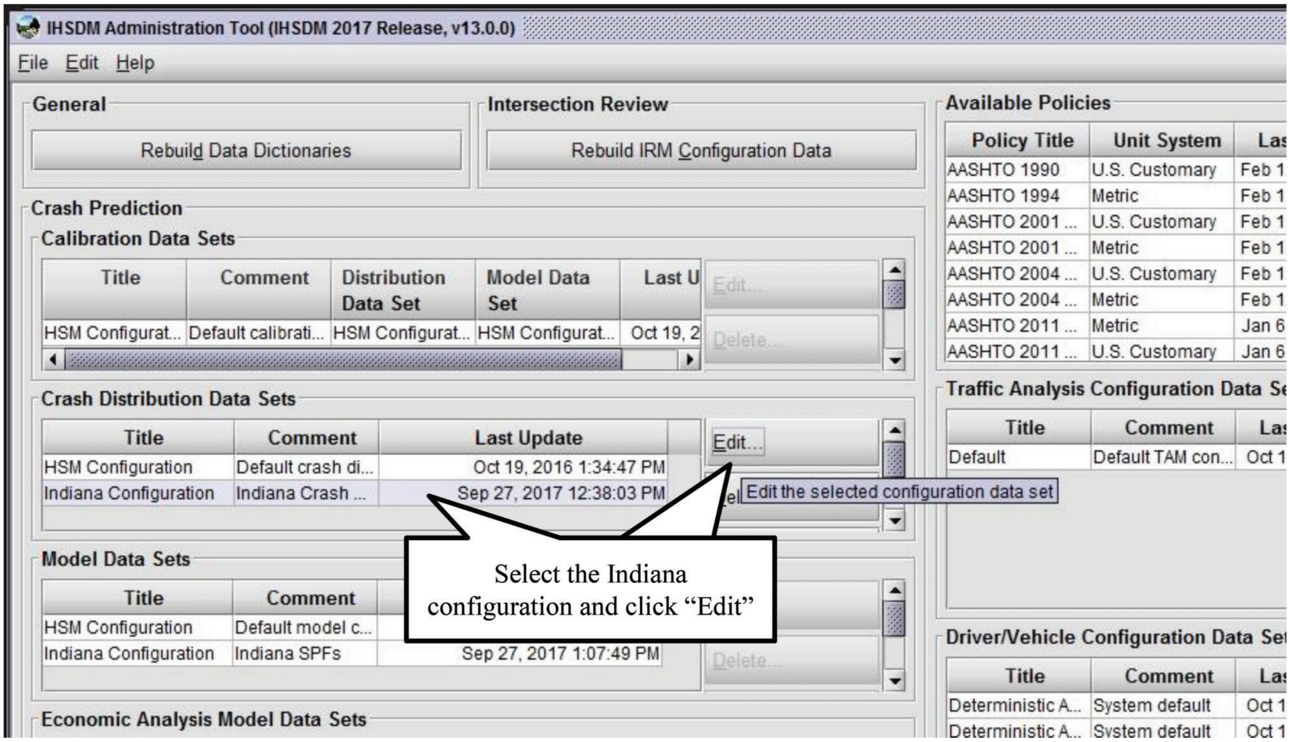
Traffic Analysis Configuration Data Sets

Title	Comment	Last Update
Default	Default TAM con...	Oct 19, 2016 1:...

Driver/Vehicle Configuration Data Sets

Title	Comment	Last Update
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...

Figure C.6 IHSDM Administration Tool with HSM and Indiana configurations.



Select the Indiana configuration and click “Edit”

Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	Last U
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct 19, 2

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Indiana Configuration	Indiana Crash ...	Sep 27, 2017 12:38:03 PM

Model Data Sets

Title	Comment	
HSM Configuration	Default model c...	
Indiana Configuration	Indiana SPFs	Sep 27, 2017 1:07:49 PM

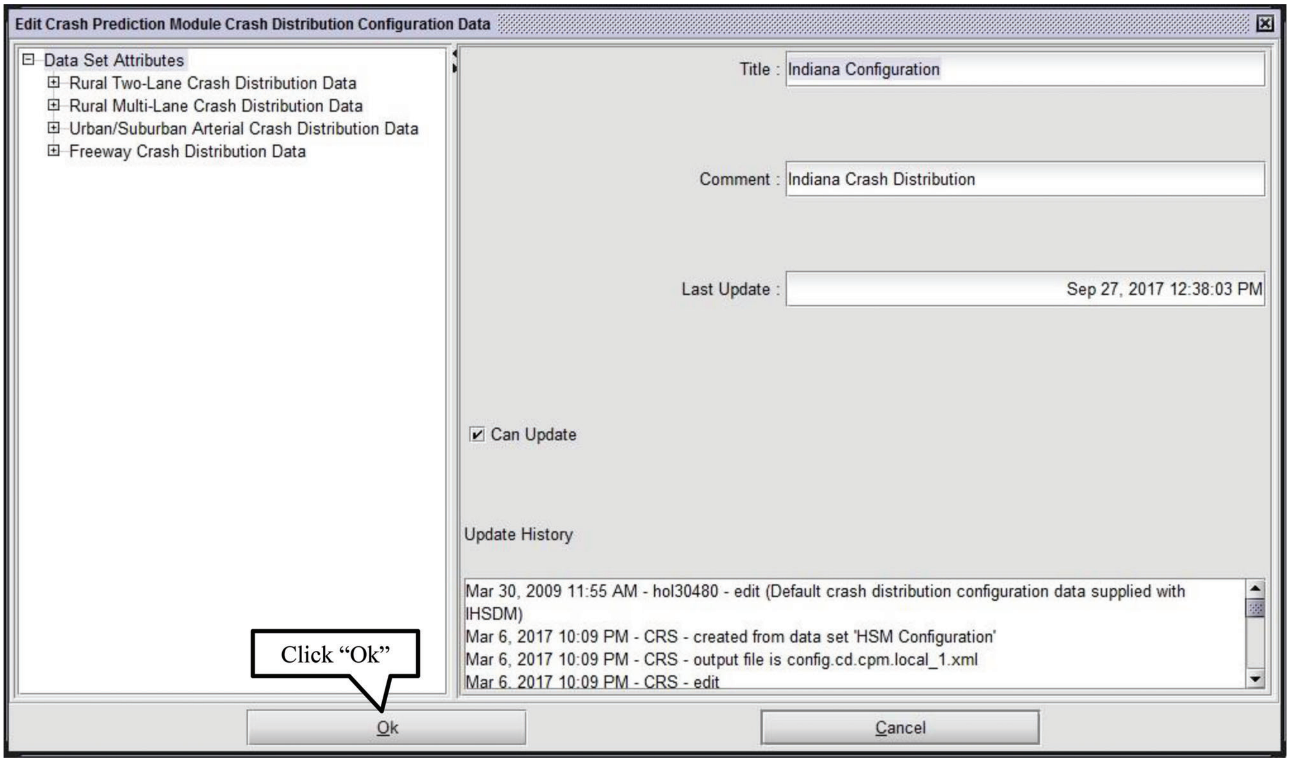
Available Policies

Policy Title	Unit System	Las
AASHTO 1990	U.S. Customary	Feb 1
AASHTO 1994	Metric	Feb 1
AASHTO 2001 ...	U.S. Customary	Feb 1
AASHTO 2001 ...	Metric	Feb 1
AASHTO 2004 ...	U.S. Customary	Feb 1
AASHTO 2004 ...	Metric	Feb 1
AASHTO 2011 ...	Metric	Jan 6
AASHTO 2011 ...	U.S. Customary	Jan 6

Title	Comment	Las
Default	Default TAM con...	Oct 1

Title	Comment	Las
Deterministic A...	System default	Oct 1
Deterministic A...	System default	Oct 1

Figure C.7 Saving backup copy of the Indiana configuration for “Crash Distribution Data Sets.”



Title : Indiana Configuration

Comment : Indiana Crash Distribution

Last Update : Sep 27, 2017 12:38:03 PM

☑ Can Update

Update History

```
Mar 30, 2009 11:55 AM - hol30480 - edit (Default crash distribution configuration data supplied with
IHSDM)
Mar 6, 2017 10:09 PM - CRS - created from data set 'HSM Configuration'
Mar 6, 2017 10:09 PM - CRS - output file is config.cd.cpm.local_1.xml
Mar 6, 2017 10:09 PM - CRS - edit
```

Click “Ok”

Figure C.8 Dialogue box for “Crash Distribution Data Sets” module.

in this case under the file path “C: > IHSDM2017 > users > ihsdm_admin > backup.” The same procedure is followed for the Indiana configuration file containing the SPF and CMF parameters (located in the “Model Data Sets” module). Figure C.9 shows what the Administration Tool should look like when finished.

Case 2—Inputting the Indiana-specific Parameters Directly into the Administration Tool

In this case, the user may have their own previously-created custom configuration already entered in the Administration Tool in addition to the HSM configuration. The Indiana crash proportions and SPF and CMF parameters may be entered by the user into the IHSDM Administration Tool by creating a new custom configuration for Indiana.

Step 1: Open the IHSDM Administration Tool from the Start menu (Figure C.10). As shown in Figure C.11, the software should open with the HSM configuration and previously-saved custom configuration appearing under the “Crash Distribution Data Sets” and “Model Data Sets.”

Step 2: Create the Indiana configuration under the “Crash Distribution Data Sets” module. This is most easily done by creating a copy of the HSM configuration and updating the crash proportions in this copy. Select the HSM configuration and click the “Copy” button (Figure C.12).

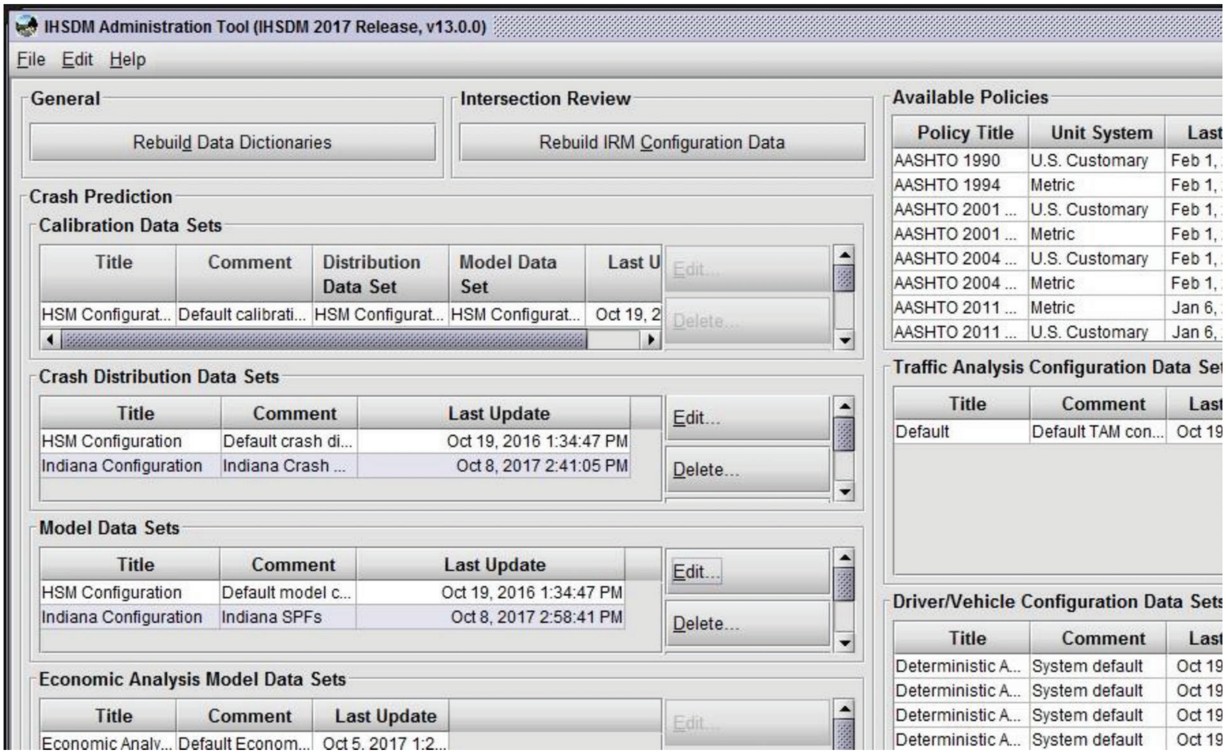
The dialogue box displayed in Figure C.13 appears. For the “Title”, the user may enter “Indiana Configuration” (or another name of personal preference). Similarly, under “Comment”, the user may enter “Indiana Crash Distribution.”

Step 3: Input the Indiana crash proportions into the tool. Under the dropdown “Data Set Attributes” on the left side of the screen, the “Rural Two-Lane Crash Distribution Data” is opened. The general crash distributions to be entered for segments may be found in Table B.4. This data is typed by the user into the appropriate boxes shown in Figure C.14 below.

The crash type proportions to be entered for rural two-lane undivided segments may be found in Table B.5. This data is input by the user into the appropriate boxes displayed in Figure C.15.

A similar procedure is followed for rural multilane divided segments and urban/suburban arterial segments using data from Table B.6 and Table B.7, respectively. Once the user has entered all of the crash proportions, click “Ok” to save the changes and return to the Administration Tool.

Step 4: Create the Indiana configuration under the “Model Data Sets” module. Again, this is most easily done be creating a copy of the HSM configuration and updating the SPF and CMF parameters in this copy. Once this has been done, the dialogue box in Figure C.16 appears.



Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	Last U
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct 19, 2

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Indiana Configuration	Indiana Crash ...	Oct 8, 2017 2:41:05 PM

Model Data Sets

Title	Comment	Last Update
HSM Configuration	Default model c...	Oct 19, 2016 1:34:47 PM
Indiana Configuration	Indiana SPFs	Oct 8, 2017 2:58:41 PM

Economic Analysis Model Data Sets

Title	Comment	Last Update
Economic Analy...	Default Econom...	Oct 5, 2017 1:2...

Available Policies

Policy Title	Unit System	Last
AASHTO 1990	U.S. Customary	Feb 1,
AASHTO 1994	Metric	Feb 1,
AASHTO 2001 ...	U.S. Customary	Feb 1,
AASHTO 2001 ...	Metric	Feb 1,
AASHTO 2004 ...	U.S. Customary	Feb 1,
AASHTO 2004 ...	Metric	Feb 1,
AASHTO 2011 ...	Metric	Jan 6,
AASHTO 2011 ...	U.S. Customary	Jan 6,

Traffic Analysis Configuration Data Se

Title	Comment	Last
Default	Default TAM con...	Oct 19

Driver/Vehicle Configuration Data Sets

Title	Comment	Last
Deterministic A...	System default	Oct 19
Deterministic A...	System default	Oct 19
Deterministic A...	System default	Oct 19
Deterministic A...	System default	Oct 19

Figure C.9 IHSDM Administration Tool after saving backup files.

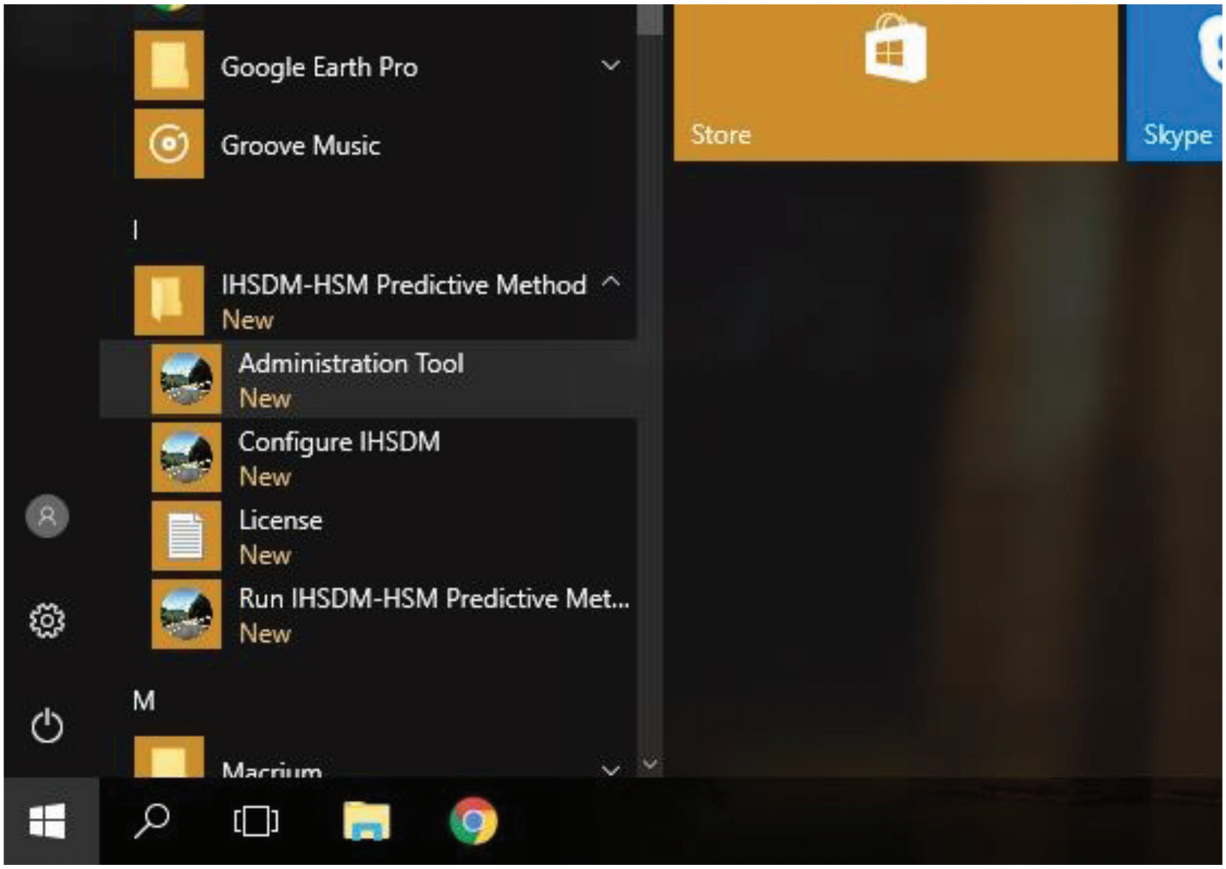
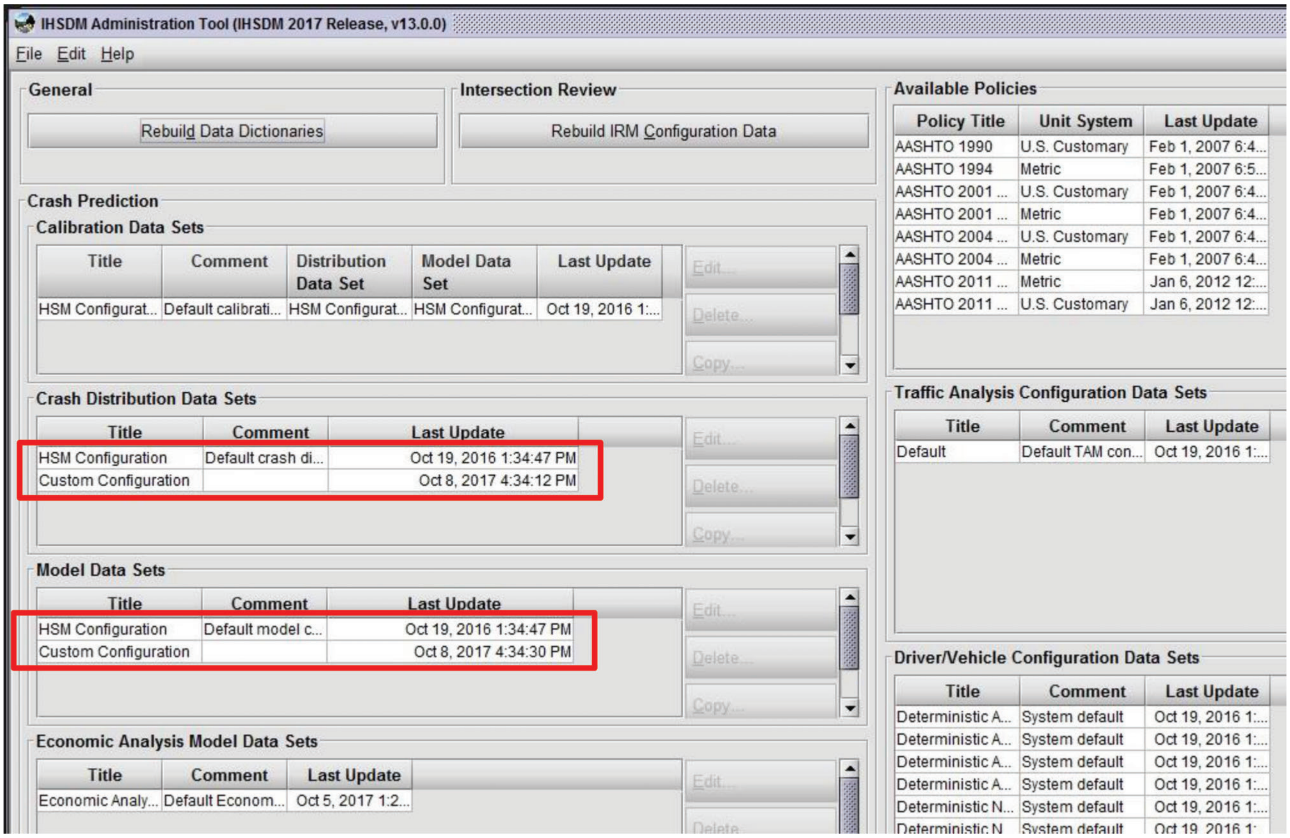


Figure C.10 Opening the IHSDM Administration Tool.



Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	Last Update
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct 19, 2016 1:...

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:12 PM

Model Data Sets

Title	Comment	Last Update
HSM Configuration	Default model c...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:30 PM

Economic Analysis Model Data Sets

Title	Comment	Last Update
Economic Analy...	Default Econom...	Oct 5, 2017 1:2...

Available Policies

Policy Title	Unit System	Last Update
AASHTO 1990	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 1994	Metric	Feb 1, 2007 6:5...
AASHTO 2001 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2001 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2004 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2004 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2011 ...	Metric	Jan 6, 2012 12:...
AASHTO 2011 ...	U.S. Customary	Jan 6, 2012 12:...

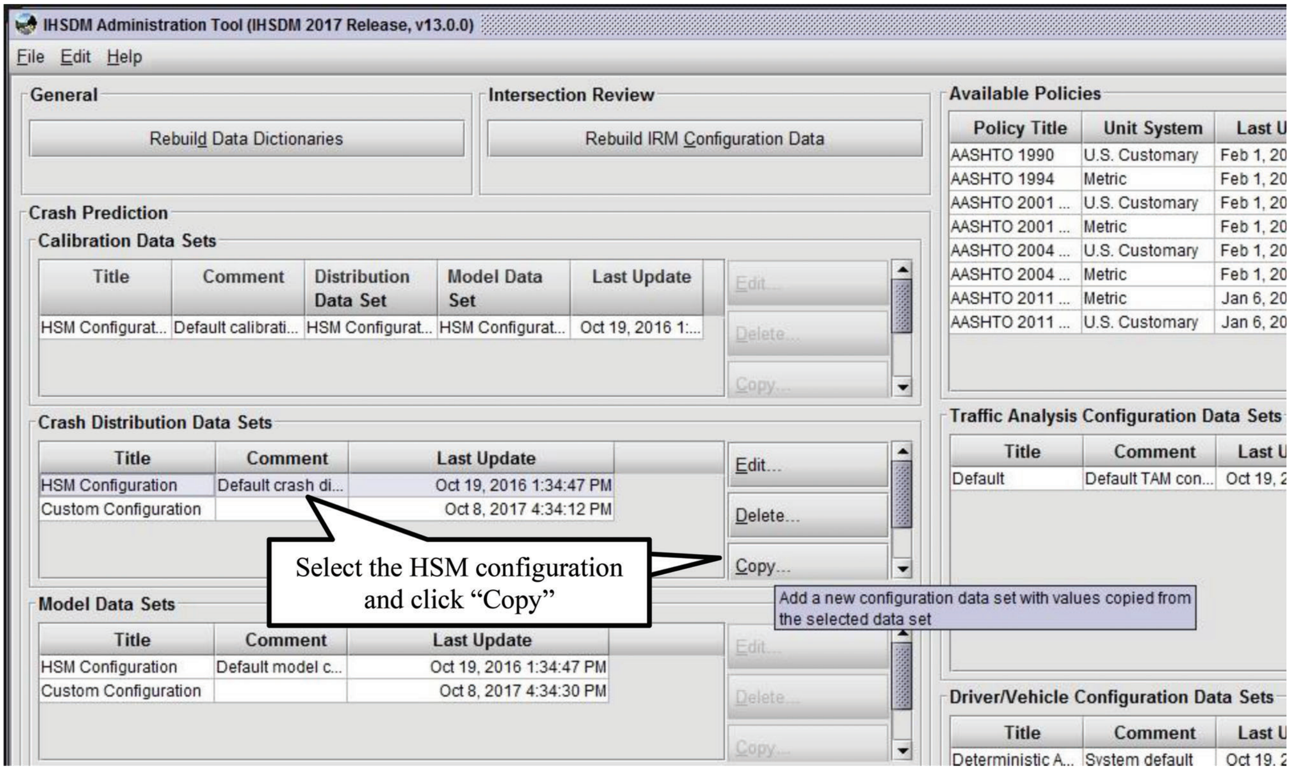
Traffic Analysis Configuration Data Sets

Title	Comment	Last Update
Default	Default TAM con...	Oct 19, 2016 1:...

Driver/Vehicle Configuration Data Sets

Title	Comment	Last Update
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N	System default	Oct 19, 2016 1:

Figure C.11 IHSDM Administration Tool with HSM and custom configurations.



Select the HSM configuration and click “Copy”

Add a new configuration data set with values copied from the selected data set

Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	Last Update
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct 19, 2016 1:...

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:12 PM

Model Data Sets

Title	Comment	Last Update
HSM Configuration	Default model c...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:30 PM

Available Policies

Policy Title	Unit System	Last U
AASHTO 1990	U.S. Customary	Feb 1, 20
AASHTO 1994	Metric	Feb 1, 20
AASHTO 2001 ...	U.S. Customary	Feb 1, 20
AASHTO 2001 ...	Metric	Feb 1, 20
AASHTO 2004 ...	U.S. Customary	Feb 1, 20
AASHTO 2004 ...	Metric	Feb 1, 20
AASHTO 2011 ...	Metric	Jan 6, 20
AASHTO 2011 ...	U.S. Customary	Jan 6, 20

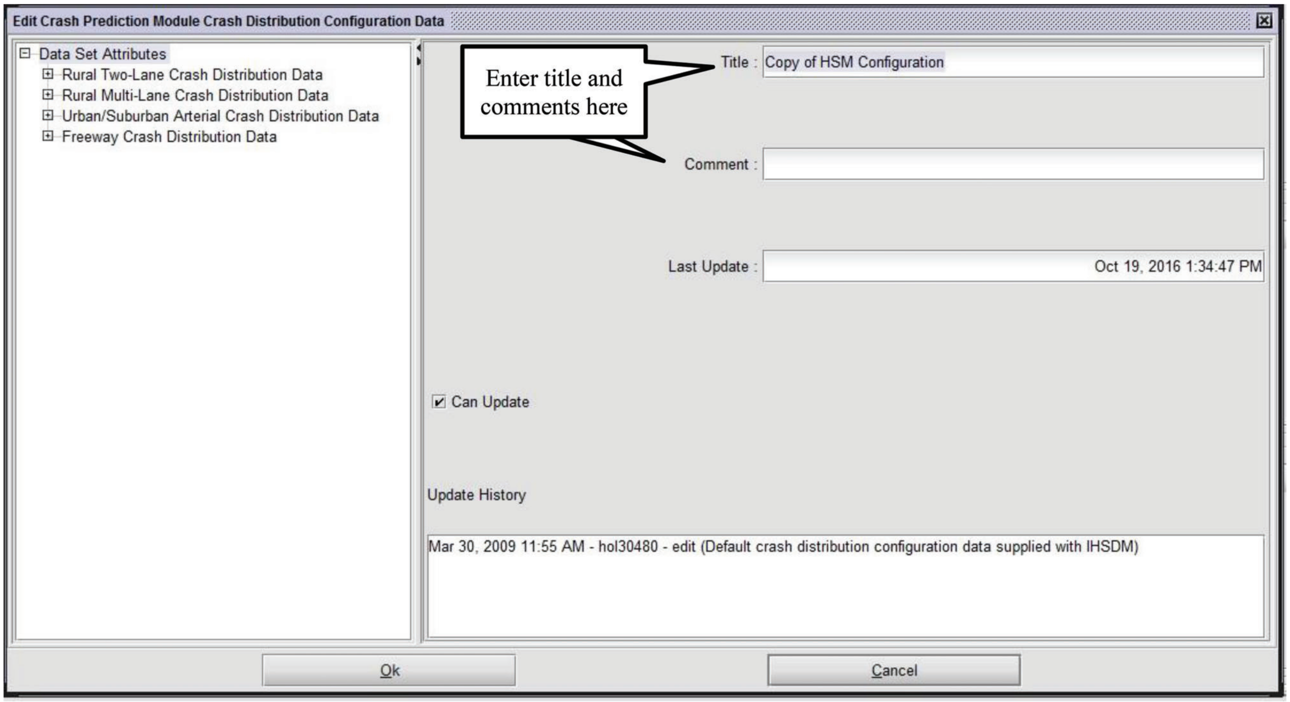
Traffic Analysis Configuration Data Sets

Title	Comment	Last U
Default	Default TAM con...	Oct 19, 2

Driver/Vehicle Configuration Data Sets

Title	Comment	Last U
Deterministic A...	System default	Oct 19, 2

Figure C.12 Creating a copy of the HSM configuration for “Crash Distribution Data Sets.”



Title : Copy of HSM Configuration

Comment :

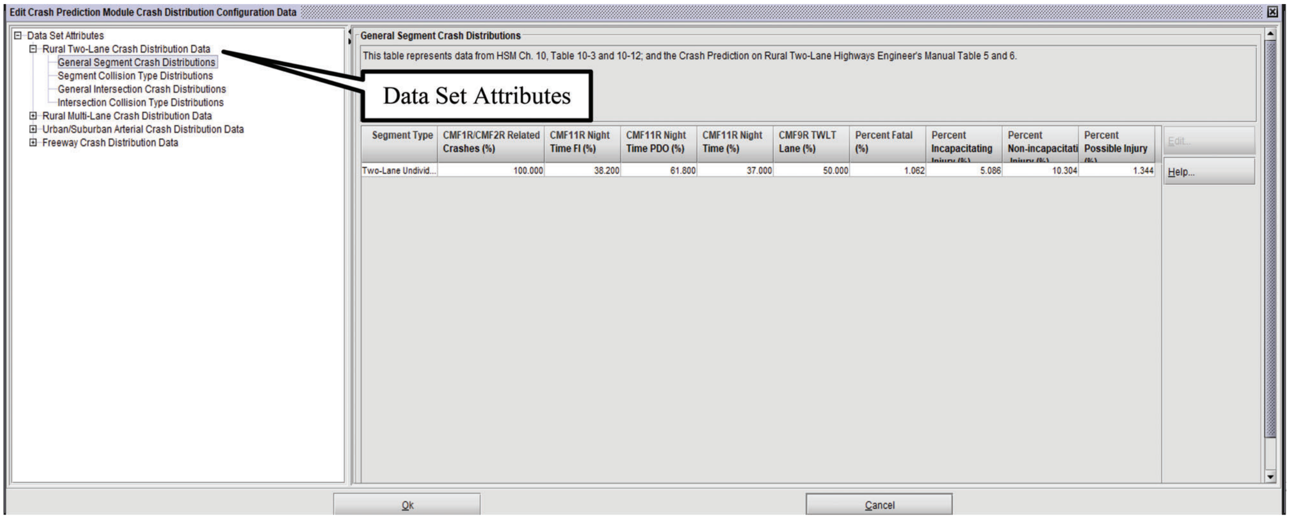
Last Update : Oct 19, 2016 1:34:47 PM

☑ Can Update

Update History

Mar 30, 2009 11:55 AM - hol30480 - edit (Default crash distribution configuration data supplied with IHSDM)

Figure C.13 Dialogue box for “Crash Distribution Data Sets” module.



General Segment Crash Distributions

This table represents data from HSM Ch. 10, Table 10-3 and 10-12; and the Crash Prediction on Rural Two-Lane Highways Engineer's Manual Table 5 and 6.

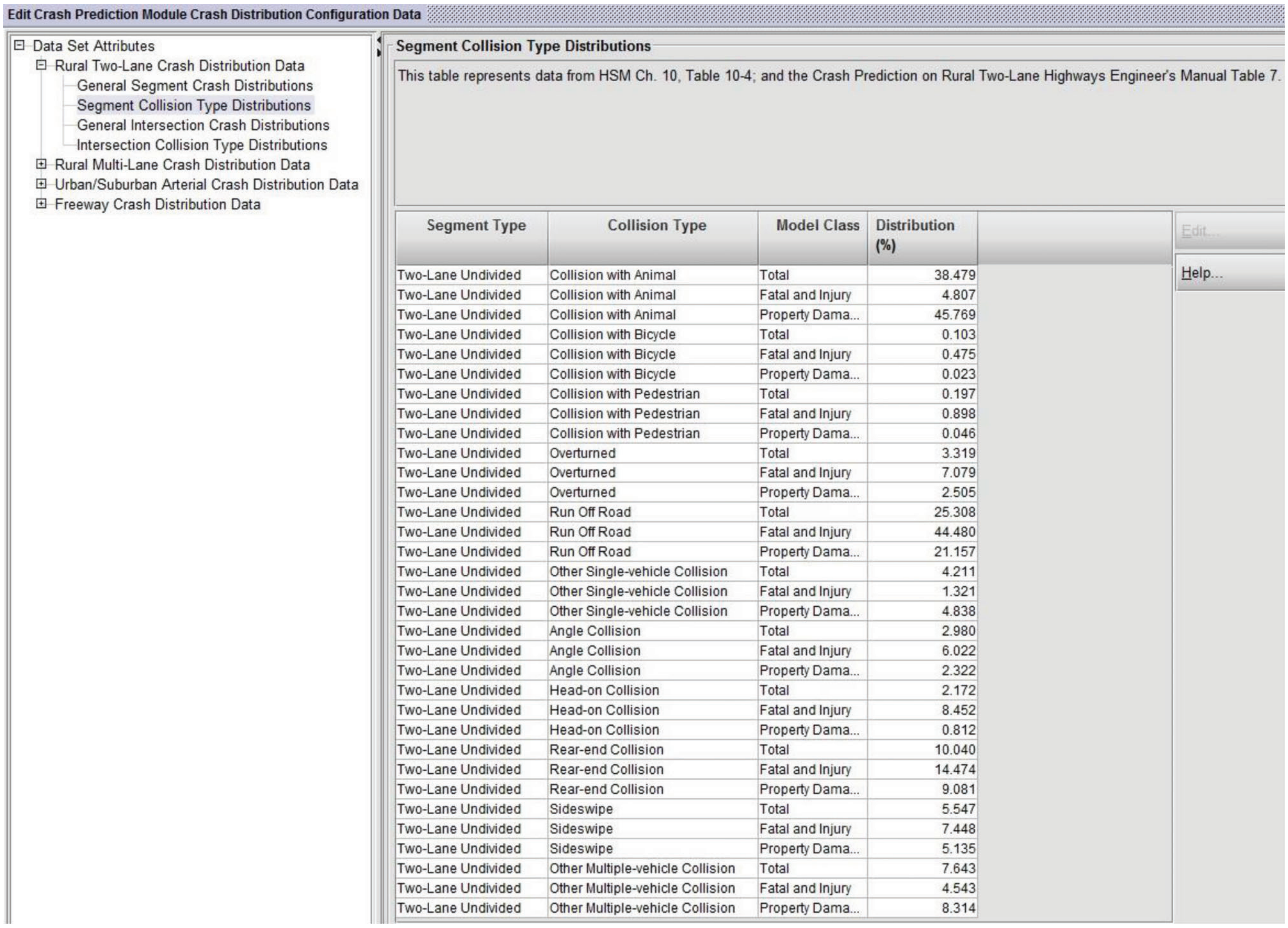
Segment Type	CMF1R/CMF2R Related Crashes (%)	CMF11R Night Time FI (%)	CMF11R Night Time PDO (%)	CMF11R Night Time (%)	CMF9R TWLT Lane (%)	Percent Fatal (%)	Percent Incapacitating	Percent Non-incapacitati	Percent Possible Injury
Two-Lane Undivid...	100.000	38.200	61.800	37.000	50.000	1.062	5.086	10.304	1.344

Figure C.14 Indiana general crash distributions for rural two-lane undivided segments.

Step 5: Input the Indiana SPF and CMF parameters into the tool. The “Rural Two-Lane Model Data” is opened under the “Data Set Attributes” from the drop-down menu. The SPF parameters to be entered for rural two-lane undivided segments (as well as rural multi-lane divided and urban/suburban arterial segments) are found in Table B.3. The parameters for rural two-lane undivided segments are input by the user into the boxes shown in Figure C.17.

The CMF parameters to be entered for lane width and shoulder width on rural two-lane undivided segments (as well as for lane width on rural multilane divided segments) are found in Table B.1. Figure C.18 and Figure C.19 display the boxes where the user may input the Indiana CMF parameters for lane width and shoulder width, respectively, on rural two-lane undivided segments.

Utilizing the data from Appendix B, a similar procedure is followed for inputting the available SPF and CMF parameters for rural multilane divided segments and urban/suburban arterial segments. Once the user is finished, click “Ok” to save the changes and return to the Administration Tool. It should now look as shown in Figure C.20.

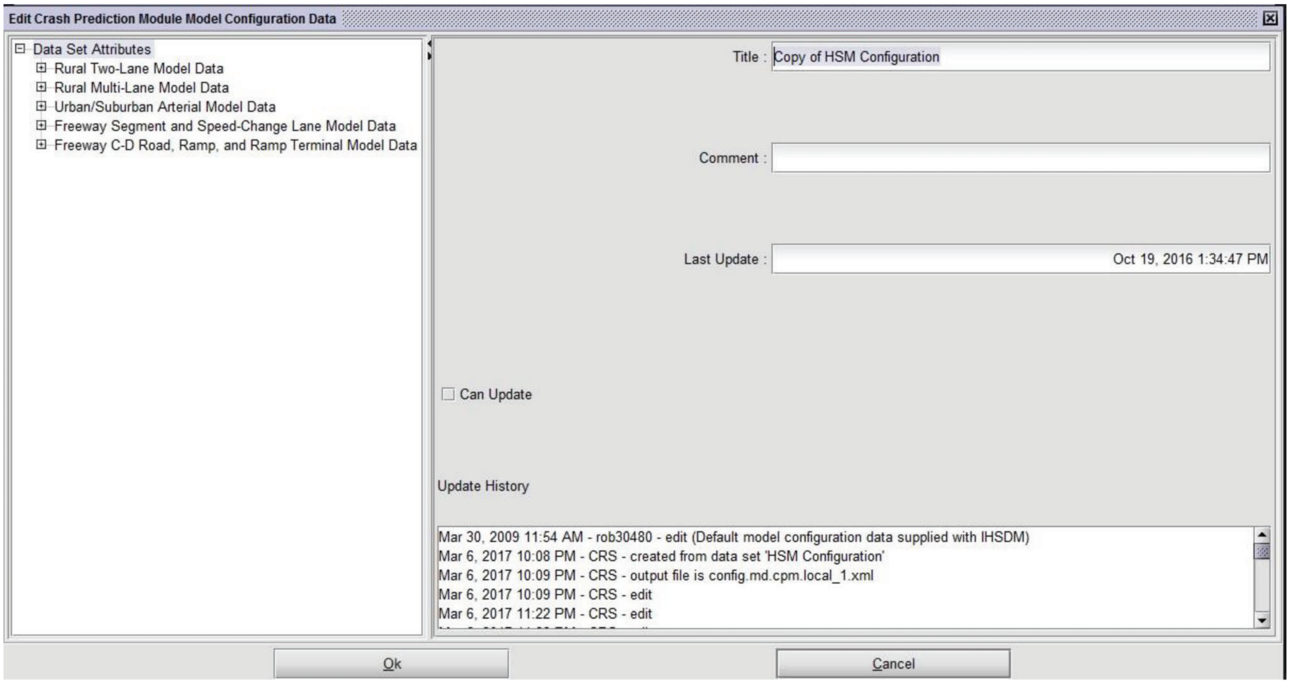


Segment Collision Type Distributions

This table represents data from HSM Ch. 10, Table 10-4; and the Crash Prediction on Rural Two-Lane Highways Engineer's Manual Table 7.

Segment Type	Collision Type	Model Class	Distribution (%)
Two-Lane Undivided	Collision with Animal	Total	38.479
Two-Lane Undivided	Collision with Animal	Fatal and Injury	4.807
Two-Lane Undivided	Collision with Animal	Property Dama...	45.769
Two-Lane Undivided	Collision with Bicycle	Total	0.103
Two-Lane Undivided	Collision with Bicycle	Fatal and Injury	0.475
Two-Lane Undivided	Collision with Bicycle	Property Dama...	0.023
Two-Lane Undivided	Collision with Pedestrian	Total	0.197
Two-Lane Undivided	Collision with Pedestrian	Fatal and Injury	0.898
Two-Lane Undivided	Collision with Pedestrian	Property Dama...	0.046
Two-Lane Undivided	Overturned	Total	3.319
Two-Lane Undivided	Overturned	Fatal and Injury	7.079
Two-Lane Undivided	Overturned	Property Dama...	2.505
Two-Lane Undivided	Run Off Road	Total	25.308
Two-Lane Undivided	Run Off Road	Fatal and Injury	44.480
Two-Lane Undivided	Run Off Road	Property Dama...	21.157
Two-Lane Undivided	Other Single-vehicle Collision	Total	4.211
Two-Lane Undivided	Other Single-vehicle Collision	Fatal and Injury	1.321
Two-Lane Undivided	Other Single-vehicle Collision	Property Dama...	4.838
Two-Lane Undivided	Angle Collision	Total	2.980
Two-Lane Undivided	Angle Collision	Fatal and Injury	6.022
Two-Lane Undivided	Angle Collision	Property Dama...	2.322
Two-Lane Undivided	Head-on Collision	Total	2.172
Two-Lane Undivided	Head-on Collision	Fatal and Injury	8.452
Two-Lane Undivided	Head-on Collision	Property Dama...	0.812
Two-Lane Undivided	Rear-end Collision	Total	10.040
Two-Lane Undivided	Rear-end Collision	Fatal and Injury	14.474
Two-Lane Undivided	Rear-end Collision	Property Dama...	9.081
Two-Lane Undivided	Sideswipe	Total	5.547
Two-Lane Undivided	Sideswipe	Fatal and Injury	7.448
Two-Lane Undivided	Sideswipe	Property Dama...	5.135
Two-Lane Undivided	Other Multiple-vehicle Collision	Total	7.643
Two-Lane Undivided	Other Multiple-vehicle Collision	Fatal and Injury	4.543
Two-Lane Undivided	Other Multiple-vehicle Collision	Property Dama...	8.314

Figure C.15 Indiana crash type proportions for rural two-lane undivided segments.



Title : Copy of HSM Configuration

Comment :

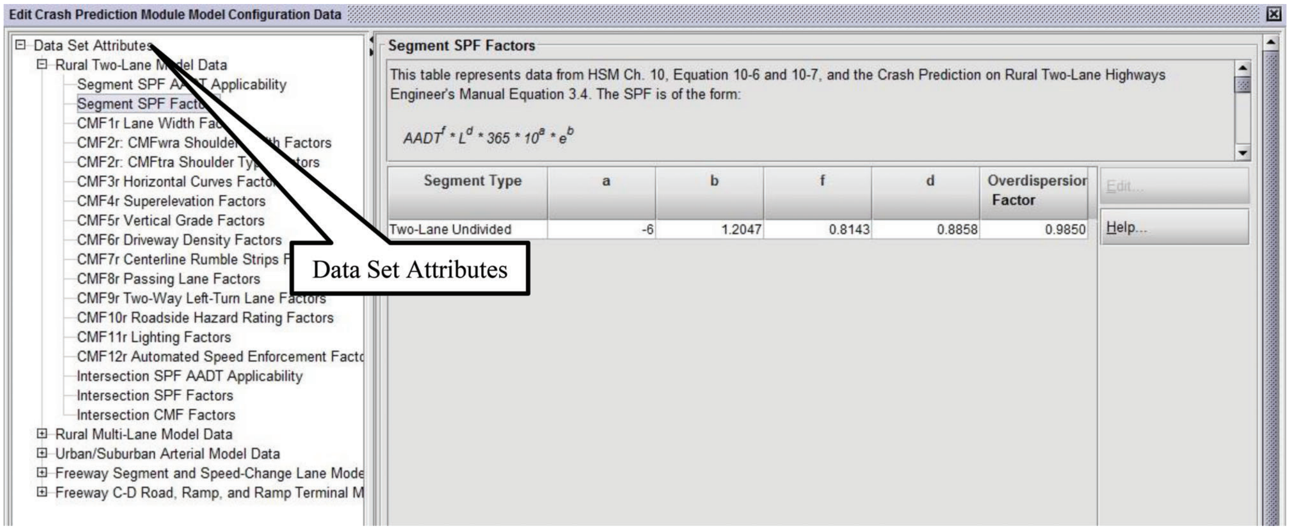
Last Update : Oct 19, 2016 1:34:47 PM

☐ Can Update

Update History

```
Mar 30, 2009 11:54 AM - rob30480 - edit (Default model configuration data supplied with IHSDM)
Mar 6, 2017 10:08 PM - CRS - created from data set 'HSM Configuration'
Mar 6, 2017 10:09 PM - CRS - output file is config.md.cpm.local_1.xml
Mar 6, 2017 10:09 PM - CRS - edit
Mar 6, 2017 11:22 PM - CRS - edit
```

Figure C.16 Dialogue box for "Model Data Sets" module.

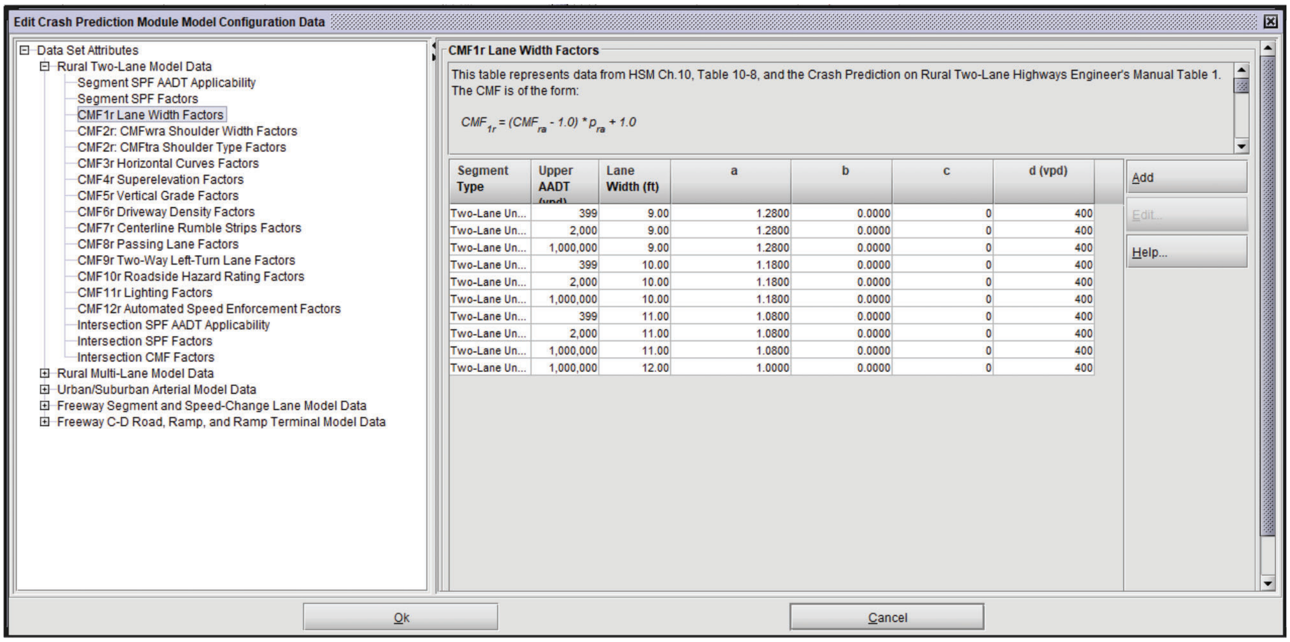


This table represents data from HSM Ch. 10, Equation 10-6 and 10-7, and the Crash Prediction on Rural Two-Lane Highways Engineer's Manual Equation 3.4. The SPF is of the form:

$$AADT^f * L^d * 365 * 10^a * e^b$$

Segment Type	a	b	f	d	Overdispersion Factor
Two-Lane Undivided	-6	1.2047	0.8143	0.8858	0.9850

Figure C.17 Indiana SPF parameters for rural two-lane undivided segments.



This table represents data from HSM Ch.10, Table 10-8, and the Crash Prediction on Rural Two-Lane Highways Engineer's Manual Table 1. The CMF is of the form:

$$CMF_{1r} = (CMF_{ra} - 1.0) * p_{ra} + 1.0$$

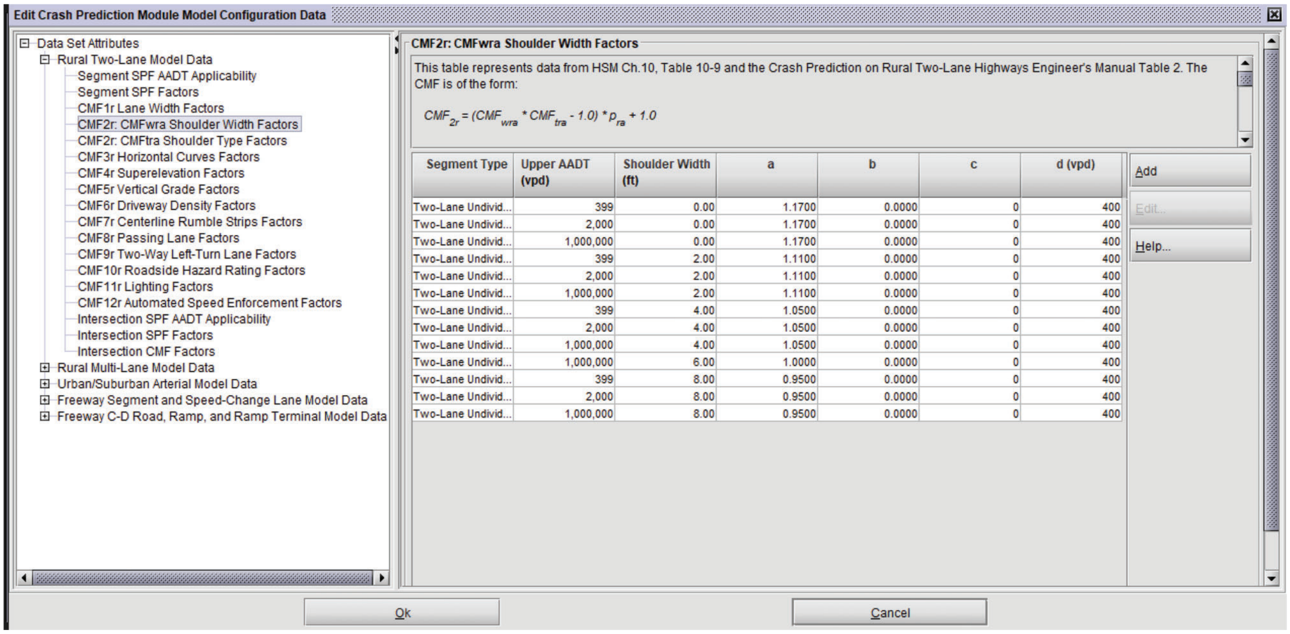
Segment Type	Upper AADT (vpd)	Lane Width (ft)	a	b	c	d (vpd)
Two-Lane Un...	399	9.00	1.2800	0.0000	0	400
Two-Lane Un...	2,000	9.00	1.2800	0.0000	0	400
Two-Lane Un...	1,000,000	9.00	1.2800	0.0000	0	400
Two-Lane Un...	399	10.00	1.1800	0.0000	0	400
Two-Lane Un...	2,000	10.00	1.1800	0.0000	0	400
Two-Lane Un...	1,000,000	10.00	1.1800	0.0000	0	400
Two-Lane Un...	399	11.00	1.0800	0.0000	0	400
Two-Lane Un...	2,000	11.00	1.0800	0.0000	0	400
Two-Lane Un...	1,000,000	11.00	1.0800	0.0000	0	400
Two-Lane Un...	1,000,000	12.00	1.0000	0.0000	0	400

Figure C.18 Indiana CMF parameters for lane width on rural two-lane undivided segments.

Selecting the Indiana Configuration for Use in the IHSDM Crash Prediction Tool

The final part of this appendix shows how the Indiana configuration is utilized for crash prediction in the IHSDM. It is assumed that the user has knowledge of the crash prediction tool, the IHSDM-HSM Predictive Method, and has created or input a rural or urban/suburban arterial segments and initiated a crash prediction evaluation. Under the "Set crash prediction attributes" dialogue box, the user is prompted to select the desired "Crash Distribution" and "Model/CMF" configurations. As seen in Figure C.21, the Indiana configuration is selected.

After the user has progressed through the setup for the crash prediction evaluation, the evaluation summary (Figure C.22) appears. The "Crash Distribution Configuration" and "Model/CMF Configuration" provide confirmation that the Indiana configuration has been selected.

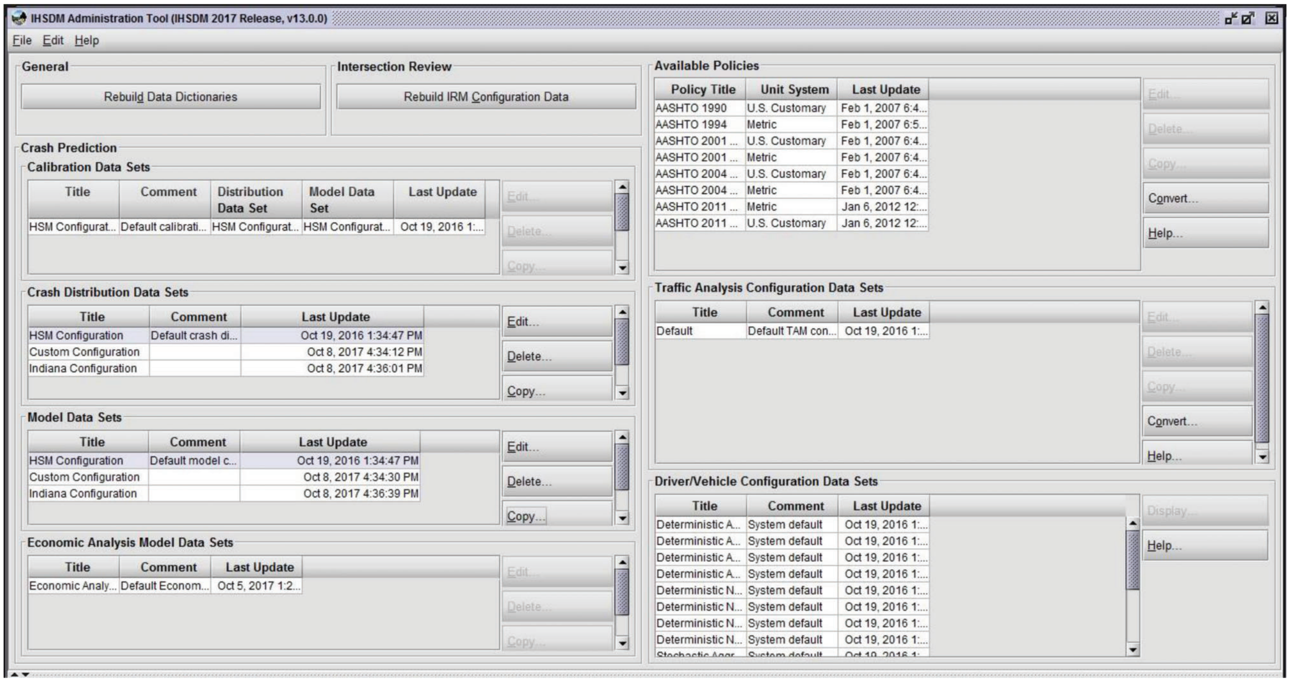


This table represents data from HSM Ch.10, Table 10-9 and the Crash Prediction on Rural Two-Lane Highways Engineer's Manual Table 2. The CMF is of the form:

$$CMF_{2r} = (CMF_{wra} * CMF_{tra} - 1.0) * p_{ra} + 1.0$$

Segment Type	Upper AADT (vpd)	Shoulder Width (ft)	a	b	c	d (vpd)
Two-Lane Undivid...	399	0.00	1.1700	0.0000	0	400
Two-Lane Undivid...	2,000	0.00	1.1700	0.0000	0	400
Two-Lane Undivid...	1,000,000	0.00	1.1700	0.0000	0	400
Two-Lane Undivid...	399	2.00	1.1100	0.0000	0	400
Two-Lane Undivid...	2,000	2.00	1.1100	0.0000	0	400
Two-Lane Undivid...	1,000,000	2.00	1.1100	0.0000	0	400
Two-Lane Undivid...	399	4.00	1.0500	0.0000	0	400
Two-Lane Undivid...	2,000	4.00	1.0500	0.0000	0	400
Two-Lane Undivid...	1,000,000	4.00	1.0500	0.0000	0	400
Two-Lane Undivid...	1,000,000	6.00	1.0000	0.0000	0	400
Two-Lane Undivid...	399	8.00	0.9500	0.0000	0	400
Two-Lane Undivid...	2,000	8.00	0.9500	0.0000	0	400
Two-Lane Undivid...	1,000,000	8.00	0.9500	0.0000	0	400

Figure C.19 Indiana CMF parameters for shoulder width on rural two-lane undivided segments.



Calibration Data Sets

Title	Comment	Distribution Data Set	Model Data Set	Last Update
HSM Configurat...	Default calibrati...	HSM Configurat...	HSM Configurat...	Oct 19, 2016 1:...

Crash Distribution Data Sets

Title	Comment	Last Update
HSM Configuration	Default crash di...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:12 PM
Indiana Configuration		Oct 8, 2017 4:36:01 PM

Model Data Sets

Title	Comment	Last Update
HSM Configuration	Default model c...	Oct 19, 2016 1:34:47 PM
Custom Configuration		Oct 8, 2017 4:34:30 PM
Indiana Configuration		Oct 8, 2017 4:36:39 PM

Economic Analysis Model Data Sets

Title	Comment	Last Update
Economic Analy...	Default Econom...	Oct 5, 2017 1:2...

Available Policies

Policy Title	Unit System	Last Update
AASHTO 1990	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 1994	Metric	Feb 1, 2007 6:5...
AASHTO 2001 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2001 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2004 ...	U.S. Customary	Feb 1, 2007 6:4...
AASHTO 2004 ...	Metric	Feb 1, 2007 6:4...
AASHTO 2011 ...	Metric	Jan 6, 2012 12:...
AASHTO 2011 ...	U.S. Customary	Jan 6, 2012 12:...

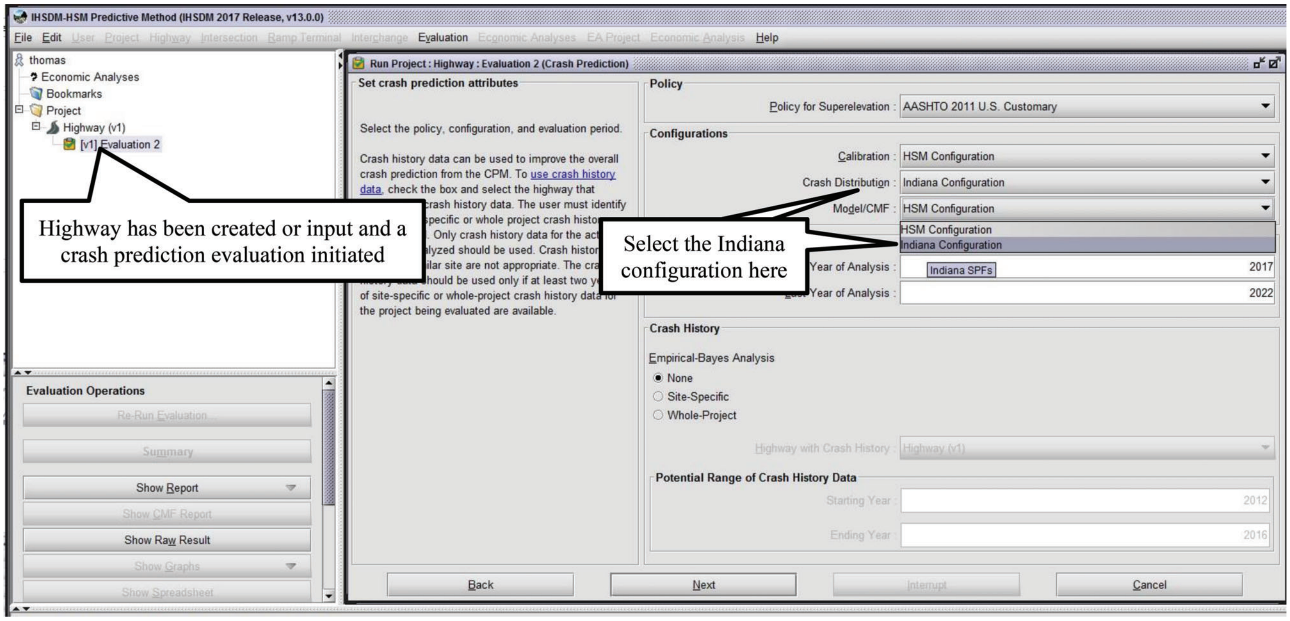
Traffic Analysis Configuration Data Sets

Title	Comment	Last Update
Default	Default TAM con...	Oct 19, 2016 1:...

Driver/Vehicle Configuration Data Sets

Title	Comment	Last Update
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic A...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Deterministic N...	System default	Oct 19, 2016 1:...
Stochastic Aggr...	System default	Oct 19, 2016 1:...

Figure C.20 IHSDM Administration Tool after creating Indiana configuration.



Highway has been created or input and a crash prediction evaluation initiated

Select the Indiana configuration here

Run Project : Highway : Evaluation 2 (Crash Prediction)

Set crash prediction attributes

Select the policy, configuration, and evaluation period.

Crash history data can be used to improve the overall crash prediction from the CPM. To use crash history data, check the box and select the highway that … crash history data. The user must identify … specific or whole project crash histo… . Only crash history data for the act… …lyzed should be used. Crash histor… …ilar site are not appropriate. The cra… …hould be used only if at least two y… of site-specific or whole-project crash history data … the project being evaluated are available.

Policy

Policy for Superelevation : AASHTO 2011 U.S. Customary

Configurations

Calibration : HSM Configuration

Crash Distribution : Indiana Configuration

Model/CMF : HSM Configuration

HSM Configuration
Indiana Configuration

…Year of Analysis : Indiana SPFs 2017

…Year of Analysis : 2022

Crash History

Empirical-Bayes Analysis

● None
○ Site-Specific
○ Whole-Project

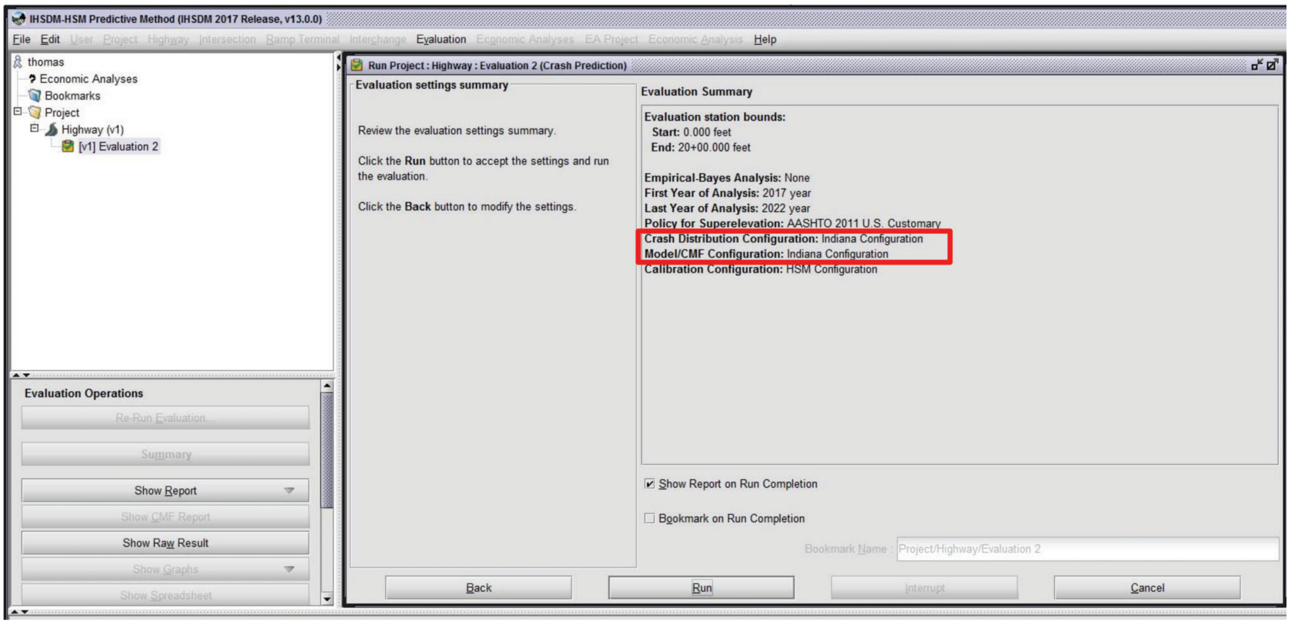
Highway with Crash History : Highway (v1)

Potential Range of Crash History Data

Starting Year : 2012

Ending Year : 2016

Figure C.21 Selecting the Indiana configuration in a crash prediction evaluation.



Run Project : Highway : Evaluation 2 (Crash Prediction)

Evaluation settings summary

Review the evaluation settings summary.

Click the **Run** button to accept the settings and run the evaluation.

Click the **Back** button to modify the settings.

Evaluation Summary

Evaluation station bounds:
Start: 0.000 feet
End: 20+00.000 feet

Empirical-Bayes Analysis: None
First Year of Analysis: 2017 year
Last Year of Analysis: 2022 year
Policy for Superelevation: AASHTO 2011 U.S. Customary
Crash Distribution Configuration: Indiana Configuration
Model/CMF Configuration: Indiana Configuration
Calibration Configuration: HSM Configuration

☑ Show Report on Run Completion

☐ Bookmark on Run Completion

Bookmark Name : Project/Highway/Evaluation 2

Figure C.22 Crash prediction evaluation summary.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Tarko, A. P., Romero, M., Hall, T., & Sultana, A. (2018). *Updating the crash modification factors and calibrating the IHSDM for Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/03). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316646