Missouri Highway Safety Manual Recalibration

Final Report
May 2018

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16. Abstract

The Highway Safety Manual (HSM) is a national manual for analyzing the highway safety of various facilities, including rural roads, urban arterials, freeways, and intersections. The HSM was first published in 2010, and a 2014 supplement addressed freeway interchanges. The HSM incorporated the safety modeling results from several National Cooperative Highway Research Program projects that used data from various states across the nation. The HSM recommended that individual states calibrate the HSM to local conditions on a regular basis. An initial statewide calibration for Missouri was finalized in 2013. The current recalibration effort builds upon the previous calibration and is designed to keep the calibration values up to date with the most current crash data and calibration methodologies. The current effort also involves the development of crash severity distribution functions so that crash frequencies can be estimated according to the severity categories of fatal, severe injury, minor injury, and property damage only. HSM calibration is a labor-intensive effort that requires the collection and use of detailed data such as road geometrics, traffic volumes, traffic signalization, land use, and crash frequency and severity. This report documents the details of the methodology employed for facility site selection, data collection, data processing, calibration, and severity assignment. Sixteen facility types were calibrated. These included rural two-lane segments with the related three-leg and four-leg intersections; rural multilane segments with the related three-leg and four-leg intersections; urban two-, four- and five-lane arterial segments; urban and rural four-lane and urban six-lane freeway segments; urban three- and four-leg signalized intersections; and urban three- and four-leg unsignalized intersections. The calibration results indicated that the HSM predicted Missouri crashes reasonably well, with the exception of a few site types for which it may be desirable for Missouri to develop its own safety performance functions in the future.

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ABBREVIATIONS AND ACRONYMS

The following is a list of common acronyms and abbreviations used in this report.

Name	Description
AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ARAN	Automated Road Analyzer
CMF	crash modification factor
EB	empirical Bayes
FHWA	Federal Highway Administration
IHSDM	Interactive Highway Safety Design Model
HCM	Highway Capacity Manual
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
KABCO	K – fatality, A – disabling injury, B – evident injury, C – possible injury, O - PDO
MoDOT	Missouri Department of Transportation
MU	University of Missouri
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
ODBC	open database connectivity
PDO	Property damage only
SPF	safety performance function
TMS	transportation management system
TRB	Transportation Research Board
US DOT	United States Department of Transportation

EXECUTIVE SUMMARY

The new Highway Safety Manual (HSM) is a national manual that facilitates the quantitative evaluation of safety. The HSM contains models that need to be calibrated in order to reflect local driver populations, conditions, and environmental issues such as driver behavior, geometric design, signage, traffic control devices, signal timing practices, climate, and animal population. A systematic calibration of HSM freeway models to account for such conditions in Missouri was previously performed by the University of Missouri (MU) using data from 2009 through 2011. MU produced 25 calibration values for 16 different types of transportation facilities, including rural undivided and divided highways, urban undivided and divided highways, rural and urban freeway segments, rural stop-controlled intersections, and urban stop-controlled and signalized intersections. These calibration values were published in the Missouri Department of Transportation (MoDOT) Engineering Policy Guide for use in all MoDOT districts.

Even though the HSM accounts for exposure variables such as average annual daily traffic (AADT) and other safety variables, such as geometrics, signalization, land use, and lighting, there are other safety-related variables, which can change over time. For example, driver behavior could change, with the prevalence of mobile device use while driving being a prime example. Another example is the increased use of automotive electronics, which improves safety through features such as object detection and video monitors but could also overtax driver attention. Therefore, the HSM recommends updating calibration values at least every two to three years. The Missouri recalibration effort described in this report used three years of data from 2012 through 2014.

The authors used the following four-step recalibration process: (1) identification of calibration samples/sites, (2) verification/collection of relevant site data, (3) prediction of HSM crash frequencies, and (4) fine-tuning calibration parameters by comparing predicted and actual crash frequencies. Steps (1) through (4) were performed for 25 values and 16 facilities. HSM freeway models were subdivided by severity and by single- or multi-vehicle crashes. Thus, three freeway facilities required 12 separate values. The 16 facilities were as follows:

- Rural two-lane undivided highway segments
- Rural multilane divided highway segments
- Urban two-lane undivided arterial segments
- Urban four-lane divided arterial segments
- Urban five-lane undivided arterial segments
- Rural four-lane freeway segments
- Urban four-lane freeway segments
- Urban six-lane freeway segments
- Urban three-leg signalized intersections
- Urban four-leg signalized intersections
- Urban three-leg stop-controlled intersections
- Urban four-leg stop-controlled intersections
- Rural two-lane three-leg stop-controlled intersections

- Rural two-lane four-leg stop-controlled intersections
- Rural multilane three-leg stop-controlled intersections
- Rural multilane four-leg stop-controlled intersections

In Step 1, the necessary samples required for HSM calibration were selected. Whenever possible, the random samples from the previous calibration were reused. Reuse of previous sites allowed the researchers to conduct an analysis of the sensitivity of the calibration value to an increase in the number of data years. However, samples were replaced if they had undergone changes in geometric design or other configuration. Sample sizes recommended by the HSM were followed unless Missouri lacked the number of samples or characteristics or it was inefficient to oversample the number of sites. The HSM recommends at least 30 sites per facility and a crash frequency of at least 100 crashes per year over all the sites of the particular facility type. Step 2 involved the verification of site characteristics to ensure that the site could still be used for recalibration. A changed site required a replacement and the collection of necessary data associated with the replacement site. The needed data could include traffic volumes, geometric data, pavement type, and signal control. Steps 3 and 4 were completed using Federal Highway Administration (FHWA) Interactive Highway Safety Design Model (IHSDM) software. Table ES1 summarizes the recalibration results.

Table ES1. Summary of HSM recalibration results for Missouri

Site type	Number of Sites	Observed Crashes	Previous Factor	Current Factor
Rural Two-Lane Undivided Highway Segments	194	281	0.82	0.97
Rural Multilane Divided Highway Segments	37	697	0.98	0.74
Urban Two-Lane Undivided Arterial Segments	75	365	0.84	1.48
Urban Four-Lane Divided Arterial Segments	66	403	0.98	0.91
Urban Five-Lane Undivided Arterial Segments	59	721	0.73	0.84
Rural Four-Lane Freeway Segments (PDO SV)	45	631	1.51	1.29
Rural Four-Lane Freeway Segments (PDO MV)	45	302	1.98	2.14
Rural Four-Lane Freeway Segments (FI SV)	45	110	0.77	0.50
Rural Four-Lane Freeway Segments (FI MV)	45	70	0.91	0.84
Urban Four-Lane Freeway Segments (PDO SV)	41	434	1.62	1.20
Urban Four-Lane Freeway Segments (PDO MV)	41	363	3.59	1.46
Urban Four-Lane Freeway Segments (FI SV)	41	95	0.70	0.60
Urban Four-Lane Freeway Segments (FI MV)	41	100	1.40	0.71
Urban Six-Lane Freeway Segments (PDO SV)	54	443	0.88	0.85
Urban Six-Lane Freeway Segments (PDO MV)	54	1,281	1.63	1.22
Urban Six-Lane Freeway Segments(FI SV)	54	189	1.01	0.96
Urban Six-Lane Freeway Segments (FI MV)	54	411	1.20	0.85
Urban Three-Leg Signalized Intersections	35	1,372	3.03	2.95
Urban Four-Leg Signalized Intersections	35	529	4.91	5.21
Urban Three-Leg Stop-Controlled Intersections	70	57	1.06	1.28
Urban Four-Leg Stop-Controlled Intersections	70	172	1.30	1.27
Rural Two-Lane Three-Leg Stop-Controlled Intersections	70	22	0.77	0.69
Rural Two-Lane Four-Leg Stop-Controlled Intersections	70	44	0.49	0.41
Rural Multilane Three-Leg Stop-Controlled Intersections	70	169	1.08	0.95
Rural Multilane Four-Leg Stop-Controlled Intersections	66	144	0.73	0.65

Unsurprisingly, the calibration values for some facilities changed from the previous calibration. These changes were due to natural data variability, driver behavior changes, changes in crash reporting, and, for a few facilities, a modification in how data were collected. Reasons specific to each facility are discussed in more detail in the facility-specific chapters. The two highest calibration values, urban three-leg and four-leg intersections, continued to be high, in line with the previous calibration values. The development of Missouri-specific safety performance functions is recommended for these two facilities.

In order to develop crash severity distributions, the crash severity of every crash on a particular type of facility in Missouri was tabulated. These sites were not limited to the calibration sites but were developed based on every possible site in Missouri. The severity levels of interest are fatal, severe injury, minor injury, and property damage only (PDO). Table ES2 summarizes the severity distribution factors for Missouri.

Table ES2. Summary of severity distribution factors for Missouri

Site type	Fatal	Severe Injury	Minor Injury	PDO	FI
Rural Two-Lane Undivided Highway Segments	0.020	0.084	0.266	0.630	0.37
Rural Multilane Divided Highway Segments	0.014	0.043	0.245	0.699	0.301
Urban Two-Lane Undivided Arterial Segments	0.008	0.039	0.235	0.718	0.282
Urban Four-Lane Divided Arterial Segments	0.003	0.024	0.228	0.745	0.255
Urban Five-Lane Undivided Arterial Segments	0.003	0.021	0.250	0.726	0.274
Rural Four-Lane Freeway Segments	0.009	0.035	0.148	0.808	0.192
Urban Four- and Six-Lane Freeway Segments	0.004	0.022	0.216	0.759	0.241
Urban Three-Leg Signalized Intersections	0.002	0.020	0.264	0.714	0.286
Urban Four-Leg Signalized Intersections	0.002	0.021	0.228	0.749	0.251
Urban Three-Leg Stop-Controlled Intersections	0.003	0.028	0.250	0.719	0.281
Urban Four-Leg Stop-Controlled Intersections	0.004	0.026	0.255	0.716	0.284
Rural Two-Lane Three-Leg Stop-Controlled Intersections	0.005	0.039	0.197	0.759	0.241
Rural Two-Lane Four-Leg Stop-Controlled Intersections	0.014	0.063	0.262	0.661	0.339
Rural Multilane Three-Leg Stop-Controlled Intersections	0.013	0.070	0.289	0.627	0.373
Rural Multilane Four-Leg Stop-Controlled Intersections	0.007	0.066	0.253	0.674	0.326

The facility types with the highest fatal plus injury (FI) crash proportions include rural two-lane undivided highways, rural two-lane four-leg stop-controlled intersections, and rural multilane three- and four-leg stop-controlled intersections. Using Table ES2, crash frequency by severity was derived by multiplying the severity distribution factor values by the predicted total crash frequency obtained from the calibrated HSM.

CHAPTER 1. INTRODUCTION

1.1 Missouri HSM Calibration Efforts

Missouri has been one of the 10 to 12 leading states in improving transportation safety analysis nationwide and promoting the use of the national Highway Safety Manual (HSM). The state actively participates in National Cooperative Highway Research Program (NCHRP) 17-50, Lead States Initiative for Implementing the Highway Safety Manual; the Highway Safety Performance Committee (ABN25) of the Transportation Research Board (TRB); and peer exchanges with other states. These efforts are important for furthering the goals of reducing traffic injuries and fatalities and improving highway safety for all Missourians.

The HSM (AASHTO 2010) is a national manual that facilitates the quantitative evaluation of safety. The HSM contains models that need to be calibrated in order to reflect local driver populations, conditions, and environments such as driver behavior, geometric design, signage, traffic control devices, signal timing practices, climate, and animal population. A systematic calibration of HSM freeway models to account for such conditions in Missouri was performed by the University of Missouri (MU) using data from 2009 through 2011 (Sun et al. 2014). MU produced 25 calibration values for 16 different types of transportation facilities, including rural undivided and divided highways, urban undivided and divided highways, rural and urban freeway segments, rural stop-controlled intersections, and urban stop-controlled and signalized intersections. These calibration values were published in the Missouri Department of Transportation (MoDOT) Engineering Policy Guide for use in all MoDOT districts.

In a 2014 supplement, freeway facilities were added to the original HSM manual, which allowed the modeling of highway interchanges. The most vital freeway interchange facility types in Missouri were calibrated, and results were reported in 2016 (Sun et al. 2016a). These facility types included nine freeway interchange terminals, including diamond, partial cloverleaf, and full cloverleaf interchanges. The non-terminal facilities included entrance and exit speed change lanes, and entrance and exit ramps. The calibrated facilities represented both rural and urban locations. For each facility type, sample sites were randomly selected from an exhaustive master list. Four types of data were collected for each site: geometric, annual average daily traffic (AADT), traffic control, and crash. Crash data were especially noteworthy because of the crash landing problem; i.e., crashes were not located on the proper interchange facility. A significant companion crash correction project (Sun et al. 2016b) was undertaken that involved the review of 12,409 crash reports and the detailed review of 9,169 crash reports. Using the corrected data, 44 calibration values were derived for freeway terminal and non-terminal facilities. These values were the first reported freeway interchange calibration values since the release of the 2014 HSM supplement.

This project involved the recalibration of the HSM for Missouri. All 25 HSM values (16 facilities) that were previously calibrated were recalibrated using additional data collected since 2011. These facilities are as follows:

- Rural two-lane undivided highway segments

- Rural multilane divided highway segments
- Urban two-lane undivided arterial segments
- Urban four-lane divided arterial segments
- Urban five-lane undivided arterial segments
- Rural four-lane freeway segments
- Urban four-lane freeway segments
- Urban six-lane freeway segments
- Urban three-leg signalized intersections
- Urban four-leg signalized intersections
- Urban three-leg stop-controlled intersections
- Urban four-leg stop-controlled intersections
- Rural two-lane three-leg stop-controlled intersections
- Rural two-lane four-leg stop-controlled intersections
- Rural multilane three-leg stop-controlled intersections
- Rural multilane four-leg stop-controlled intersections

The recalibration of freeway interchange facilities was not undertaken because they had been recently calibrated. By keeping HSM calibration values up to date, changes in driver behavior, crash reporting, and other safety-influencing factors can be taken into account when applying the HSM guidelines. In addition, this project produced severity distribution factors for all corresponding road facilities. These factors allowed the estimation of crash frequency according to the severities of fatal, severe injury, minor injury, and property damage only (PDO).

1.2 General Goals

The calibration of the HSM for Missouri and the application of the HSM directly supports four key focus areas of the USDOT, as outlined in the 2014–2018 strategic plan (USDOT 2014), and MoDOT:

- Enhance safety
- Improve the state of good repair
- Improve economic competiveness
- Improve environmental sustainability of the US surface transportation system

The most critical area is enhancing safety. The HSM can be used in MoDOT planning, design, operations, and maintenance. For example, HSM analysis is required for safety-related road design exceptions such as lane width, shoulder type, turn lanes, and geometric alignment. The HSM can be used to analyze projects that are funded by the Highway Safety Improvement Program and for the development and repair of infrastructure. Because of the elevated risks associated with work zones during construction, it is important to include safety considerations in implementing construction and rehabilitation work. The HSM also supports the goal of economic competiveness because it facilitates the economic estimation of crash reduction benefits, design alternatives, and project improvements. Finally, the HSM can be a useful tool during the National Environmental and Policy Act (NEPA) process for quantifying the safety impacts of various alternatives.

1.3 Organization of the Report

Chapter 2 summarizes calibration efforts across the US and internationally. Chapter 3 presents the overall calibration methodology. Each facility type has its own set of unique characteristics, resulting in unique methodological components for each facility. The calibration of individual facilities is discussed in Chapters 4 to 9 for rural two-lane undivided roadway segments, rural multilane divided segments, urban arterial segments, freeway segments, urban signalized intersections, and unsignalized intersections, respectively. Each of these six chapters covers a specific facility type and includes scope, data requirements, HSM methodology, sampling, data description, and results. Some of these chapter subsections are similar across the various facilities; however, some do have significant differences. In order to improve readability, each chapter was written so that it can be read independently. Some material is repeated purposely across the different chapters to aid the reader.

CHAPTER 2. NATIONAL CALIBRATION EFFORTS

Since the publication of the HSM, several states have started to calibrate the manual to local conditions. The most common type of facility to be calibrated has been rural two-lane highway segments. This is probably due to the relative ease of modeling this facility as compared to other facilities and the prevalence of such facilities. This chapter surveys the efforts on HSM calibration of non-interchange facilities across the nation. (Interchange facilities are outside the scope of this report.) The state efforts are presented in alphabetical order. There are several ongoing calibration projects, so other states will eventually report on their calibration results.

2.1 Alabama

Mehta and Lou (2013) described both the calibration and development of safety performance functions for two-lane two-way rural roads and four-lane divided highways in Alabama. The calibration results were 1.392 for two-lane roads and 1.103 for four-lane roads. The authors described an alternate calibration approach involving the use of negative binomial regression. The alternate approach produced slightly different results of 1.522 for two-lane roads and 1.863 for four-lane roads.

2.2 Arizona

Srinivasan et al. (2016) calibrated rural two-lane roads in Arizona. The authors also discussed the option of developing calibration functions in addition to calibration factors. Instead of a constant calibration factor, the use of functions allows the calibration values to vary according to different variable values.

2.3 Florida

Sivaramakrishnan et al. (2011) produced calibration factors for Florida. The facility types were rural two-lane and multilane segments, and urban and suburban arterial segments and intersections. The authors produced calibration factors by year and focused on fatal and injury crashes. Most calibration values were much less than 2.0, but urban three- and four-leg intersections had higher calibration factor values of around 2.0 for most years.

2.4 Illinois

One Illinois calibration effort involved rural two-lane highways (Williamson and Zhou 2012). Three years of data from 2005 to 2007 were used. The sample contained 165 total crashes. Five random segments were selected from each of six counties. In 2009, the property damage threshold was significantly increased from $500 to $1,500. Thus, future calibrations would result in lower calibration values because of the decrease in the number of property damage only crash reports.

2.5 Kansas

Dissanayake and Aziz (2016) calibrated rural four-lane divided and undivided highways in Kansas. They found that that the HSM underpredicted crashes by 48% and 64% for four-lane divided and undivided highways, respectively. The authors also developed Kansas-specific safety performance factors (SPFs) and found them to be more accurate than the calibrated HSM SPFs.

2.6 Louisiana

Sun et al. (2006) calibrated rural two-lane facilities in Louisiana. Three years of data from 1999 to 2001 were used. Sampling of sites was divided into two groups of 26 and 16 samples. The calibration result for the first group was 1.1 times higher than the state average, and the result for the second group was 2.5 times higher.

2.7 Maryland

Maryland (Shin et al. 2014) calibrated 18 facility types, including eight segment and 10 intersection types. Segments reviewed included rural two-lane and four-lane undivided, and urban two-, three-, four-, and five-lane undivided and divided. The intersection types included both stop-controlled and signalized intersections for both rural and urban roads. Other than a calibration value of 2.26 for rural four-lane undivided segments, the rest of the segment values were near or less than 1.0. The intersection values were all much smaller than 1.0.

2.8 North Carolina

One North Carolina calibration effort (Srinivasan and Carter 2011) included the six segment types of rural four-lane divided, urban two-lane undivided, urban two-lane with two-way left-turn lane, urban four-lane divided, and urban four-lane with two-way left-turn lane roadways. The eight intersection facility types included rural two-lane three- and four-leg stop-controlled, rural two-lane three- and four-leg signalized, urban arterial three- and four-leg signalized, and urban arterial three- and four-leg stop-controlled intersections. In order to maximize sampling efficiency, entire routes were used for segments. For intersections, the sampling varied from 19 samples for rural two-lane four-leg signalized intersections to 133 samples for rural two-lane three-leg stop-controlled intersections. Half of the intersection types did not reach the 100 crashes per year threshold recommended by the HSM. Several of the North Carolina segment types yielded high calibration values. For example, the calibration values for urban two-lane with two-way left-turn was 3.62, urban four-lane divided was 3.87, and urban four-lane undivided was 4.04. Intersection values were closer to 1.0, except for the calibration values of 2.45 for the urban arterial signalized three-leg intersection and 2.79 for the urban arterial signalized four-leg intersection.

2.9 Ohio

Troyer et al. (2015) calibrated 18 facility types in Ohio. These facilities, both rural and urban, included eight segment types, with two being divided. The 10 intersection types included rural and urban intersections with stop control and signals, and with three and four legs. The urban three-leg and four-leg arterials had the highest calibration values of 3.35 and 3.71, respectively. Urban four-lane arterials and five-lane arterials with two-way left-turn lanes had the lowest calibration values of 0.24 and 0.36, respectively.

2.10 Oregon

Xie et al. (2011) calibrated several Oregon facilities. The segment facilities included rural two-lane and multilane, and urban two- to five-lane arterials. The intersection types included both stop-controlled and signalized for rural two-lane, rural multilane, and urban arterial roadways. None of the calibration values were very high, and most were under the value of 1.0. One reason for the low calibration factors could have been the higher crash reporting threshold of $1,500 for property damage. In contrast, Missouri uses a much lower property damage threshold of $500.

2.11 Utah

One Utah calibration (Brimley et al. 2012) involved rural two-lane highways. The sample sites were limited to AADTs of less than 10,000 and speed limits higher than 55 mph. The calibration factor was 1.16. In addition to calibration, Utah also developed jurisdiction-specific SPFs using 157 segments.

2.12 Virginia

Kweon et al. (2014) published guidance for the state of Virginia, not only on calibration but also on customizing HSM procedures and on SPF development. The calibration was limited to divided segments and four-leg signalized intersections on rural multilane highways. District-specific calibration factors were derived. For four-leg signalized intersections, the number of sites in each district was limited, and a multiplication scheme was devised to rectify this issue. The district-specific calibration factors for four-lane divided segments were all close to the value of 1.0, with some districts being slightly under and others being slightly over.

2.13 Washington

Banihashemi (2011) compared new models versus calibration for rural two-lane segments in Washington state. The author used over 5,000 mi of data, and half were used to compare the Washington-specific SPF against the calibrated HSM SPF. The performance of the Washington-specific SPF was comparable to that of the calibrated HSM models.

2.14 International Efforts

There have been HSM calibration efforts performed outside the US. Martinelli et al. (2009) calibrated rural two-lane highways in Arezzo, Italy. The calibration factor value was 0.17. The authors explained that this factor was partly because many sections of roadways did not have crash records. Young and Park (2012) compared the use of the HSM with locally developed models in Regina, Canada. Abdel-Aty (2015) calibrated urban four-lane divided highways in Riyadh, Saudi Arabia.

CHAPTER 3. OVERVIEW OF CALIBRATION METHDOLOGY

This chapter presents an overview of the calibration methodology for all facility types. HSM calibration follows these general steps:

1. Identification and sampling of facility sites
2. Collection of relevant site data
3. Modeling and prediction using HSM methodology
4. Derivation of calibration factors

Each specific facility type has unique characteristics for each of these steps. Chapters 4 to 9 will cover aspects of the methodology that are particular to each facility.

3.1 Site Identification and Sampling

There are several objectives when compiling a list of sites for calibrating a facility type. One objective is to obtain a random set of samples. This objective is important for performing statistical inference. Inference refers to the use of a set of sample data in order to explain the characteristics of the general population of interest. Here, population, as used in a statistical sense, refers to a particular type of facility in Missouri. For example, a population could be all urban four-leg signalized intersections in Missouri, and the sample could be a set of 35 intersections in Missouri. If the sample does not include a random set of facilities, then the inference would be biased towards the characteristics of the sample. In other words, the safety level would be more reflective of the sample than the population. Random sampling was performed in the 2013 Missouri calibration and was continued with this current calibration.

A second objective is to obtain a sample size that will result in conclusions that are statistically significant. Unfortunately, there is a chicken and egg problem related to sample size determination. The required sample size is not known until a significant sample has been obtained and can be analyzed for its distributional properties. The HSM recommends that at least 30 to 50 sites be used for calibration and that the selected sites include a total of at least 100 crashes per year. This is a practical recommendation; otherwise, sampling becomes a very elaborate exercise of sampling until the sample set meets certain distribution characteristics, some of which relate to data variability. For this calibration effort, the HSM recommendation was followed unless it was prohibitive. For example, due to the low volumes and the low number of crashes on rural roads, meeting the 100 crashes per year criterion was difficult.

Another objective is geographic representation throughout the state. The state of Missouri is divided into seven MoDOT districts. These districts cover a wide range of driving populations, terrain, weather, and population areas. For example, St. Louis and Kansas City are major metropolitan areas while other districts are mostly rural. For most facility types, five random samples were selected from each MoDOT district, resulting in at least 35 samples per facility type. This was not possible for all facility types due to the lack of a particular facility in certain districts. For example, urban six-lane freeway segments were located mostly in St. Louis and Kansas City.

A fourth objective is to exclude any anomalous samples that could bias the calibration result. For example, the Columbia Police Department does not follow the $500 property damage threshold; so PDO crashes are underrepresented in Columbia. Therefore, Columbia sites were excluded.

In contrast to intersections, the sampling of segments requires an additional step of deciding how to segment. The most important aspect of this step was to ensure that each segment is homogeneous with respect to characteristics such as volume, geometric design, and speed limit. For the sake of efficiency, a minimum segment length was applied to sampling because overly short segments have very few crashes. Generally, a minimum segment length of 0.5 mi was used, although there were some exceptions due to difficulty in obtaining samples. This threshold is longer than the minimum of 0.1 mile recommended by the HSM.

The last objective is to maintain the same list of sites used in the previous Missouri calibration effort. This allows the comparison of results across multiple calibration cycles and reveals the sensitivity of calibration over time. Some sites had to be replaced due to changes at the site or other issues.

After the initial samples were determined, visual verification took place via the use of aerial photographs. This was necessary because there are sometimes coding errors and other data issues with electronic databases. For example, a segment coded as a five-lane segment with a two-way left-turn lane might actually be a four-lane divided road for a portion of the roadway. Another example is signalized driveways that should be coded as an intersection leg according to the HSM.

3.2 Data Collection

A primary source of data was the MoDOT Transportation Management System (TMS). The TMS provides several databases from which various types of data can be obtained, including crash, geometric design, pavement, functional classification, and traffic data. Examples of geometric design data include lane widths, shoulder widths, median type, and presence of left-turn lanes. TMS also provides videos collected from Automated Road Analyzer (ARAN) vehicles. These are useful for identifying items such as roadside components, the number of driveways, the distance to fixed objects, and type of parking. The ARAN video is indexed to the roadway log mile, which makes locating objects and road distances easy. One issue with ARAN video is that frames are sometimes skipped, so the video footage is not continuous.

Photographs, both aerial and street view, were another primary source of data. Aerial photographs present a bird’s eye view, while street view photographs present a driver’s eye view. These sources of information, along with the TMS databases and ARAN videos, are complementary and can be used for cross-checking. Aerial images were used to collect data such as the number of turn lanes, median type, skew angle, maximum number of lanes crossed by pedestrians, and the number of schools, bus stops, and alcohol sales establishments within 1,000 ft of a signalized intersection. Aerial images can also be imported into a computer-aided design (CAD) application to derive the horizontal radius of curves and ramps. Street view photographs were utilized to identify the number of legs at a signalized intersection, type of parking, posted speed limit, and median barrier type and to verify that an intersection was signalized.

3.3 HSM Modeling/Prediction

In general, HSM prediction involves the multiplication of the base SPF with several crash modification factors (CMFs) and the calibration factor.

$$N_{predicted} = N_{spf} \times C \times (CMF_1 \times CMF_2 \times \ldots \times CMF_n) \quad \textbf{(3.1)}$$

where

$N_{predicted}$ is the predicted average crash frequency of an individual facility for the selected year

N_{spf} is the predicted average crash frequency of an individual facility with given base conditions

C is the calibration factor for a specific facility type developed for use in Missouri

$CMF_1 \ldots CMF_n$ are various crash modification factors, such as lane width, horizontal curve radius, driveway density, and lighting

Each facility type has a SPF or multiple SPFs specific to that facility. The number and types of CMFs vary depending on the complexity of the facility. Freeway segments, for example, have over 20 different CMFs.

3.4 Calibration Factor Derivation

The Interactive Highway Safety Design Model (IHSDM) was used for performing HSM prediction and calibration. The SPFs and CMFs related to various facility types are coded into the IHSDM. The IHSDM is developed through the Federal Highway Administration (FHWA) Every Day Counts program. The software and technical support are provided by FHWA free of charge. All crash, geometric, traffic, and land use data are entered into the IHSDM, and the IHSDM outputs the overall calibration factor. The observed and predicted number of crashes can also be derived for each individual site to check for outliers.

CHAPTER 4. RURAL TWO-LANE UNDIVIDED ROADWAY SEGMENTS

4.1 Introduction and Scope

Chapter 10 of the HSM describes the methodology for crash prediction on rural two-lane undivided roadway segments. Rural two-lane undivided highways are common across all Missouri districts, and this facility type has been calibrated in many states.

4.2 Calibration Data Requirements

The input data in the IHSDM are divided into required and desired data. The required data consist of site, crash, and traffic data. The desired data are optional and include variables such as superelevation variance, presence of lighting, and automated speed enforcement.

4.2.1 Required Site Data

4.2.1.1 Area Type

The classification of areas depends on the roadway characteristics, surrounding population, and land use. Based on the FHWA guidelines, the HSM defines urban areas as regions with a population greater than 5,000 people. Rural areas are designated as regions outside urban areas with a population of fewer than 5,000 people. Although the terms metropolitan, urbanized, or suburban refer to urban subcategories, the HSM does not make a distinction among these subgroups and considers all as urban (AASHTO 2010). MoDOT uses the same area classification.

4.2.1.2 Segment Length

The roadway segment length for rural two-lane undivided segments consists of the total length in miles over a homogenous segment with no significant changes in travelway cross-section geometry and speed limit. In addition, rural two-lane undivided segments should not intersect or have interchange facilities as part of the segment. The HSM recommends a minimum of 0.1 mi to reduce calculation efforts. In the previous MoDOT HSM calibration, a minimum of 0.5 mi was specified in order to obtain a more efficient segment length. Very short segments have a relatively small likelihood of experiencing crashes while requiring a similar level of coding effort as longer segments. The present calibration no longer uses the 0.5 mile minimum, although only one rural two-lane undivided segment was shorter than 0.5 mi, measuring 0.36 miles.

4.2.1.3 Left/Right Side Lane Width

The IHSDM input for rural two-lane undivided segments requires the lane width for the roadway in each direction. It was decided that the right side lane was in the direction of increasing milepost, and the left side was in the opposing direction. If different lane width values are observed by direction, an average value should be used. The input value should be in feet and larger than zero.

4.2.1.4 Left/Right Side Shoulder Width and Type

The IHSDM input for rural two-lane undivided segments requires the shoulder width for the roadway in each direction. If different shoulder width values are observed by direction, an average value should be used. The input value should be in feet and larger than zero. The particular shoulder types, as described by the HSM, are paved, gravel, and turf, according to their safety effectiveness.

4.2.1.5 Curve Radius and Length

In the case that a segment contains a curved section of roadway, the radius of the curve should be measured in feet along the inside edge of the curved roadway. The input value should be greater than or equal to zero. The length of curvature should be measured in miles and should be greater than or equal to zero.

4.2.1.6 Presence of Two-Way Left-Turn Lane

Special attention should be paid if a portion of the segment contains a two-way left-turn(TWLT) lane because each segment must be considered homogenous. The presence of a TWLT lane should be introduced as a “yes” or a “no”. Figure 4.1 is an example of a segment with a TWLT lane present.

© Google 2016

Figure 4.1 Segment containing two-way left-turn lane

4.2.2 Required Crash and Traffic Data

4.2.2.1 Years of Crash Data

The years associated with the calibration should be specified. The IHSDM considers up to three years for the input data.

4.2.2.2 Observed Number of Crashes

On rural two-lane roadways, observed crashes are assigned to either segments or intersections depending on the geometric, traffic control, and operational characteristics. Intersection influence areas should not be included as part of segments. This is because the contributory circumstances of intersection crashes generally differ from those of segment crashes. MoDOT assigns crashes to an intersection if the crash is located within 132 ft of the intersection. For this calibration, intersection-related crashes were removed based on the intersection identification number designated in the crash data. Figure 4.2 illustrates the intersection influence area graphically.

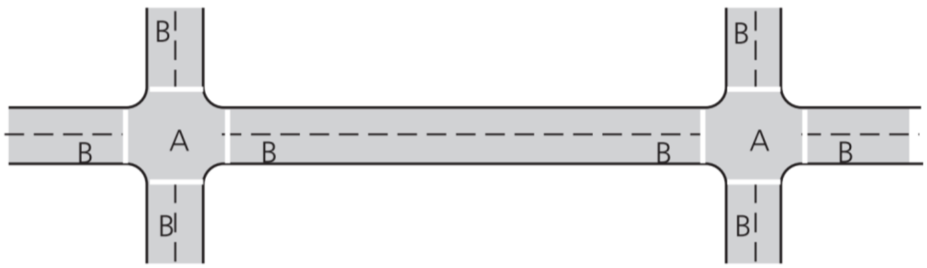

Figure 4.2 HSM definition of segment and intersection crashes

Crashes in area A are classified as intersection crashes as they occur physically within the intersection area. Crashes in area B are classified as either segment or intersection related, depending on the specific crash characteristics.

4.2.2.3 Segment AADT

The total segment AADT, in both directions, should be collected for all years of analysis. The HSM-recommended AADT range for rural two-lane highway segments is 0 to 17,800 vehicles per day. AADT data can be obtained using the MoDOT TMS system. Note that AADT data might not be actual counted traffic volumes, but rather estimates based on historical or nearby counts. In rural areas, traffic volume is counted less frequently.

4.2.3 Desired Site Data

4.2.3.1 Presence of Spirals

Any spiral transitions for horizontal curves within the segment should be noted. MoDOT indicated that most existing horizontal curves on Missouri roadways do not contain spirals. Therefore, it was assumed that no curved segments contained spirals.

4.2.3.2 Superelevation Variance

This is the percent difference between actual superelevation and the superelevation identified by American Association of State Highway and Transportation Officials (AASHTO) policy. It was reasonable to assume that all horizontal curves were designed to the appropriate superelevation rate. Therefore, the base condition of 0% variance was assumed for all curved samples.

4.2.3.3 Grade

The vertical grade of the segments could not be accurately determined from databases and, therefore, was assumed as the base condition of 0%. This value correlated to the level terrain category in the HSM that included grades between +/- 3%. MoDOT indicated that although vertical grade was collected by ARAN, it was not readily available through TMS. MoDOT has recently made grade information available for use in future calibrations.

4.2.3.4 Driveway Density

The driveway density, combined for both sides of the roadway, is given as the number of driveways per mile.

4.2.3.5 Presence of Centerline Rumble Strip

This input indicates the presence of rumble strips along the centerline of the roadway segment. The IHSDM data input only requires specifying whether or not rumble strips exist along the segment (i.e., yes or no).

4.2.3.6 Presence of Passing Lanes

In some cases, short sections of certain rural two-lane undivided highway segments may contain additional lanes that serve exclusively to increase passing opportunities through side-by-side passing lanes. It should be noted whether passing lanes exist on one or both sides of the roadway or do not exist at all. Special consideration should be given if passing lanes exist for a long stretch of roadway because this situation would no longer be considered a two-lane facility.

4.2.3.7 Roadside Hazard Rating

The roadside hazard rating (RHR) is a common ranking system from 1 (best) to 7 (worst) (Zegeer et al. 1981). Pictures and quantitative definitions of the rating categories appear in the HSM (2010) in Appendix 13A. The RHR is used to estimate the potential for accidents to occur on rural two-lane highways. The ranking involves the clear zone, side slope, guardrail presence, presence of obstacles, and other attributes of the roadway segment.

4.2.3.8 Presence of Lighting

The presence of lighting along the segment is considered in the crash prediction process. The IHSDM data input only requires specifying the presence of lighting along the segment (i.e., yes or no).

4.2.3.9 Automated Speed Enforcement

Automated speed enforcement may use video or photographic identification in combination with radar or laser data to detect vehicles exceeding the posted speed limit of the segment. The system automatically records the information when the vehicle is at fault. The IHSDM data input only requires specifying the presence of automated speed enforcement along the segment (i.e., yes or no). Figure 4.3 illustrates examples of speed enforcement cameras and signs.

Seat Pleasant 2017, MoDOT 2017

Figure 4.3 Automated speed enforcement camera

4.3 HSM Methodology

As described in Chapter 10 of the HSM, the SPFs for rural two-lane undivided segments predict the number of total crashes on a segment per year for base conditions. The SPF is obtained through equations 4.1 and 4.2, with the base conditions listed in Table 4.1:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r}) \quad \textbf{(4.1)}$$

where

$N_{predicted,rs}$ is the predicted average crash frequency of an individual roadway segment for a selected year

$N_{spf\ rs}$ is the predicted average crash frequency of an individual roadway segment with given base conditions

C_r is the calibration factor for roadway segments of a specific type developed for use in Missouri

$CMF_{1r} \ldots CMF_{12r}$ are various crash modification factors such as lane width, horizontal curve radius, driveway density, and lighting

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \quad \textbf{(4.2)}$$

where

$N_{spf\ rs}$ is the predicted average crash frequency of an individual roadway segment with given base conditions

$AADT$ is the annual average daily traffic (vehicles/day) on a roadway segment

L is the length of the roadway (miles)

Table 4.1 shows the base conditions applicable to $N_{spf\ rs}$.

Table 4.1 Base conditions in HSM for SPF for rural two-lane undivided segments

Description	Base Condition
Lane Width	12 ft
Shoulder Width	6 ft
Shoulder Type	Paved
Roadside Hazard Rating	3
Driveway Density	5 driveways/mile
Horizontal Curvature	None
Vertical Curvature	None
Centerline Rumble Strips	None
Passing Lanes	None
Two-Way Left-Turn Lanes	None
Lighting	None
Automated Speed Enforcement	None
Grade Level	0%

Deviations from the base conditions are addressed by the corresponding CMF. For example, a lane width narrower than 12 ft is taken into account by multiplying by a CMF that is greater than 1.0. In other words, safety decreased slightly from the base conditions with the reduction in lane width.

4.4 Sampling Considerations

For this calibration effort, it was desirable to reuse the same sites that were used in the previous calibration project (Sun et al. 2014). The sampling process for the previous calibration of rural two-lane undivided segments included a random sample of five sites from each MoDOT district based on a minimum length of 0.5 mi per site. TMS was used to generate database queries with a list of rural two-lane candidate sites for each district. The criteria used to generate the queries are shown in Table 4.2.

Table 4.2 Query criteria for rural two-lane undivided segments

Table	Field	Criterion
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2012
TMS_TRF_INFO_SEGMENT_VW	BEG_DISTRICT_ABBR	Varies
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRF_INFO_NAME	AADT
TMS_TRF_INFO_SEGMENT_VW	BEG_OVERLAPPING_INDICATOR	not S
TMS_TRF_INFO_SEGMENT_VW	BEG_URBAN_RURAL_CLASS	RURAL
TMS_TRF_INFO_SEGMENT_VW	BEG_DIVIDED_UNDIVIDED	UNDIVIDED
TMS_SS_PAVEMENT	NUMBER_OF_LANES	2

Column 1 is the table or a particular TMS database. Two separate databases were used for rural two-lane undivided segments. Column 2 is the specific data field. Column 3 is the query criterion, often a limitation on the data sought. For example, the field DRVD_TRFRNGINFO_YEAR was used to specify the query for 2012 data because TMS contained AADT data for each year. The AADT data for other years were obtained later by using other queries in a similar fashion. A separate query was run for each MoDOT district using the BEG_DISTRICT_ABBR field. The DRVD_TRF_INFO_NAME field was used to specify that AADT is needed. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes that overlapped with primary routes. The BEG_URBAN_RURAL_CLASS field was used to limit the query to rural segments. The query was limited to two-lane segments by using the NUMBER_OF_LANES field.

In order to eliminate data errors, each site was individually reviewed and verified for this calibration process. During the site verification, each segment was inspected to ensure that there were no apparent changes to the roadway facility from the time of the previous calibration. Special attention was paid to ensure that each site satisfied the necessary criteria to be considered a valid sample for this facility type. The sampled sites were also reviewed to ensure that ARAN data were available for the sites and to verify that the sites were of the proper type and were homogeneous with respect to the cross-section. Some sampled sites were discarded and replaced because they did not contain adequate ARAN data. The replacement sampling was performed in the same fashion as the original sampling. For a particular district, a random number generator selected a specific site from a list of all possible rural two-lane segments in the district. The END_URBAN_RURAL_CLASS field was also checked in TMS to confirm that the value of the field was rural. If the value of this field was not rural, the sample site was verified using an ARAN video to determine whether the site was rural or urban, based on surrounding land use characteristics. The list of sampled sites is shown in Table 4.3. Most of the sites were Missouri state highways, although a few sites were US highways. The sample set included sites from 24 Missouri counties.

Table 4.3 List of sites for rural two-lane undivided segments

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	County	Length (mi)
1	CD	MO 185	S	39.54	44.00	Washington	4.46
2	CD	MO 5	S	220.91	222.15	Camden	1.24
3	CD	MO 17	N	156.57	160.31	Miller	3.74
4	CD	MO 5	N	222.80	226.89	Howard	4.09
5	CD	MO 124	W	23.24	25.06	Howard	1.82
6	KC	MO 13	S	127.13	130.91	Johnson	3.78
7	KC	MO 45	N	9.29	15.80	Platte	6.51
8	KC	MO 210	E	25.32	26.63	Ray	1.31
9	KC	MO 273	S	19.16	22.94	Platte	3.78
10	KC	MO 58	E	47.62	49.39	Johnson	1.77
11	NE	MO 47	S	49.97	52.87	Warren	2.89
12	NE	MO 19	S	21.55	22.05	Ralls	0.50
13	NE	MO 6	E	168.84	176.65	Knox	7.81
14	NE	MO 94	W	61.00	61.69	Warren	0.72
15	NE	MO 15	N	112.45	115.65	Scotland	3.20
16	NW	MO 5	S	87.90	95.61	Chariton	7.71
17	NW	US 24	E	109.73	111.92	Chariton	2.19
18	NW	MO 139	N	9.26	14.23	Carroll	4.97
19	NW	US 136	W	92.50	94.62	Putnam	2.12
20	NW	US 169	N	27.46	28.46	Clinton	1.00
21	SE	MO 25	S	32.32	32.86	Stoddard	0.54
22	SE	US 160	W	107.55	110.25	Howell	2.70
23	SE	MO 137	S	39.02	41.86	Howell	2.84
24	SE	MO 91	S	17.92	18.87	Stoddard	0.95
25	SE	MO 34	E	71.46	73.68	Bollinger	2.22
26	SL	MO 100	E	56.23	57.12	Franklin	0.89
27	SL	MO 110	W	1.34	2.93	Jefferson	1.59
28	SL	RT H	E	4.22	10.77	Jefferson	6.55
29	SL	RT C	S	13.52	14.35	Franklin	0.83
30	SL	RT B	N	6.00	6.56	Jefferson	0.56
31	SW	MO 73	S	4.26	6.18	Dallas	1.92
32	SW	RT H	S	15.83	20.33	Greene	4.50
33	SW	MO 76	W	179.95	184.74	McDonald	4.79
34	SW	MO 76	E	133.06	138.20	Taney	5.14
35	SW	MO 125	S	18.92	20.87	Greene	1.95
36	SW	MO 125	S	20.95	21.41	Greene	0.46

Because the HSM methodology contained a CMF for horizontal curvature, it was necessary to subdivide these 36 sites further based on horizontal curvature. Each site was subdivided into curve and tangent sections. The limits of the curve and tangent sections were determined based on aerial imagery. For future calibrations, the new MoDOT curves list can also be used. A separate segment was created for each section of each horizontal curve. All of the tangent sections from a given site were combined into one segment because they were homogeneous with respect to cross-section and horizontal curvature. The calibration data set consisted of 194 segments, 158 of which were horizontal curves.

4.5 Data Collection

A list of the data types collected for rural two-lane undivided highways and their sources is shown in Table 4.4.

Table 4.4 Data sources for rural two-lane undivided segments

Data Description	Source
AADT	TMS
Lane Width	TMS
Shoulder Width	TMS
Shoulder Type	TMS
Horizontal Curve Radius	Aerial Imagery/CAD
Horizontal Curve Length	Aerial Imagery/CAD
Superelevation Variance	Assumed to be 0%
Presence of Spirals	Assumed not present
Vertical Grade	Assumed to be 0%
Driveway Density	ARAN, Aerial Imagery
Presence of Centerline Rumble Strips	ARAN, Aerial Imagery
Presence of Passing Lanes	ARAN, Aerial Imagery
Presence of Two-Way Left-Turn Lane	ARAN, Aerial Imagery
Roadside Hazard Rating	ARAN
Presence of Lighting	ARAN, Aerial Imagery
Presence of Automated Speed Enforcement	ARAN, Aerial Imagery
Number of Crashes	Accident Browser (TMS)

All data, except for horizontal curve data, were collected before the sites in Table 4.3 were subdivided based on horizontal curvature. This method of data collection was used to help ensure that bias created by short segments (i.e., due to horizontal curvature) was not introduced. Lane width and outside paved shoulder width were assumed to be the same in each direction. This assumption was reasonable because most rural two-lane highways were symmetric with respect to cross-sections. The relationship between the TMS shoulder type and the HSM shoulder type is shown in Table 4.5.

Table 4.5 Relationship between TMS shoulder type and HSM shoulder type

HSM Shoulder Type	TMS Shoulder Type	TMS Shoulder Description
Paved	AC	Asphaltic Concrete
	BM	Bituminous Mat
	BRK	Brick
	LC	Asphalt leveling course
	PC	Concrete Unknown Reinforcement
	PCN	Concrete Non-Reinforced
	PCR	Concrete Reinforced
	SLC	Superpave Leveling Course
	SP	Superpave
	UTA	Ultra-Thin Bonded A
	UTB	Ultra-Thin Bonded B
	UTC	Ultra-Thin Bonded C
Gravel	AG	Aggregate
	OA	Oil Aggregate
	TP1	Type 1 Aggregate
	TP2	Type 2 Aggregate
	TP3	Type 3 Aggregate
	TP4	Type 4 Aggregate
	TP5	Type 5 Aggregate
Turf	ERT	Earth

ARAN was used to determine driveway density, presence of centerline rumble strips, presence of passing lanes, presence of a two-way left-turn lane, roadside hazard rating, and the presence of lighting.

The horizontal curve data were measured using aerial imagery of the segments in conjunction with a CAD program. One concern related to the curve data for rural two-lane undivided highway segments was the creation of too many short segments due to subdivisions for horizontal curves. To help alleviate this concern, curves that visually appeared to be straight in the aerial photographs were treated as tangents. In addition, all of the tangent sections on a given site were treated as one segment in the calibration because they were homogeneous with respect to horizontal alignment, AADT, and cross-section.

The following data were not readily available: superelevation variance, presence of spirals, and grade. Based on discussions with MoDOT, it was reasonable to assume that all horizontal curves were designed to the appropriate superelevation rate. Therefore, the superelevation variance was assumed to have a value of zero. According to EPG 230.1.5, spiral curves are to be used on all roadways with design traffic greater than 400 vehicles per day, an anticipated posted speed limit greater than 50 mph, and a curve radius less than 2,865 ft. However, MoDOT indicated that most existing horizontal curves on Missouri highways do not have spirals. Therefore, it was assumed, for calibration purposes, that no horizontal curves contained spirals. A grade value of 0% was also assumed. This value correlated to the level terrain category in the HSM that includes grades between -3% and 3%. MoDOT explained that, though grade was collected by ARAN, it was not available through TMS. The assumptions made regarding superelevation variance, the presence of spirals, and grade corresponded to the base conditions for these factors in the HSM.

4.5.1 Summary Statistics for Rural Two-Lane Undivided Roadway Segments

Descriptive statistics for segments are shown in Table 4.6.

Table 4.6 Descriptive statistics for rural two-lane undivided segment samples

Description	Average	Min.	Max.	Std. Dev.
Segment Length	0.54	0.02	7.52	1.12
AADT (bidirectional)	2,621	265	10,939	1,982
Lane Width (ft)	11.1	10.0	12.5	0.8
Shoulder Width (ft)	3.7	2.0	10.0	2.6
Driveway Density (drives/mi)	9.5	0.8	35.6	5.1
Roadside Hazard Rating	4.3	1.0	6.0	1.0
Horizontal Curve Radius (ft)	1,690	208	8,483	1,462
Horizontal Curve Length (mi)	0.16	0.02	0.64	0.10
Presence of Spirals	0	0	0	0
Superelevation Variance	0	0	0	0
Grade	0	0	0	0
Number of Observed Crashes	1.4	0.0	48.0	4.4
Description				**No. of Segments**
Shoulder Type = Paved				17
Shoulder Type = Gravel				7
Shoulder Type = Turf				12
Tangent Segments				36
Curve Segments				158
Centerline Rumble Strips				3
Passing Lanes				0
Two-Way Left-Turn Lane				1
Lighting				9
Automated Speed Enforcement				0

The average length of the sampled segments was 0.54 mi. The segments ranged from 0.02 mi to 7.52 mi in length. The length standard deviation was 1.12 mi. Many of the segment lengths were short due to the presence of horizontal curves. The minimum length for segments with no horizontal curves was 0.36 mi. The segments were relatively uniform with respect to lane width but showed some variation with respect to shoulder width. The average values for the driveway density and roadside hazard rating were greater than the values that corresponded to the base conditions in the HSM. A majority of the segments contained paved shoulders. Three of the segments had centerline rumble strips, and one of the segments had a two-way left-turn lane. Nine of the segments had lighting, and no segments contained automated speed enforcement. The segments with horizontal curves had an average curve radius of 1,680 ft and an average curve length of 0.16 mi. The radii of the curve segments varied between 208 ft and 8,483 ft, with a standard deviation of 1,462 ft. The average number of observed crashes was 1.4 and ranged from 0 to 48 crashes. The standard deviation of observed crashes was 4.4. The total number of crashes for the segments was 281 (93.7 per year), which is close to the HSM sampling recommendation of having 100 total crashes per year for a specific facility type.

4.6 Results and Discussion

4.6.1 Calibration Factor

The calibration factor for rural two-lane undivided roadway segments in Missouri yielded a calibration factor value of 0.97. The IHSDM output is shown in Figure 4.4.

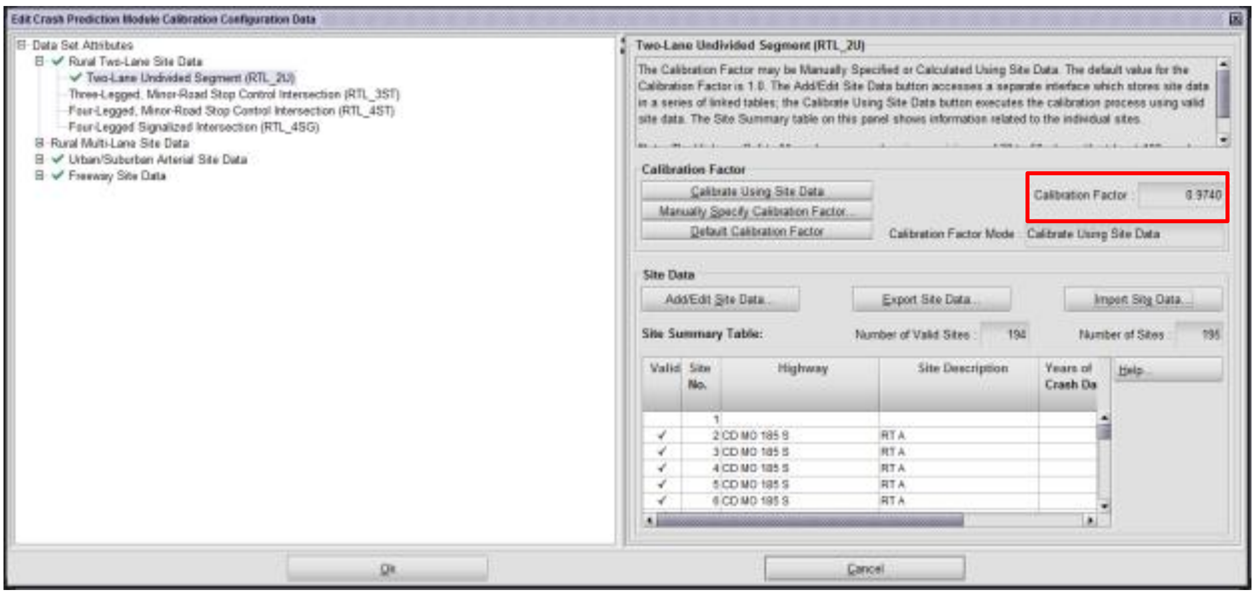

Figure 4.4 Calibration output for rural two-lane undivided roadway segments

The observed and predicted crash frequencies for each segment appear in Table 4.7, which is consistent with the IHSDM output.

Table 4.7 Calibration results for rural two-lane undivided roadway segments

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
1	CD	MO 185 S	39.54	44.00	14	8
2	CD	MO 5 S	220.91	222.15	1	11
3	CD	MO 17 N	156.57	160.31	9	13
4	CD	MO 5 N	222.80	226.89	3	10
5	CD	MO 124 W	23.24	25.06	4	3
6	KC	MO 13 S	127.13	130.91	10	14
7	KC	MO 45 N	9.29	15.80	51	19
8	KC	MO 210 E	25.32	26.63	6	0
9	KC	MO 273 S	19.16	22.94	22	23
10	KC	MO 58 E	47.62	49.39	12	7
11	NE	MO 47 S	49.97	52.87	5	7
12	NE	MO 19 S	21.55	22.05	0	1
13	NE	MO 6 E	168.84	176.65	8	16
14	NE	MO 94 W	61.00	61.69	4	9
15	NE	MO 15 N	112.45	115.65	4	6
16	NW	MO 5 S	87.90	95.61	5	5
17	NW	US 24 E	109.73	111.92	0	5
18	NW	MO 139 N	9.26	14.23	0	1
19	NW	US 136 W	92.50	94.62	2	5
20	NW	US 169 N	27.46	28.46	4	5
21	SE	MO 25 S	32.32	32.86	1	2
22	SE	US 160 W	107.55	110.25	11	13
23	SE	MO 137 S	39.02	41.86	3	2
24	SE	MO 91 S	17.92	18.87	1	1
25	SE	MO 34 E	71.46	73.68	10	8
26	SL	MO 100 E	56.23	57.12	11	7
27	SL	MO 110 W	1.34	2.93	7	14
28	SL	RT H E	4.22	10.77	41	19
29	SL	RT C S	13.52	14.35	1	1
30	SL	RT B N	6.00	6.56	3	3
31	SW	MO 73 S	4.26	6.18	1	5
32	SW	RT H S	15.83	20.33	14	19
33	SW	MO 76 W	179.95	184.74	7	8
34	SW	MO 76 E	133.06	138.20	3	4
35	SW	MO 125 S	18.92	20.87	1	11
36	SW	MO 125 S	20.95	21.41	2	2
Sum					**281**	**289**
Calibration Factor					**0.97**	

These results indicate that the number of crashes observed in Missouri was slightly lower than the number of crashes predicted by the uncalibrated HSM for this site type. The uncalibrated HSM models were obtained using data from two states: Minnesota and Washington. The base models were developed by Vogt and Bared (1998). The model was developed with data from 619 rural two-lane highway segments in Minnesota and 712 roadway segments in Washington obtained from the FHWA Highway Safety Information System (HSIS). These roadway segments included approximately 1,130 km (700 mi) of two-lane roadway in Minnesota and 850 km (530 mi) of roadway in Washington. The database available for model development included five years of crash data (1985 to 1989) for each Minnesota roadway segment and three years of crash data (1993 to 1995) for each Washington roadway segment.

The calibration factor value of 0.97 is higher than the previous Missouri calibration value of 0.82. In addition to natural variability, a major reason for the increase is an improvement in crash data processing. The previous calibration removed all crashes identified as intersection crashes. After analyzing intersection crashes associated with rural two-lane segments, the research team realized that TMS designates some larger driveways with an intersection node identification number, with some being stop-controlled and others being signalized. To be consistent with the HSM, these driveways are now included in the current calibration, whereas they were excluded from the previous calibration. There are also other possible reasons for the increase, including driver behavior changes, changes in crash reporting, and changes in the calibration sample.

4.6.2 Severity Distribution Factors

Using data from the calibration, severity distribution factors (SDF) were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 4.8 shows the SDFs for rural two-lane undivided segments. MV refers to multi-vehicle and SV refers to single-vehicle crashes.

Table 4.8 Severity distribution factors for rural two-lane undivided segments

	MV		**SV**	
Severity	**Crashes**	**SDF**	**Crashes**	**SDF**
Fatal	3	0.041	6	0.029
Disabling Injury	6	0.082	17	0.081
Minor Injury	17	0.233	51	0.243
Property Damage Only	47	0.644	136	0.648

4.6.3 Crash Type Distribution Factors

The crash type distribution factors (CDFs) are used to determine the proportion of predicted crashes according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because Missouri crash type categories differ from those of the HSM. Therefore, different categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were estimated for total crashes in correspondence to the calibration factor severity. Based on the classification of crash types in Missouri, Table 4.9 provides the CDFs for rural two-lane undivided roadway segments.

Table 4.9 Crash type distribution factors for rural two-lane undivided segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Rear-end	30	0.106
Head-on	6	0.021
Right-angle	8	0.028
Sideswipe	20	0.071
Other	8	0.028
Single-Vehicle		
Crash with Animal	49	0.173
Crash with Fixed Object	4	0.014
Out of Control	134	0.473
Other	24	0.085

CHAPTER 5. RURAL MULTILANE DIVIDED SEGMENTS

5.1 Introduction and Scope

Chapter 11 of the HSM describes the methodology for crash prediction on rural multilane highways, including both divided and undivided segments. Rural multilane divided segments were calibrated as part of this project. Rural multilane undivided segments were not calibrated because they are not common in Missouri. The HSM crash prediction models for this site type applied only to segments with four through lanes.

5.2 Calibration Data Requirements

The input data in the IHSDM were divided into required and desired data. The required data consisted of site, crash, and traffic data. The desired data were optional and included variables such as lighting and automated speed enforcement.

5.2.1 Required Site Data

5.2.1.1 Area Type and Functional Classification

The classification of areas depends on the roadway characteristics, surrounding population, and land use. Based on the FHWA guidelines, the HSM defines urban areas as regions with a population greater than 5,000 people. Rural areas are designated as regions outside urban areas with a population of fewer than 5,000 people. Although the terms metropolitan, urbanized, or suburban refer to urban subcategories, the HSM does not make a distinction among these subgroups and considers all as urban (AASHTO 2010). MoDOT uses the same area classification. The arterial roadway segment functional classification should include facilities designated as arterial or expressways.

5.2.1.2 Segment Length

The roadway segment length for rural multilane divided segments consists of the total length in miles over a homogenous segment with no significant changes in travelway, cross-section geometry, and speed limit. In addition, rural multilane segments should not intersect or have interchange facilities as part of the segment. The HSM recommends a minimum segment length of 0.1 mi to reduce calculation efforts. The rural multilane divided segments used for calibration were all longer than 1 mi.

5.2.1.3 Left/Right Side Lane Width

The IHSDM input for rural multilane divided segments requires the lane width for the left and right lanes of the road in each direction. If different lane width values are observed by direction, an average value should be used. The input value should be introduced in feet and be larger than zero. Figure 5.1 illustrates the location and lane width convention used in specifying input data.

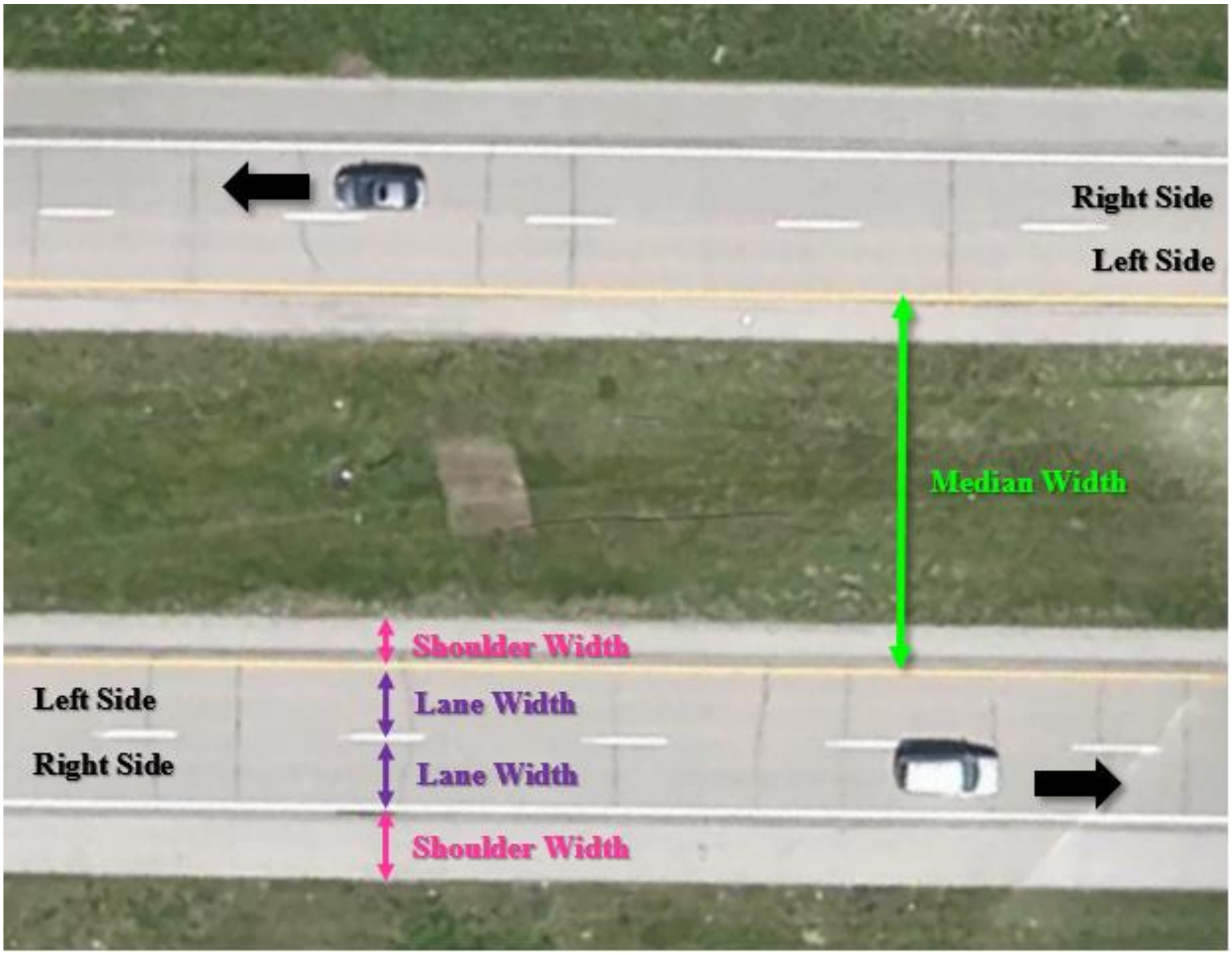

Figure 5.1 Lane, shoulder, and median width illustration

5.2.1.4 Left/Right Side Paved Shoulder Width

For the right side, the shoulder width should be measured from the outside continuous travelway white marking up to the edge of the shoulder. For the left (median) side, the shoulder should be measured from the yellow continuous line at the edge of the travelway up to the end of the inside shoulder. If the shoulder widths for each direction are different, the average should be calculated. Figure 5.1 illustrates the measurement and location of lane, median, and shoulder widths.

5.2.1.5 Effective Median Width

The effective median width is measured between the inside edges of the travelway (through lanes) in the opposing direction of travel. Therefore, inside shoulders and turning lanes are included in the median width if present. Figure 5.1 illustrates the measurement of the effective median.

5.2.2 Required Crash and Traffic Data

5.2.2.1 Years of Crash Data

The years associated with the calibration should be specified. The IHSDM considers up to three years for the input data.

5.2.2.2 Observed Number of Crashes

The HSM predictive method estimates crash frequency of rural multilane divided segment related crashes. Crash assignments to segments and intersections are based on geometric, traffic control, and operations characteristics. Stop-controlled and signalized intersections may be present along rural multilane segments; however, intersection related crashes should be removed. In the case of Missouri, intersection-related crashes were removed based on the intersection identification number that was designated in the crash data. MoDOT assigns a crash to an intersection if it is located within 132 ft of the intersection.

5.2.2.3 Segment AADT

The total segment AADT (both directions) should be collected for all years being analyzed.

5.2.3 Desired Data

5.2.3.1 Lighting

Lighting is considered to be the presence of illumination along the segment. The IHSDM data input only requires specifying the presence of lighting along the segment (i.e., yes or no).

5.2.3.2 Automated Speed Enforcement

Automated speed enforcement of rural multilane segments may use video or photographic identification in combination with radar or laser data to detect drivers exceeding the posted speed limit of the segment. The system automatically records the identifying information for the vehicle at fault. The IHSDM data input only requires specifying the presence of automated speed enforcement along the segment (i.e., yes or no).

5.3 HSM Methodology

As described in Chapter 11 of the HSM, the SPF for rural multilane divided highway segments predicts the total number of crashes on the segment per year for base conditions. The SPF is based on the AADT and length of the segment and is given by the following equation:

$$N_{spf,rd} = e^{[a+b\times ln(AADT)+ln(L)]} \qquad \textbf{(5.1)}$$

where

$N_{spf,rd}$ is the base total number of roadway segment crashes per year

AADT is the annual average daily traffic (vehicles/day) on the roadway segment

L is the length of the roadway segment (miles)

a and *b* are regression coefficients

The base conditions for the SPF are shown in Table 5.1. Crash modification factors were applied when the conditions deviated from the base conditions.

Table 5.1 SPF base conditions for rural multilane divided segments

Description	Base Condition
Lane Width	12 ft
Right Paved Shoulder Width	8 ft
Median Width	30 ft
Lighting	None
Automated Speed Enforcement	None

5.4 Sampling Considerations

For rural multilane divided highways, a random sample of five segments from each MoDOT district was created. TMS was used to generate database queries with a list of candidate rural multilane divided segments for each district. The criteria used to generate the queries are shown in Table 5.2.

Table 5.2 Query criteria for rural multilane divided segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2012
TMS_TRF_INFO_SEGMENT_VW	BEG_DISTRICT_ABBR	Varies
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRF_INFO_NAME	AADT
TMS_TRF_INFO_SEGMENT_VW	BEG_OVERLAPPING_INDICATOR	not S
TMS_TRF_INFO_SEGMENT_VW	BEG_URBAN_RURAL_CLASS	RURAL
TMS_TRF_INFO_SEGMENT_VW	BEG_DIVIDED_UNDIVIDED	DIVIDED
TMS_SS_PAVEMENT	NUMBER_OF_LANES	> 2

The field DRVD_TRFRNGINFO_YEAR was used to limit the query to an individual year, e.g., 2012 because TMS contained AADT data for each year. The AADT data for other years were obtained later by using other queries. A separate query was run for each MoDOT district using the BEG_DISTRICT_ABBR field. The DRVD_TRF_INFO_NAME field was used to specify AADT in the query output. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes that overlapped with primary routes. The BEG_URBAN_RURAL_CLASS field was used to limit the query to rural segments. The query was limited to rural multilane segments by using the BEG_DIVIDED_UNDIVIDED and NUMBER_OF_LANES fields.

During the sampling process, the functional class of each segment was verified using TMS State of the System, and the segment was discarded if it was a freeway segment. The sample segments were also observed with the ARAN viewer to ensure that ARAN data were available for the segments and that the segments were homogeneous and represented the correct site type. Some sample segments were discarded and replaced with another random sample segment because they did not have adequate ARAN data. The END_URBAN_RURAL_CLASS field was also checked in TMS to confirm that the value of the field was rural. If the value of this field was not rural, the sample segment was also checked in ARAN to determine whether the segment was rural or urban based upon surrounding land use characteristics.

The limits of interchanges within the segment were determined using the MoDOT TMS Maps application because interchanges were not included in the HSM methodology for rural multilane facilities. The interchange limits were defined as spanning the beginning of the deceleration lane for the exit ramp to the end of the acceleration lane for the entrance ramp. If the interchange contained only an entrance or exit ramp, the end of the gore area was taken as the other interchange limit.

If a segment contained two types of medians (a traversable median and a median barrier), it was classified as heterogeneous. These segments were subdivided based on median type to ensure that each segment had a homogeneous cross-section. The final sample for the calibration of rural multilane divided highways consisted of 37 segments. The list of the sample segments appears in Table 5.3.

Table 5.3 List of samples for rural multilane divided segments

No.	City	County	Dist.	Description	Primary Dir.	Primary Begin Log	Primary End Log	Length (mi)
1	Centertown	Cole	CD	US 50	W	134.43	136.61	2.18
2	Loose Creek	Osage	CD	US 50	E	154.56	156.08	1.53
3	Linn Creek	Camden	CD	US 54	W	156.26	157.56	1.30
4	Clark	Boone	CD	US 63	S	99.70	101.58	1.88
5	Camdenton	Camden	CD	MO 5	S	226.78	227.84	1.06
6	Elm	Johnson	KC	US 50	E	28.90	31.27	2.37
7	Henrietta	Ray	KC	MO 13	N	212.04	213.64	1.60
8	Lexington	Ray	KC	MO 13	N	208.31	209.32	1.01
9	Garden City	Cass	KC	MO 7	N	137.92	140.69	2.76
10	Spring Fork	Pettis	KC	US 65	N	154.42	157.63	3.20
11	Knob Noster	Johnson	KC	US 50	W	202.90	206.43	3.52
12	La Grande	Lewis	NE	US 61	S	34.47	37.61	3.14
13	Winchester	Clark	NE	US 61	S	9.24	11.21	1.98
14	Ely	Marion	NE	US 24	E	186.28	187.96	1.69
15	Eolia	Pike	NE	US 61	N	291.34	294.18	2.85
16	Millard	Adair	NE	US 63	S	35.75	39.28	3.53
17	Savannah	Andrew	NW	US 59	S	68.99	70.77	1.78
18	Pumpkin Center	Nodaway	NW	US 71	N	283.65	286.98	3.33
19	Amazonia	Andrew	NW	US 59	N	33.86	35.37	1.51
20	Meadville	Linn	NW	US 36	W	107.75	109.84	2.09
21	Cameron	DeKalb	NW	US 36	E	31.40	32.79	1.39
22	Halifax	St. Francois	SE	US 67	S	77.01	84.45	7.44
23	Wilby	Butler	SE	US 67	N	27.82	31.81	3.98
24	Mountain Grove	Wright	SE	US 60	W	198.09	204.03	5.95
25	Willow Springs	Howell	SE	US 63	S	292.25	294.71	2.46
26	Cabool	Texas	SE	US 60	W	186.22	188.14	1.93
27	Goldman	Jefferson	SL	MO 21	N	173.01	174.78	1.77
28	Wentzville	St. Charles	SL	US 61	S	130.67	132.56	1.89
29	Villa Ridge	Franklin	SL	MO 100	W	44.40	47.69	3.28
30	Villa Ridge	Franklin	SL	MO 100	W	42.20	44.16	1.95
31	Olympian Village	Jefferson	SL	US 67	N	130.21	133.46	3.25
32	Goldman	Jefferson	SL	MO 21	S	21.98	24.22	2.24
33	Ridgedale	Taney	SW	US 65	S	310.42	312.39	1.97
34	Hartwell	Henry	SW	MO 7	N	119.88	123.45	3.57
35	Osceola	St. Clair	SW	MO 13	S	171.07	172.42	1.35
36	Seymour	Webster	SW	US 60	W	227.07	229.70	2.64
37	Osceola	St. Clair	SW	MO 13	N	122.92	124.35	1.43

Twenty-six segments were US numbered highways, and 11 were Missouri numbered highways. No single highway contributed more than four segments. The highways with four segments in the sample were MO 13, US 50, and US 61. The total length of the segments in the sample was approximately 93 mi. Segment lengths will be discussed in detail in the next section.

As shown in Table 5.3, the segments from each district came from three to five different counties, with four being the most common. Twenty-nine of 114 Missouri counties (25%) were represented in the sample. The sample, therefore, had representation from all MoDOT districts and many counties within each district.

5.5 Data Collection

A list of the data types collected for rural multilane divided highways and their sources is shown in Table 5.4.

Table 5.4 Data sources for rural multilane divided segments

Data Description	Source
AADT	State of the System (TMS)
Lane Width	State of the System (TMS)
Shoulder Width	State of the System (TMS)
Median Type	ARAN
Effective Median Width	Aerials
Presence of Lighting	ARAN
Presence of Automated Speed Enforcement	MoDOT
Number of Crashes	Accident Browser (TMS)

Lane width and outside paved shoulder width were determined separately for each direction. The ARAN viewer and Google maps street view were used to determine whether the segment had a median barrier or a traversable median. For segments with a traversable median, the median width was measured from aerial images in Google Maps. The median width was measured from the edge of the through lanes in the opposing directions. Therefore, the median width included both median turn lanes and median shoulders. Segment length was calculated in both directions using beginning and end log miles. As previously discussed, sampling was done so that there were no interchanges within the segments. A list of automated enforcement locations was provided by MoDOT.

Descriptive statistics for the segments are shown in Table 5.5.

Table 5.5 Descriptive statistics for rural multilane divided samples

Description	Average	Min.	Max.	Std. Dev.
Length (mi)	2.51	1.01	7.44	1.30
AADT (2012-2014)	12,719	4,705	43,421	7,294
Left lane width (ft)	12.00	12.00	12.00	0.00
Right lane width (ft)	12.00	12.00	12.00	0.00
Left outside paved shoulder width (ft)	4.68	4.00	8.00	1.11
Right outside paved shoulder. width (ft)	9.84	8.00	10.00	0.55
Effective median width (ft)	68.24	15.00	120.00	24.13
Number of crashes	13.97	1.00	98.00	18.14
Description				**No. of Segments**
Non-traversable median				4
Lighting				0
Automated speed enforcement				0

The average length of the sampled segments was well above 0.5 mi. The segments ranged in length from 1.01 to 7.44 mi, with an average length of 2.51 mi and a median length of 2.09 mi. The length standard deviation was 1.30 mi. The volumes averaged 12,719 AADT, with a maximum of 43,421. The segments were relatively uniform with respect to lane and shoulder width but showed some variation in effective median width. The average number of crashes was 13.97 and ranged from 1 to 98 crashes. The standard deviation of crashes was 18.14, which was larger than the average. The total number of crashes was 516, which exceeded the HSM recommendation of 100 crashes per year. Most of the segments had traversable medians. None of the segments had lighting or automated speed enforcement.

5.6 Results and Discussion

The original models were developed using data from Texas, California, New York, and Washington. (Lord et al. 2008). Some of the summary statistics for the data used as the basis for model development are shown in Table 5.6.

Table 5.6 Descriptive statistics for HSM model data for rural multilane divided highways

State	Number of Segments	Total Length (mi)	Minimum AADT (vpd)	Maximum AADT (vpd)
Texas	1,733	1,750	160	90,000
California	1,087	519	1,300	61,000
New York	197	139	1,082	46,717
Washington	35	196	3,187	61,947

Even though four states were sampled, Texas and California accounted for 92.4% of the segments and 87.1% of the total length. In summary, HSM rural multilane divided highway data consisted of 3,052 segments covering 2,604 mi in four different states. Even though none of the states was in the Midwest, the data set was a large national data set that should reflect design and behavior in a large number of US states.

The calibration factor for rural multilane divided highways in Missouri yielded a value of 0.74. The IHSDM output is shown in Figure 5.2.

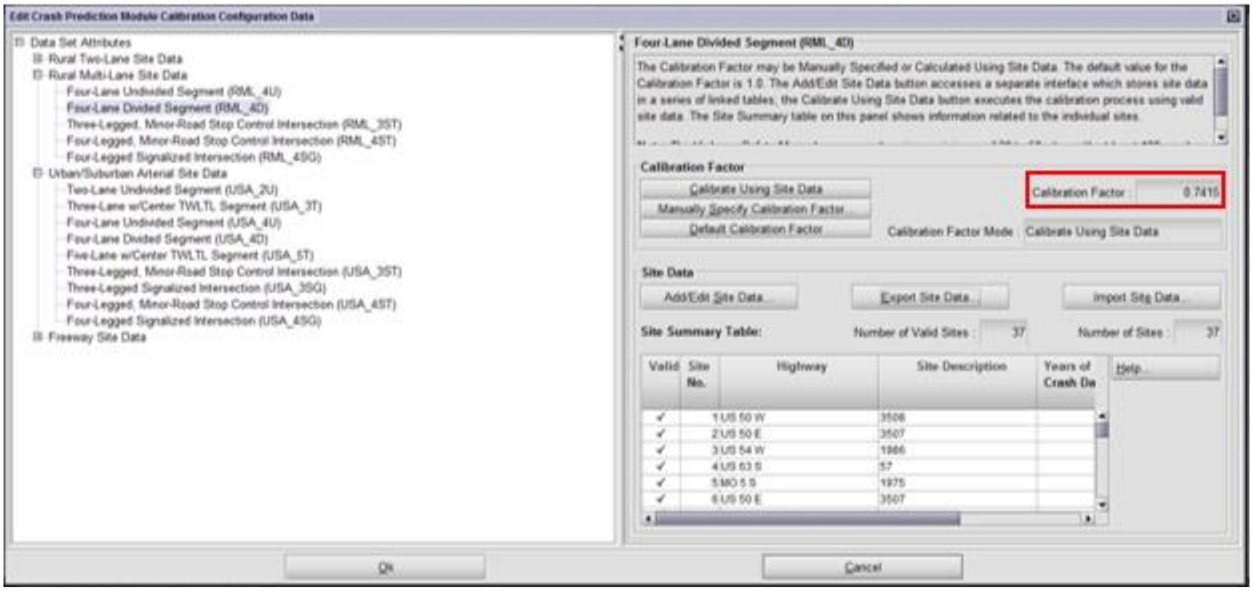

Figure 5.2 Calibration output for rural multilane divided segments

Table 5.7 provides detailed results of predictions and observations by facility. These results indicated that the number of crashes observed in Missouri was lower than the number of crashes predicted by the HSM for this facility type.

Table 5.7 Calibration results for rural multilane divided segments

No.	District	Segment	Begin Log	Length (mi)	All Crashes Observed	All Crashes Predicted
1	CD	US 50 W	134.43	2.18	9	10
2	CD	US 50 E	154.56	1.53	3	8
3	CD	US 54 W	156.26	1.30	8	22
4	CD	US 63 S	99.70	1.88	8	14
5	CD	MO 5 S	226.78	1.06	1	9
6	KC	US 50 E	28.90	2.37	17	20
7	KC	MO 13 N	212.04	1.60	1	4
8	KC	MO 13 N	208.31	1.01	2	3
9	KC	MO 7 N	137.92	2.76	15	19
10	KC	US 65 N	154.42	3.20	26	17
11	KC	US 50 W	202.90	3.52	27	29
12	NE	US 61 S	34.47	3.14	12	13
13	NE	US 61 S	9.24	1.98	3	8
14	NE	US 24 E	186.28	1.69	4	9
15	NE	US 61 N	291.34	2.85	13	19
16	NE	US 63 S	35.75	3.53	10	13
17	NW	US 59 S	68.99	1.78	1	7
18	NW	US 71 N	283.65	3.33	4	11
19	NW	US 59 N	33.86	1.51	2	8
20	NW	US 36 W	107.75	2.09	9	9
21	NW	US 36 E	31.40	1.39	6	8
22	SE	US 67 S	77.01	7.44	98	79
23	SE	US 67 N	27.82	3.98	14	15
24	SE	US 60 W	198.09	5.95	19	46
25	SE	US 63 S	292.25	2.46	8	14
26	SE	US 60 W	186.22	1.93	7	14
27	SL	MO 21 N	173.01	1.77	14	15
28	SL	US 61 S	130.67	1.89	34	42
29	SL	MO 100 W	44.40	3.28	21	31
30	SL	MO 100 W	42.20	1.95	8	19
31	SL	US 67 N	130.21	3.25	59	69
32	SL	MO 21 S	21.98	2.24	19	19
33	SW	US 65 S	310.42	1.97	5	16
34	SW	MO 7 N	119.88	3.57	15	22
35	SW	MO 13 S	171.07	1.35	3	5
36	SW	US 60 W	227.07	2.64	11	23
37	SW	MO 13 N	122.92	1.43	1	9
Sum					**517**	**697**
Calibration Factor					**0.741**	

The result of the recalibration in this project was different from that of the previous calibration performed for the period of 2009 to 2012. The previous calibration factor was 0.98. The main differences were due to crash data processing and effective segment length determination. The previous calibration queried for all crashes within a segment. The crash query included intersections, interchanges, and other inconsistent sections. The segment length and crashes were processed later by removing sections of the segment to omit interchanges and inconsistent sections. In the case of intersections, all intersection related crashes were removed from the query. The resulting segment length in the previous HSM calibration was an effective length that was a combination of multiple sections along the queried segment. Although this practice is common, the capability and precision to consistently remove crashes and sections within segments was lacking because of data characteristics. Missouri crash data were sometimes inaccurately landed close to interchanges because the interchange polygon defined by MoDOT may extend further down the approaching segments or assign crossroad crashes to the mainline. Therefore, the samples in the new recalibration were readjusted so the segments were not a combination of separate sections. In other words, the new samples were adjusted to establish continuous segments away from interchanges. As a result, the new samples had fewer crashes across the board because the queries were consistent and continuous along the segments without including other crashes corresponding to interchanges or inconsistent sections.

5.6.1 Severity Distribution Factors

Using the data from the calibration, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 5.8 shows the SDFs obtained for rural multilane segments.

Table 5.8 Severity distribution factors for rural multilane divided segments

Severity	Crashes	SDF
Fatal	6	0.012
Disabling Injury	20	0.039
Minor Injury	118	0.228
Property Damage Only	373	0.721

5.6.2 Crash Type Distribution Factors

The CDFs are used to determine the proportion of predicted crashes according to the type of crash. The data from the calibration were used to estimate these factors. Some data processing was required because Missouri crash type categories were different than those of the HSM. Therefore, different Missouri categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were estimated for total crashes in correspondence to the calibration factor severity. Table 5.9 provides the CDFs for rural multilane divided segments.

Table 5.9 Crash type distribution factors rural multilane divided segments

Collision Type	Crashes	CDF
Head-on	1	0.002
Sideswipe	33	0.064
Rear-end	58	0.112
Angle collision	7	0.014
Collision with animal	111	0.215
Collision with fixed object	11	0.021
Collision with parked vehicle	5	0.010
Out of control	234	0.453
Other	57	0.110

CHAPTER 6 URBAN ARTERIAL SEGMENTS

6.1 Introduction and Scope

Chapter 12 of the HSM describes the methodology for crash prediction on urban arterial segments, including two-lane and four-lane undivided segments, four-lane divided segments, and three-lane and five-lane undivided segments with two-way left-turn lanes. Because some of these site types were not common in Missouri, the calibration of urban arterial segments in this project was performed only for two-lane undivided segments, four-lane divided segments, and five-lane undivided segments with a two-way left-turn lane.

6.2 Calibration Data Requirements

The input data in the IHSDM were divided into required and desired data. The required data consisted of site, crash, and traffic data. The desired data were optional and included variables such as fixed objects, lighting, and automated speed enforcement.

6.2.1 Required Site Data

6.2.1.1 Area Type

The classification of areas depends on the roadway characteristics, surrounding population, and land use. Based on the FHWA guidelines, the HSM defines urban areas as regions with a population greater than 5,000 people. Rural areas are designated as regions outside urban areas with a population less than 5,000 people. Although the terms metropolitan, urbanized, or suburban refer to urban subcategories, the HSM does not make a distinction among these subgroups and considers all as urban (AASHTO 2010). MoDOT uses the same area classification.

6.2.1.2 Segment Length

The roadway segment length for urban arterials consists of the total length in miles over a homogenous segment with no significant changes in travelway, cross-section, geometry, and speed limit. The HSM recommends a minimum of 0.1 mi to reduce calculation efforts. Due to the urban environment, long segments were not as plentiful as in other facility types. Nineteen of the 75 four-lane divided arterial segments and 32 of the 59 four-lane undivided arterial segments were shorter than 0.5 mi. Figure 6.1 illustrates a homogenous segment including a horizontal curve that was limited by two stop-controlled intersections.

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Figure 6.1 Segment length of a homogenous segment

6.2.1.3 Number of Driveways

Driveways are defined as frontage access along an establishment property with the road segment arterial. The driveway designation is restricted to unsignalized driveways only. The number of driveways counted should be within the roadway segment, including all driveways on both sides of the road. Driveways are categorized by commercial, industrial/institutional, residential, and other driveways. Commercial driveways are facilities that provide access to retail establishments. Commercial driveways with no restriction of access along an entire property frontage can be counted as two driveways. Figure 6.2 shows an example of a commercial driveway that leads to a fast food drive-through.

© Google 2016

Figure 6.2 Commercial driveway at an urban arterial segment

Industrial/institutional driveways are designated as facilities that provide access to factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Figure 6.3 shows examples of institutional driveways of a hospital complex. Note that the signalized driveway in Figure 6.3 should be considered as an intersection.

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Figure 6.3 Institutional driveways at an arterial segment

Residential driveways provide access to single and multiple family homes. A residential driveway could be a driveway directly connecting a home to the arterial segment or a driveway that connects to a network of homes.

Figure 6.4 provides an example of a major residential driveway that provides access to a neighborhood without cutting through to a city street.

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Figure 6.4 Residential driveway at an urban arterial

A residential driveway should not include public streets that serve traffic in addition to a specific residential complex. Therefore, public streets should be designated as intersections according to their control type. Driveways are further divided into major and minor driveways based on the estimated number of parking spaces to which the driveway connects. Major driveways accommodate 50 or more parking spaces, and minor driveways serve fewer than 50 parking spaces (AASHTO 2010).

6.2.1.4 Type of Parking and Land Use

Parking is designated according to the type of on-street parking allowed, including parallel, angle, or no parking. In addition, the land use of the adjacent establishment in which parking is located is designated as commercial/industrial/institutional or residential/other. The type of parking and land use is further classified as left or right side. The left side parking designation is present at divided road segments with wide medians capable of accommodating parked vehicles. Figure 6.5 provides an example of angle parking and Figure 6.6 illustrates parallel parking on one side of the roadway.

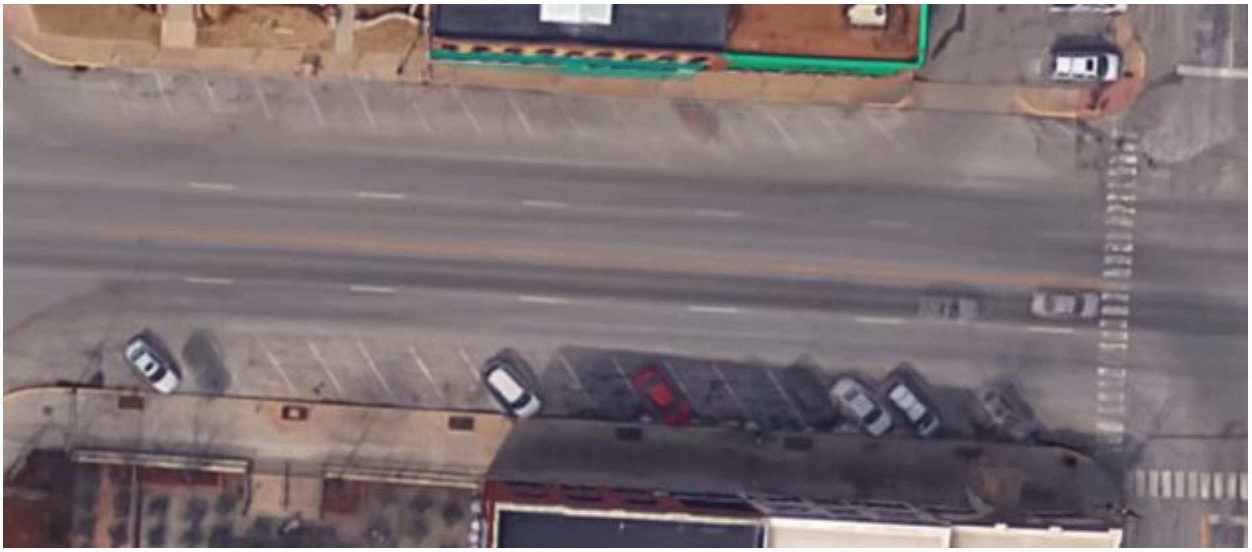

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Figure 6.5 Angle parking on right side of the road

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Figure 6.6 Parallel parking on one side of the road only (right side)

6.2.1.5 Proportion of Curb Length with Parking

The proportion of the curb length with on-street parking represents the portion of the road segment that contains parking and should include parking that is available on either side of the roadway. The left side parking would be found primarily at divided road segments that allow parked vehicles on the left side on one-way segments.

6.2.1.6 Speed Category

Pedestrians and bicycle crashes are part of the prediction methodology based on posted speed limit categories. Two speed categories are considered: (1) Low (30 mph or lower) and (2) Intermediate/High (more than 30 mph). Street view images were used to verify the posted speed limits within the segments.

6.2.1.7 Effective Median Width and Type

This section applies to divided segments only. The effective median width is the total length of median that remains constant throughout the segment delineated by the edges of travelway, including inside shoulders, if present. The median width is measured in feet. If there are significant variations of median width within a segment, the segment should be divided into different sections or a weighted average width should be used. There are several possible median configurations. Arterials with no physical separation (i.e., painted medians) are considered undivided facilities. The HSM defines two types of medians: (1) traversable and (2) non-traversable. Figure 6.7 shows examples of various types of medians.

(a) Painted median **(b) Median concrete barrier**

(c) Median W-beam barrier **(d) Median cable barrier**

(e) Depressed median **(f) Flush paved median**

(g) Rapid transit median **(h) Railroad median**

Figure 6.7 Examples of different median types

6.2.2 Required Crash and Traffic Data

6.2.2.1 Years of Crash Data

The IHSDM considers up to three years for the input data. The years associated with the calibration were specified as 2012 to 2014.

6.2.2.2 Observed Number of Crashes

The HSM predictive method estimates crash frequency of urban arterial segment crashes. Crash assignment to segments or intersections is based on geometric, traffic control, and operations characteristics. It is common to find urban arterial segments limited by intersections; therefore, intersection related crashes should not be considered as segment related crashes. In Missouri's case, intersection-related crashes were removed based on the intersection identification number that was designated in the crash data. MoDOT assigns crashes to an intersection if they are located within 132 ft of the intersection. Note that some driveways are assigned intersection node numbers on the TMS system, and crashes associated with these driveways should not be excluded. All segment-related crashes should be included with no additional separation by severity or single/multiple vehicle designation, as is done in Chapter 7 for freeway segments. Figure 6.8 provides the definition from the HSM for segmentation and crash assignment for segments and intersections.

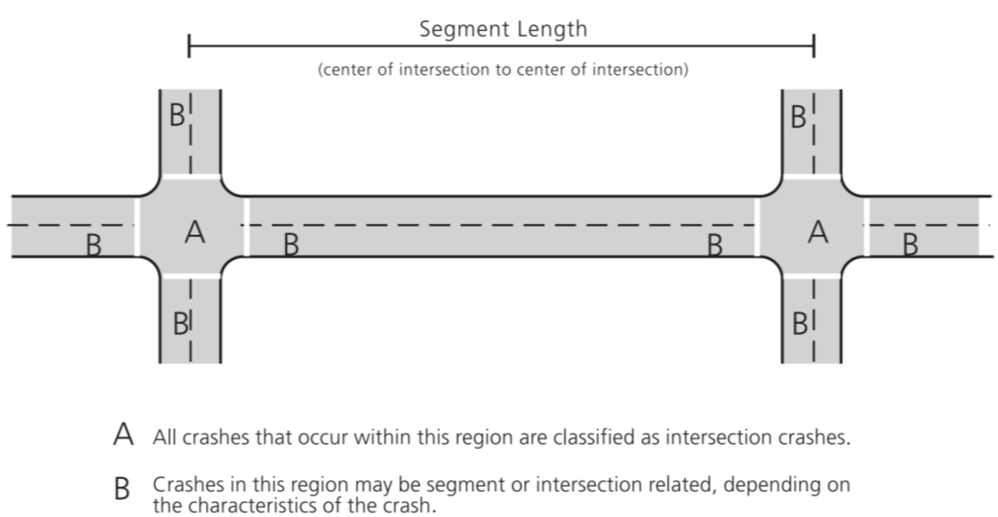

Figure 6.8 HSM definition of segment and intersection crashes

6.2.2.3 Segment AADT

The total segment AADT (in both directions) was collected for all years of analysis.

6.2.3 Desired Data

6.2.3.1 Offset to Fixed Objects

Fixed objects that are 4 in. or more in diameter and do not have breakaway design are applicable. The average offset of objects (from the edge of the travelway) within a segment on the right side of the roadway in each direction of travel was considered; fixed objects in the roadway median on divided arterials were not considered (AASHTO 2010). Figure 6.9 shows an example of an offset to a commercial sign.

Figure 6.9 Offset to fixed object

6.2.3.2 Fixed Object Density

According to the HSM, "point objects that are within 70 feet of one another longitudinally along the road are counted as a single object. Continuous objects that are not behind point objects are counted as one point object for each 70 feet of length." (AASHTO 2010). Fixed object density for both sides of the road is considered in units of fixed objects per mile. Figure 6.10 illustrates utility posts along one side of the road at a constant spacing (defined as one object for every 70 ft).

Figure 6.10 Utility posts on one side of the road

6.2.3.3 Lighting

Lighting is defined as the presence of illumination along a segment. The IHSDM data input only requires specifying whether or not there is lighting along the segment (i.e., yes or no). Figure 6.11 shows a common lighting configuration on both sides of the road on an urban arterial.

Figure 6.11 Illumination on both sides of the road

6.2.3.4 Automated Speed Enforcement

Automated speed enforcement of arterial segments may use video or photographic identification in combination with radar or laser data to detect drivers going over the posted speed limit of the segment. The system automatically records information when the vehicle is at fault. The IHSDM data input only requires specifying whether or not there is automated speed enforcement along the segment (i.e., yes or no). Figure 6.12 illustrates common configurations and signs for automated speed enforcement.

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Figure 6.12 Automated speed enforcement camera

6.3 HSM Methodology

As described in Chapter 12 of the HSM, the SPFs for urban arterial segments predict the number of total crashes on a segment per year for the base conditions. The SPF is a function of the AADT and length of the segment and is obtained through equations 6.1 to 6.8 below. The vehicular and non-vehicular (pedestrian and bicycle) crashes are added together to obtain the total number of crashes on a segment.

$$N_{predicted,rs} = C_r \times (N_{br} + N_{pedr} + N_{biker}) \quad \textbf{(6.1)}$$

where

$N_{predicted,rs}$ is the predicted average crash frequency of an individual roadway segment for the selected year

C_r is the calibration factor for roadway segments of a specific type developed for use for a particular geographical area

N_{br} is the predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions)

N_{pedr} is the predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment

N_{biker} is the predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment

$$N_{br} = N_{spf,rs} \times (CMF_{lr} \times CMF_{2lr} \times ... \times CMF_{nr}) \quad \textbf{(6.2)}$$

where $N_{spf,rs}$ is the predicted total average crash frequency of an individual roadway segment for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions) and $CMF_{lr} \times ... \times CMF_{nr}$ are the crash modification factors for roadway segments. The vehicular-related crashes are the sum of multi-vehicle, single-vehicle, and driveway crashes.

$$N_{spf,rs} = N_{brmv} + N_{brsv} + N_{brdwy} \quad \textbf{(6.3)}$$

where

N_{brmv} is the predicted average crash frequency of multiple-vehicle non-driveway crashes for base conditions

N_{brsv} is the predicted average crash frequency of single-vehicle crashes for base conditions

$N_{brdwy}$is the predicted average crash frequency of multiple-vehicle driveway-related collisions

$$N_{brmv} = e^{(a+b\times\ln(AADT)+\ln(L))} \quad \textbf{(6.4)}$$

$$N_{brsv} = e^{(a+b\times\ln(AADT)+\ln(L))} \quad \textbf{(6.5)}$$

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)} \quad \textbf{(6.6)}$$

where

$a + b$ are the regression coefficients

$AADT$ is the annual average daily traffic volume (vehicles/day) on roadway segment

L is the length of roadway segment (mi)

n_j is the number of driveways within roadway segment of driveway type *j*, including all driveways on both sides of the road

N_j is the number of driveway-related collisions per driveway per year for driveway type *j*

t is the coefficient of traffic volume adjustment

Even though the model forms are the same for multi-vehicle and single-vehicle equations (i.e., 6.4 and 6.5), the coefficients, a and b, are different.

$$N_{pedr} = N_{br} \times f_{pedr} \tag{6.7}$$

$$N_{biker} = N_{br} \times f_{biker} \tag{6.8}$$

where f_{pedr} is the pedestrian crash adjustment factor and f_{biker} is the bicycle crash adjustment factor

The base conditions are listed in Table 6.1.

Table 6.1 Base conditions in HSM for SPF for urban arterial segments

Description	Base Condition
On-Street Parking	None
Roadside Fixed Objects	None
Median Width	15 ft
Lighting	None
Automated Speed Enforcement	None

6.4 Sampling Considerations

In order to select sample urban arterial segments, a list of all segments for each district and each site type was generated using TMS database queries. Duplicate samples were filtered out using a spreadsheet. During the sampling process, an attempt was made to obtain 10 samples from each district with a minimum segment length of 0.25 mi. A greater number of samples was used for urban arterials because the segments were shorter. However, it was not possible to meet this goal for all of the site types due to the lack of a sufficient number of samples. The urban two-lane arterial segments were subdivided if the speed limit changed from 30 mph and below to over 30 mph because the CMF for the speed category was based upon these speed limit ranges. Variations of 5 to 10 mph in the posted speed limit were tolerated. Significant variations in speed limits were not considered as homogenous segments. The segments were not subdivided based on minor changes in cross-section. The urban four-lane divided arterial segments were subdivided based on changes in median type or significant changes in median width. Major signalized intersections were avoided within the segments. In addition, the proximity to interchange facilities was avoided. The specific considerations for each site type are described below.

6.4.1 Sampling for Urban Two-Lane Undivided Arterial Segments

The query criteria used to generate the master list of urban two-lane arterial undivided segments are shown in Table 6.2.

Table 6.2 Query criteria for urban two-lane undivided arterial segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2012
TMS_TRF_INFO_SEGMENT_VW	BEG_DISTRICT_ABBR	Varies
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRF_INFO_NAME	AADT
TMS_TRF_INFO_SEGMENT_VW	BEG_OVERLAPPING_INDICATOR	not S
TMS_TRF_INFO_SEGMENT_VW	BEG_URBAN_RURAL_CLASS	URBAN
TMS_TRF_INFO_SEGMENT_VW	BEG_DIVIDED_UNDIVIDED	UNDIVIDED
TMS_TRF_INFO_SEGMENT_VW	END_DIVIDED_UNDIVIDED	UNDIVIDED
TMS_SS_PAVEMENT	ROADWAY_TYPE_NAME	TWO-LANE or SUPER TWO-LANE

The query utilized the ROADWAY_TYPE_NAME field in the TMS table TMS_SS_PAVEMENT to obtain segments that were classified as either TWO_LANE or SUPER TWO-LANE. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes that overlapped with primary routes. The BEG_URBAN_RURAL_CLASS field was used to limit the query to urban segments. The query was limited to undivided segments by using the BEG_DIVIDED_UNDIVIDED and END_DIVIDED_UNDIVIDED fields.

Sampling for urban two-lane undivided arterial segments was performed based on the master list generated from the database queries. All data requirements were reviewed along with the segments using ARAN video, TMS information, and Google Maps. At least nine random samples from each district were generated. Therefore, the sample set for calibration included 75 sites.

A list of samples for urban two-lane undivided arterial segments is shown in Table 6.3. The samples were distributed among the seven MoDOT districts as follows:

- 11 samples from the Central District
- 9 samples from the Kansas City District
- 10 samples from the Northeast District
- 9 samples from the Northwest District
- 12 samples from the Southeast District
- 9 samples from the St. Louis District
- 13 samples from the Southwest District

The samples represent geographic diversity from around Missouri. The samples included US and Missouri highways as well as segments from 34 counties in Missouri, including large counties such as Jackson and small counties such as Pike.

Table 6.3 List of sites for urban two-lane undivided arterial segments

No.	City	County	Dist.	Description	Primary Dir.	Begin Log	End Log	Length (mi)
1	Fulton	Callaway	CD	RT F	E	7.58	9.03	1.45
2	Fulton	Callaway	CD	RT O	E	0.25	0.93	0.68
3	Boonville	Cooper	CD	US 40	E	105.74	106.14	0.40
4	Boonville	Cooper	CD	MO 87	S	22.69	23.28	0.59
5	Waynesville	Pulaski	CD	MO 17	N	136.31	136.86	0.55
6	New Franklin	Howard	CD	MO 5	N	210.76	211.61	0.85
7	Boonville	Cooper	CD	RT B	N	23.39	24.10	0.71
8	Salem	Dent	CD	RT J	E	1.03	1.76	0.74
9	Salem	Dent	CD	RT HH	S	0.00	0.45	0.45
10	Fulton	Callaway	CD	BU 54	E	4.48	4.86	0.38
11	Eldon	Howard	CD	MO 87	S	75.57	75.97	0.40
12	Sedalia	Pettis	KC	US 50	E	83.46	84.51	1.05
13	Marshall	Saline	KC	MO 240	E	0.65	1.46	0.81
14	Marshall	Saline	KC	US 65	N	194.14	194.78	0.64
15	Marshall	Saline	KC	RT WW	E	0.70	1.65	0.95
16	Marshall	Saline	KC	RT WW	W	2.78	3.39	0.61
17	Marshall	Saline	KC	BU 65	S	2.27	2.52	0.25
18	Excelsior Springs	Clay	KC	SP 10	E	0.07	0.60	0.53
19	Oak Grove	Jackson	KC	RT F	S	2.07	2.49	0.42
20	Excelsior Springs	Clay	KC	RT N	S	0.54	1.10	0.56
21	Oak Grove	Jackson	KC	RT F	S	0.99	2.07	1.08
22	Sedalia	Pettis	KC	US 50	E	82.50	83.33	0.83
23	Mexico	Audrain	NE	MO 15	N	2.38	2.75	0.37
24	Mexico	Audrain	NE	MO 15	N	2.87	3.22	0.35
25	Mexico	Audrain	NE	MO 22	E	22.96	23.86	0.90
26	Bowling Green	Pike	NE	MO 161	S	0.46	1.07	0.61
27	Moberly	Randolph	NE	RT M	W	23.71	24.73	1.02
28	Bowling Green	Pike	NE	BU 61	S	1.96	2.46	0.50
29	Troy	Lincoln	NE	RT J	S	0.63	1.43	0.80
30	Moberly	Randolph	NE	BU 63	N	5.29	6.30	1.01
31	Kirksville	Adair	NE	RT P	E	0.24	0.68	0.43
32	Kirksville	Adair	NE	RT B	S	11.69	12.58	0.89
33	Cameron	DeKalb	NW	BU 36	W	0.59	1.40	0.81
34	Blake	Daviess	NW	RT V	N	0.59	1.00	0.40
35	Trenton	Grundy	NW	MO 6	E	79.82	80.46	0.64
36	Maryville	Nodaway	NW	BU 71	N	3.23	4.42	1.18
37	Cameron	DeKalb	NW	US 69	S	67.65	67.99	0.34
38	Maryville	Nodaway	NW	MO 46	E	27.11	27.46	0.34
39	Trenton	Grundy	NW	RT AA	N	0.00	0.57	0.57
40	Cameron	Clinton	NW	RT A	N	15.78	16.30	0.51
41	Maryville	Nodaway	NW	RT V	E	11.75	12.18	0.43

No.	City	County	Dist.	Description	Primary Dir.	Primary Begin Log	Primary End Log	Length (mi)
42	Cape Girardeau	Cape Girardeau	SE	RT W	S	5.89	7.19	1.30
43	Cape Girardeau	Cape Girardeau	SE	RT W	S	7.68	8.47	0.79
44	Cape Girardeau	Cape Girardeau	SE	RT W	S	8.97	9.55	0.59
45	Perryville	Perry	SE	RT B	S	0.08	0.45	0.37
46	Miner	Scott	SE	US 62	E	62.72	63.24	0.52
47	Jackson	Cape Girardeau	SE	RT PP	S	0.06	1.03	0.97
48	Desloge	St. Francois	SE	MO 8	E	70.74	71.16	0.42
49	Perryville	Perry	SE	MO 51	S	15.20	15.54	0.34
50	Malden	Dunklin	SE	RT J	E	10.94	11.42	0.48
51	Cape Girardeau	Scott	SE	RT AB	W	4.08	5.73	1.65
52	Dexter	Stoddard	SE	MO 114	E	0.28	0.78	0.50
53	Kennett	Dunklin	SE	RT E	E	0.16	2.20	2.04
54	De Soto	Jefferson	SL	RT E	N	14.83	15.92	1.09
55	St. Clair	Franklin	SL	MO 47	N	49.14	49.83	0.69
56	Sullivan	Franklin	SL	MO 185	N	37.12	37.71	0.59
57	Sullivan	Franklin	SL	MO 185	S	30.24	30.85	0.61
58	Cedar Hill	Jefferson	SL	RT NN	N	0.07	1.13	1.06
59	Union	Franklin	SL	MO 47	S	65.02	66.65	1.64
60	St. Clair	Franklin	SL	MO 47	N	47.14	47.58	0.44
61	Sullivan	Crawford	SL	RT D	S	0.64	1.32	0.68
62	Sullivan	Crawford	SL	RT D	S	1.42	2.41	1.00
63	Hollister	Taney	SW	RT BB	S	0.03	1.37	1.34
64	Hollister	Taney	SW	BU 65	N	1.30	1.86	0.55
65	Hollister	Taney	SW	BU 65	N	2.02	2.36	0.34
66	Aurora	Lawrence	SW	BU 60	E	6.51	7.24	0.73
67	Forsyth	Taney	SW	US 160	W	177.11	177.94	0.83
68	Forsyth	Taney	SW	US 160	W	178.19	179.08	0.89
69	Aurora	Lawrence	SW	BU 60	E	4.80	5.66	0.86
70	Marshfield	Webster	SW	RT CC	S	16.61	17.49	0.88
71	Marshfield	Webster	SW	RT CC	N	0.11	0.74	0.63
72	Clinton	Henry	SW	BU 13	S	0.12	1.10	0.98
73	Nevada	Vernon	SW	RT BB	S	0.08	0.90	0.82
74	Nevada	Vernon	SW	RT BB	S	0.95	1.55	0.60
75	Carthage	Jasper	SW	MO 96	E	14.92	15.80	0.88

6.4.2 Sampling for Urban Four-Lane Divided Arterial Segments

The query criteria used to generate the master list of urban four-lane divided arterial segments are shown in Table 6.4.

Table 6.4 Query criteria for urban four-lane divided arterial segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2012
TMS_TRF_INFO_SEGMENT_VW	BEG_DISTRICT_ABBR	Varies
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRF_INFO_NAME	AADT
TMS_TRF_INFO_SEGMENT_VW	BEG_OVERLAPPING_INDICATOR	not S
TMS_TRF_INFO_SEGMENT_VW	BEG_URBAN_RURAL_CLASS	URBAN
TMS_TRF_INFO_SEGMENT_VW	BEG_DIVIDED_UNDIVIDED	DIVIDED
TMS_TRF_INFO_SEGMENT_VW	BEG_FUNCTIONAL CLASS	not INTERSTATE

These criteria were similar to the criteria used for urban two-lane undivided segments, with a few differences. The query utilized the BEG_DIVIDED_UNDIVIDED field to obtain segments that were classified as DIVIDED. The query also excluded Interstate segments by using the field BEG_FUNCTIONAL CLASS.

Samples were selected from the aforementioned master list. Freeway segments were removed from the list of candidate segments using spreadsheet filtering. In some cases, the limits of the segments were revised after viewing them in ARAN because a portion of the segment was located within the limits of an interchange, was not urban, or was not of the proper site type. For this site type, it was not possible to obtain 10 random samples from each district due to the lack of a sufficient number of samples. At-large samples were taken from the entire state in order to obtain as many samples as possible. One segment from the Central District was subdivided into three segments due to significant changes in median width. One segment from the Northeast District was subdivided into two segments because a portion of the segment contained a median cable barrier. The sample set for calibration included 66 sites.

A list of samples for urban four-lane undivided arterial segments is shown in Table 6.5. The samples were distributed among the seven MoDOT districts as follows:

- 1 sample from the Central District
- 7 samples from the Kansas City District
- 7 samples from the Northeast District
- 2 samples from the Northwest District
- 19 samples from the Southeast District
- 22 samples from the St. Louis District
- 8 samples from the Southwest District

The sample set included arterial segments that represented geographic diversity from around Missouri, although approximately one-third of the samples were from the St. Louis District. The sample set included segments from 22 Missouri counties, including large counties such as Jefferson and small counties such as Scott. The majority of the segments were on Missouri highways, while the remaining segments were on US highways.

Table 6.5 List of sites for urban four-lane divided arterial segments

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length	County
1	CD	LP 44	E	7.62	7.92	0.30	Jackson
2	KC	US 50	E	61.26	61.70	0.44	Johnson
3	NE	US 61	S	63.95	64.62	0.66	Ralls
4	NE	US 61	S	88.81	89.19	0.38	Pike
5	NE	US 61	S	120.25	120.74	0.49	Lincoln
6	NE	US 61	S	123.47	124.06	0.59	Lincoln
7	NE	US 63	N	252.78	253.35	0.58	Randolph
8	NE	US 63	N	250.75	251.48	0.73	Randolph
9	NE	US 36	E	131.64	132.52	0.87	Macon
10	NW	US 36	E	71.99	72.41	0.42	Livingston
11	NW	US 36	E	73.31	73.81	0.50	Livingston
12	SE	US 61	S	285.52	286.00	0.48	Cape Girardeau
13	SE	US 67	N	99.50	99.97	0.48	St. Francois
14	KC	MO 291	S	14.89	15.47	0.57	Jackson
15	KC	MO 291	S	16.86	17.12	0.27	Jackson
16	SE	US 67	N	106.81	107.22	0.41	St. Francois
17	SE	US 67	N	108.17	108.99	0.82	St. Francois
18	SE	US 67	N	109.59	111.65	2.06	St. Francois
19	KC	MO 291	S	17.27	17.58	0.31	Jackson
20	SE	MO 25	S	47.77	48.13	0.36	Stoddard
21	SE	MO 25	S	49.02	49.42	0.40	Stoddard
22	KC	MO 291	S	19.77	20.21	0.44	Jackson
23	KC	US 69	N	8.38	8.65	0.27	Clay
24	SE	MO 34	E	101.25	102.04	0.79	Cape Girardeau
25	SE	MO 34	E	102.27	102.63	0.36	Cape Girardeau
26	SE	MO 74	E	7.78	8.19	0.42	Cape Girardeau
27	SE	MO 32	E	247.21	248.02	0.81	St. Francois
28	SE	MO 232	E	248.78	249.70	0.92	St. Francois
29	SE	MO 32	E	254.38	254.63	0.26	St. Francois
30	SE	MO 412	W	25.95	26.35	0.40	Dunklin
31	SE	US 61	N	101.36	101.99	0.63	Cape Girardeau
32	SE	US 60	E	290.88	291.80	0.91	Stoddard
33	SE	US 60	E	314.49	315.88	1.39	New Madrid
34	SE	US 60	E	316.20	316.54	0.34	Scott
35	SE	BU 67	S	4.70	5.01	0.32	Butler
36	SL	MO 30	E	21.02	21.69	0.67	Jefferson
37	SL	MO 30	E	22.26	22.62	0.36	Jefferson
38	SL	MO 30	E	22.79	23.10	0.30	Jefferson
39	SL	MO 30	E	23.47	23.78	0.31	Jefferson
40	SL	MO 30	E	24.62	25.33	0.71	Jefferson
41	SL	MO 30	E	25.48	26.43	0.95	Jefferson
42	SL	MO 30	E	26.96	27.33	0.37	Jefferson
43	SL	MO 30	E	28.03	29.26	1.23	Jefferson
44	SL	MO 30	E	30.18	30.50	0.32	Jefferson
45	SL	MO 30	E	31.57	32.07	0.50	Jefferson

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length	County
46	SL	MO 30	E	32.33	32.87	0.54	Jefferson
47	SL	MO 30	E	33.58	34.19	0.55	Jefferson
48	KC	US 40	E	15.48	15.85	0.37	Jackson
49	SL	MO 30	E	39.98	40.35	0.37	St. Louis
50	SL	MO 30	E	41.11	41.37	0.29	St. Louis
51	SW	MO 13	S	147.27	147.74	0.48	Henry
52	SW	RT D	E	0.18	1.27	1.08	Newton
53	SW	MO 59	S	19.66	19.93	0.28	Newton
54	SW	MO 59	S	20.07	20.70	0.63	Newton
55	SW	MO 59	S	21.45	22.25	0.80	Newton
56	SW	MO 59	S	22.37	22.77	0.40	Newton
57	SW	US 60	E	75.70	76.64	0.94	Greene
58	SW	US 60	E	77.12	77.40	0.28	Greene
59	SL	MO 94	E	100.68	101.12	0.44	St. Charles
60	SL	MO 94	E	101.32	102.02	0.70	St. Charles
61	SL	MO 141	S	29.28	29.90	0.62	Jefferson
62	SL	MO 141	S	28.21	28.93	0.73	Jefferson
63	SL	MO 141	S	27.52	27.96	0.44	Jefferson
64	SL	MO 141	S	26.03	26.46	0.43	Jefferson
65	SL	MO 141	S	24.66	25.26	0.60	Jefferson
66	SL	Midland Blvd.	E	2.93	3.40	0.47	St. Louis

6.4.3 Sampling for Urban Five-Lane Undivided Arterial Segments

The query criteria used to generate the master list of urban five-lane arterial undivided segments are shown in Table 6.6.

Table 6.6 Query criteria for urban five-lane undivided arterial segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2012
TMS_TRF_INFO_SEGMENT_VW	BEG_DISTRICT_ABBR	Varies
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRF_INFO_NAME	AADT
TMS_TRF_INFO_SEGMENT_VW	BEG_OVERLAPPING_INDICATOR	P
TMS_TRF_INFO_SEGMENT_VW	BEG_URBAN_RURAL_CLASS	URBAN
TMS_SS_PAVEMENT	ROADWAY_TYPE_NAME	5 LANE SECTION

These criteria were similar to the ones used for urban two-lane undivided segments, with a few differences. The query did not use the fields BEG_DIVIDED_UNDIVIDED or END_DIVIDED_UNDIVIDED. Instead, the query utilized the ROADWAY_TYPE_NAME field in the TMS table TMS_SS_PAVEMENT to obtain segments that were classified as 5 LANE SECTION.

A master list from a database query was used to generate the samples. In some cases, the limits of the segments were revised after viewing them in ARAN because a portion of the segment was not urban or of the proper site type. For this site type, it was not possible to obtain 10 random samples from each district due to the lack of a sufficient number of samples. At-large samples were taken from the entire state in order to obtain as many samples as possible. The sample set for calibration included 59 sites.

A list of samples for urban five-lane undivided arterial segments is shown in Table 6.7. The samples were distributed among the seven MoDOT districts as follows:

- 13 samples from the Central District
- 9 samples from the Kansas City District
- 6 samples from the Northeast District
- 6 samples from the Northwest District
- 10 samples from the Southeast District
- 5 samples from the St. Louis District
- 10 samples from the Southwest District

The samples were representative of geographic diversity from around Missouri. The sample set included segments from 20 Missouri counties, including more populous counties such as Greene and less populous counties such as Livingston. US highways and Missouri highways were represented nearly equally.

Table 6.7 List of sites for urban five-lane undivided arterial segments

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	County	Length (mi)
1	CD	US 63	N	123.10	124.18	Phelps	1.08
2	CD	MO 72	E	0.08	0.59	Phelps	0.50
3	CD	MO 72	E	0.59	1.75	Phelps	1.16
4	CD	MO 72	E	1.75	2.34	Phelps	0.59
5	CD	MO 5	S	248.31	249.06	Laclede	0.75
6	CD	MO 5	S	249.06	249.54	Laclede	0.48
7	CD	MO 5	S	249.54	250.01	Laclede	0.47
8	CD	MO 5	S	250.64	250.90	Laclede	0.26
9	CD	MO 5	S	251.01	251.51	Laclede	0.50
10	CD	MO 5	S	251.83	252.13	Laclede	0.31
11	CD	LP 44	E	0.29	1.17	Laclede	0.88
12	CD	LP 44	E	1.17	1.88	Laclede	0.70
13	CD	LP 44	E	2.59	3.02	Laclede	0.42
14	KC	US 65	S	150.28	151.20	Pettis	0.92
15	KC	US 65	S	151.20	152.11	Pettis	0.91
16	KC	US 50	E	77.78	78.20	Pettis	0.42
17	KC	US 50	E	78.55	78.80	Pettis	0.25
18	KC	US 50	E	79.16	79.53	Pettis	0.38
19	KC	US 50	E	80.66	80.97	Pettis	0.31
20	KC	US 50	E	81.09	81.38	Pettis	0.29
21	KC	US 50	E	81.38	82.01	Pettis	0.63
22	KC	MO 58	E	6.55	7.01	Cass	0.47
23	NW	US 65	S	55.50	56.69	Livingston	1.18
24	NW	US 65	S	56.69	57.32	Livingston	0.63
25	NW	US 65	S	57.68	58.16	Livingston	0.48
26	NW	US 65	S	58.75	59.02	Livingston	0.28
27	NW	US 65	S	59.02	59.72	Livingston	0.70
28	NW	US 69	N	55.80	56.08	DeKalb	0.29
29	SE	US 63	N	30.34	30.92	Howell	0.58
30	SE	US 63	N	30.93	33.15	Howell	2.23
31	SE	BU 67	S	3.90	4.27	Butler	0.37
32	SE	BU 60	W	5.45	5.71	Butler	0.26
33	SE	BU 60	W	5.71	6.40	Butler	0.69
34	SE	BU 60	W	6.40	7.06	Butler	0.66
35	SE	MO 32	E	254.84	255.24	St. Francois	0.40
36	SE	MO 32	E	255.43	256.01	St. Francois	0.58
37	SE	MO 32	E	256.01	256.26	St. Francois	0.25
38	SE	MO 32	E	256.26	256.56	St. Francois	0.30
39	SL	LP 44	E	3.08	3.40	Franklin	0.33
40	SL	US 67	N	137.18	137.55	Jefferson	0.38
41	SL	MO 47	S	70.65	70.97	Franklin	0.31

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	County	Length (mi)
42	SL	US 50	E	216.15	216.90	Franklin	0.76
43	SL	US 50	E	215.67	216.15	Franklin	0.48
44	SW	MO 7	N	107.24	107.49	Henry	0.25
45	SW	MO 7	N	111.01	111.75	Henry	0.74
46	SW	MO 96	E	13.44	13.69	Jasper	0.25
47	SW	US 54	E	14.07	14.49	Vernon	0.42
48	SW	MO 376	W	0.00	1.00	Taney	1.00
49	SW	MO 86	W	91.45	92.95	Newton	1.50
50	SW	MO 248	E	53.90	55.56	Taney	1.66
51	SW	BU 65	S	3.31	3.74	Taney	0.44
52	SW	US 60	E	72.62	73.08	Greene	0.45
53	SW	US 60	E	71.98	72.45	Greene	0.47
54	NE	US 61	S	60.76	61.03	Marion	0.27
55	NE	US 61	S	60.05	60.49	Marion	0.44
56	NE	US 24	E	135.46	135.80	Randolph	0.34
57	NE	MO 47	S	33.69	34.04	Warren	0.35
58	NE	BU 63	N	7.51	8.34	Randolph	0.83
59	NE	US 24	E	136.07	136.32	Randolph	0.25

6.5 Data Collection

A list of the data types collected for urban arterial segments and their sources is shown in Table 6.8.

Table 6.8 List of data sources for urban arterial segments

Data Description	Source
AADT	ODBC
No. of Major Commercial Driveways	ARAN/Aerials
No. of Minor Commercial Driveways	ARAN/Aerials
No. of Major Industrial/Institutional Driveways	ARAN/Aerials
No. of Minor Industrial/Institutional Driveways	ARAN/Aerials
No. of Major Residential Driveways	ARAN/Aerials
No. of Minor Residential Driveways	ARAN/Aerials
No. of Other Driveways	ARAN/Aerials
Type of Parking	ARAN/Aerials
Land Use	ARAN/Aerials
Proportion of Curb Length with Parking	ARAN/Aerials
Speed Category	TMS/Street View
Offset to Fixed Objects	Aerial/Street View
Fixed Object Density	Aerial/Street View
Presence of Lighting	Aerial/Street View
Presence of Automated Speed Enforcement	MoDOT
Number of Crashes	TMS

The number of driveways of each type was counted. The HSM defines major driveways as connecting to 50 or more parking spaces and minor as connecting to fewer than 50 parking spaces. The driveways were classified using the HSM definition by viewing ARAN, Google street view, and aerial photographs. The number of fixed objects and offset for the fixed objects was estimated visually from street view and aerial images. It should be noted that the HSM defines fixed objects as objects that are 4 in. or greater in diameter and not breakaway. The types of land use and parking, and proportion of curb length with parking, were determined separately for each side of the roadway using street view and aerial images. In most cases, the road segments did not contain parking. Because IHSDM requires a value to be set for the type of parking, regardless of the existence of parking, the type of parking was arbitrarily set as parallel if there was no parking on the segment. Using the arbitrary parallel type was inconsequential because the proportion of curb length with parking was coded with a value of zero for segments with no parking. Speed limit values at the beginning and end of each segment were retrieved from the TMS database and validated through street view images, Street view was also used to determine whether lighting was present on the segment. MoDOT provided information regarding locations with automated speed enforcement.

6.5.1 Summary Statistics for Urban Two-Lane Undivided Arterial Segments

Descriptive statistics for urban two-lane undivided arterial segments are shown in Table 6.9.

Table 6.9 Sample descriptive statistics for urban two-lane undivided arterial segments

Description	Average	Min.	Max.	Std. Dev.
AADT (2012 to 2014)	5,232	450	15,762	3,685
Length	0.75	0.25	2.04	0.34
No. of Major Commercial Driveways	0.05	0.00	2.00	0.28
No. of Minor Commercial Driveways	2.51	0.00	31.00	5.36
No. of Major Industrial/Institutional Driveways	1.00	0.00	10.00	1.98
No. of Minor Industrial/Institutional Driveways	7.28	0.00	30.00	8.10
No. of Major Residential Driveways	0.28	0.00	9.00	1.20
No. of Minor Residential Driveways	9.93	0.00	48.00	9.48
Proportion of Right Curb Length with Parking	0.00	0.00	0.08	0.01
Offset to Fixed Objects (ft)	20.20	5.00	30.00	7.71
Fixed Object Density (per mi)	48.64	13.10	98.40	20.18
No. of Observed Crashes	4.87	0.00	40.00	6.85
Description				**No. of Segments**
All Samples				75
Speed Category = Low				14
Speed Category = Intermediate/High				61
Presence of Street Lighting				50
Presence of Automated Speed Enforcement				0

The average AADT was 5,232 vehicles per day (vpd), and the standard deviation was 3,685 vpd. Thus, the sample set contained a wide range of AADT values. The average segment length was 0.75 mi, which was greater than the minimum segment length of 0.25 mi. The most common driveway types for the sample set were minor residential driveways, minor industrial/institutional driveways, and minor commercial driveways. The presence of parking on these segments was not common. The average offset to fixed objects was 20.20 ft, and the average fixed object density was 48.635 fixed objects per mile. The standard deviation of the fixed object density was 20.18 fixed objects per mile, indicating that segments had a wide variation in fixed object density. Fifty sites out of the 75 segments had lighting. None of the segments had automated speed enforcement. Only 14 of the segments fell under the low speed category. The average number of crashes was 4.87. The standard deviation for the number of crashes was 6.85, indicating that the number of crashes on these segments varied considerably. The total number of crashes on these segments from 2012 to 2014 was 349 (116.33 per year), which was greater than the standard of 100 crashes per year recommended by the HSM.

6.5.2 Summary Statistics for Urban Four-Lane Divided Arterial Segments

Descriptive statistics for urban four-lane divided arterial segments are shown in Table 6.10.

Table 6.10 Sample descriptive statistics for urban four-lane divided arterial segments

Description	Average	Min.	Max.	Std. Dev.
AADT (2014)	19,880	5,418	51,640	11,230
Length	0.57	0.26	2.06	0.31
No. of Major Commercial Driveways	0.3	0.0	11.0	1.4
No. of Minor Commercial Driveways	0.4	0.0	4.0	0.9
No. of Major Industrial/Institutional Driveways	0.3	0.0	4.0	0.8
No. of Minor Industrial/Institutional Driveways	0.3	0.0	8.0	1.1
No. of Major Residential Driveways	0.1	0.0	1.0	0.3
No. of Minor Residential Driveways	1.3	0.0	36.0	4.7
No. of Other Driveways	0.2	0.0	3.0	0.6
Proportion of Right Curb Length with Parking	0.00	0.00	0.00	0.00
Proportion of Left Curb Length with Parking	0.00	0.00	0.00	0.00
Offset to Fixed Objects (ft)	55.5	0.0	120	29.6
Fixed Object Density (per mi)	23.1	0.0	76.1	18.5
Number of Crashes	6.3	0.0	35.0	6.9
Description				**No. of Segments**
All Samples				66
Speed Category = Low				0
Parking Type (Right) = Parallel				1
Parking Type (Left) = Parallel				0
Land Use (Right) = Residential				1
Land Use (Left) = Residential				0
Presence of Lighting				7
Presence of Automated Speed Enforcement				0

The average AADT was 19,880 vpd, meaning that the average urban four-lane AADT was around two-and-a-half times that of the urban two-lane. The standard deviation was 11,230 vpd. Therefore, the sample set contained a wide range of AADT values. The average segment length was 0.57 mi. The segments in the sample set did not contain many driveways. Minor commercial driveways were the most common driveway type for the sample set. None of the segments had parking or automated speed enforcement. The average offset to fixed objects was 55.5 ft, and the average fixed object density was 23.1 fixed objects per mile. The four-lane offset was approximately 2.6 times longer than that of the two-lane, but the density was only 37% of the two-lane. The standard deviation of the fixed object density was 18.5 fixed objects per mile, indicating that the segments displayed a wide variability in fixed object density. As with two-lane segments, residential land use was slightly more prevalent than commercial land use. Lighting was present on 12 of the segments. None of the segments fell under the low speed category. The average number of crashes was 6.3. The standard deviation for the number of crashes was 6.9, indicating that the number of crashes on these segments varied considerably. The total number of crashes on these segments from 2012 to 2014 was 567 (189 per year), which was greater than the standard 100 crashes per year recommended by the HSM.

6.5.3. Summary Statistics for Urban Five-Lane Undivided Arterial Segments

Descriptive statistics for urban five-lane undivided arterial segments are shown in Table 6.11.

Table 6.11 Sample descriptive statistics for urban five-lane undivided arterial segments

Description	Average	Min.	Max.	Std. Dev.
AADT (2012 to 2014)	15,613	3,622	32,058	5,823
Segment Length	0.58	0.25	2.23	0.38
No. of Major Commercial Driveways	1.80	0	10	2.31
No. of Minor Commercial Driveways	11.81	0	42	10.00
No. of Major Industrial/Institutional Driveways	0.69	0	10	1.58
No. of Minor Industrial/Institutional Driveways	1.24	0	7	1.73
No. of Major Residential Driveways	0.17	0	4	0.62
No. of Minor Residential Driveways	3.29	0	33	6.25
Proportion of Right Curb Length with Parking	0.00	0	0	0.00
Proportion of Left Curb Length with Parking	0.00	0	0	0.00
Offset to Fixed Objects (ft)	20.04	0	43.86	8.37
Fixed Object Density (per mi)	38.94	0	151.39	24.96
No. of Observed Crashes	12.22	0	88	16.66
Description				**No. of Segments**
All Samples				59
Speed Category = Low				1
Speed Category = Intermediate/High				58
Presence of Street Lighting				53
Presence of Automated Speed Enforcement				0

The AADT data had an average of 15,613 vpd, minimum of 3,622 vpd, maximum of 32,058, and standard deviation of 5,823 vpd. Thus, the sample set of AADT values was slightly skewed towards the higher values. The average segment length was 0.58 mi, and all segments met the minimum segment length criteria of 0.25 mi. The most common driveway types for the sample set were minor commercial driveways and minor residential driveways. None of the sites contained any curbside parking facilities. The average fixed object density was 38.94 fixed objects per mile at an average offset of 20.04 ft. The standard deviation of the fixed object density was 24.96 fixed objects per mile, indicating that the presence of fixed objects varied widely across the samples. Fifty-three sites of the 59 segments contained street lighting. None of the segments had automated speed enforcement. Only one of the segments was classified in the low speed category. The average number of crashes was 12.22 with a standard deviation of 16.66, indicating that the number of crashes on these segments varied considerably. The total number of crashes across all segments from 2012 to 2014 was 721 (240.33 per year), which was greater than the standard of 100 crashes per year recommended by the HSM.

6.6 Results and Discussion

The original HSM models were developed using data from Minnesota, Michigan, and Washington. The data from Minnesota and Michigan were used to develop the HSM methodology, while the data from Washington were used in validating the methodology (Harwood et al. 2007). The database used for urban and suburban segment model development was divided into individual blocks, where each block began and ended at a public intersection of the arterial segment being studied. The database included 4,255 blocks: 2,436 in Minnesota and 1,819 in Michigan. Blocks ranged in length from 0.04 to 1.42 mi. The total length of all blocks was 553.3 mi: 303.9 mi from Minnesota with an average block length of 0.12 mi, and 294.4 mi from Michigan with an average block length of 0.14 mi. Most of the data collected from Minnesota came from the Twin Cities metropolitan area, while the data collected in Michigan were primarily from Oakland County, Michigan. Even though these states are located in the northern part of the country, data were collected at a variety of sites to develop a database that should reflect national design and behavior.

6.6.1 Results for Urban Two-Lane Undivided Arterial Segments

6.6.1.1 Calibration Factor

The calibration factor for urban two-lane undivided arterial segments in Missouri yielded a value of 1.48. The IHSDM output is shown in Figure 6.13, and a summary of crash prediction versus observation by sites is presented in Table 6.12.

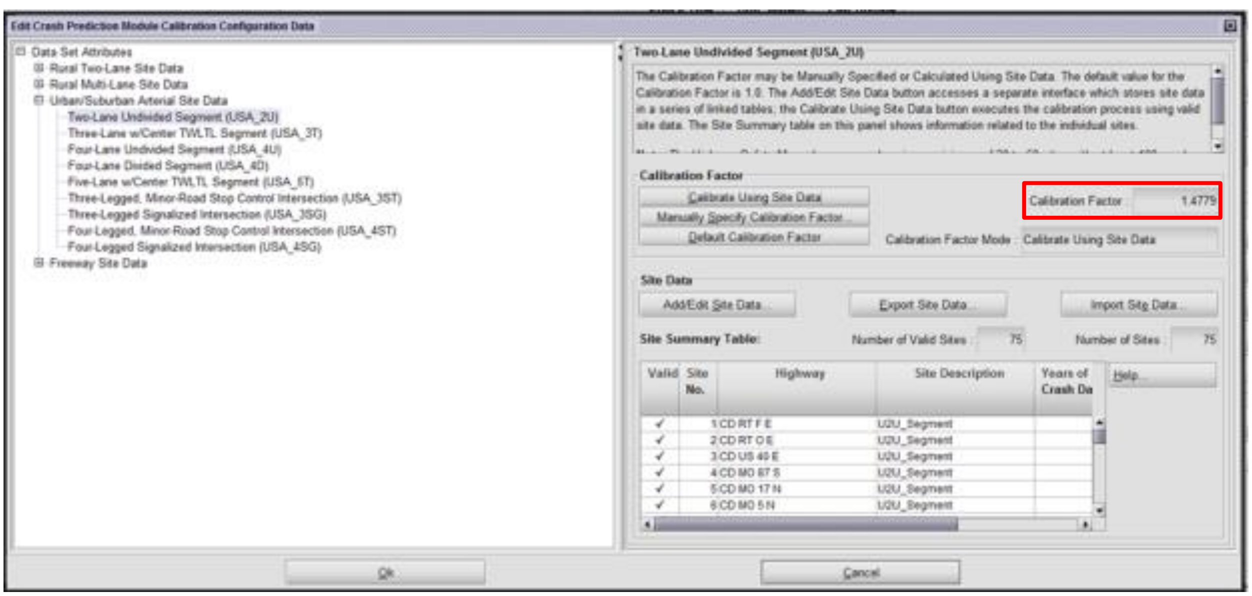

Figure 6.13 Calibration output for urban two-lane undivided arterial segments

Table 6.12 Calibration results for urban two-lane undivided arterial segments

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
1	CD	RT F E	7.58	1.45	11	5
2	CD	RT O E	0.25	0.68	5	5
3	CD	US 40 E	105.74	0.40	1	4
4	CD	MO 87 S	22.69	0.59	2	2
5	CD	MO 17 N	136.31	0.55	24	4
6	CD	MO 5 N	210.76	0.85	1	2
7	CD	RT B N	23.39	0.71	4	4
8	CD	RT J E	1.03	0.74	0	3
9	CD	RT HH S	0.00	0.45	3	0
10	CD	BU 54 E	4.48	0.38	12	2
11	CD	MO 87 S	75.57	0.40	2	2
12	KC	US 50 E	83.46	1.05	10	7
13	KC	MO 240	0.65	0.81	0	2
14	KC	US 65 N	194.14	0.64	2	2
15	KC	RT WW E	0.70	0.95	0	0
16	KC	RT WW W	2.78	0.61	0	1
17	KC	BU 65 S	2.27	0.25	0	3
18	KC	SP 10 E	0.07	0.53	0	1
19	KC	RT F S	2.07	0.42	4	2
20	KC	RT N S	0.54	0.56	0	0
21	KC	RT F S	0.99	1.08	25	14
22	KC	US 50 E	82.50	0.83	10	6
23	NE	MO 15 N	2.38	0.37	4	3
24	NE	MO 15 N	2.87	0.35	6	4
25	NE	MO 22 E	22.96	0.90	4	3
26	NE	MO 161	0.46	0.61	9	4
27	NE	RT M W	23.71	1.02	6	3
28	NE	BU 61 S	1.96	0.50	2	2
29	NE	RT J S	0.63	0.80	7	2
30	NE	BU 63 N	5.29	1.01	12	5
31	NE	RT P E	0.24	0.43	0	1
32	NE	RT B S	11.69	0.89	0	1
33	NW	BU 36 W	0.59	0.81	3	2
34	NW	RT V N	0.59	0.40	0	0
35	NW	MO 6 E	79.82	0.64	1	1
36	NW	BU 71 N	3.23	1.18	4	2
37	NW	US 69 S	67.65	0.34	0	1
38	NW	MO 46 E	27.11	0.34	0	2
39	NW	RT AA N	0.00	0.57	1	1
40	NW	RT A N	15.78	0.51	0	1
41	NW	RT V E	11.75	0.43	0	1

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
42	SE	RT W S	5.89	1.30	7	2
43	SE	RT W S	7.68	0.79	3	1
44	SE	RT W S	8.97	0.59	2	2
45	SE	RT B S	0.08	0.37	3	3
46	SE	US 62 E	62.72	0.52	1	2
47	SE	RT PP S	0.06	0.97	4	2
48	SE	MO 8 E	70.74	0.42	0	5
49	SE	MO 51 S	15.20	0.34	1	3
50	SE	RT J E	10.94	0.48	0	1
51	SE	RT AB W	4.08	1.65	10	2
52	SE	MO 114	0.28	0.50	0	1
53	SE	RT E E	0.16	2.04	5	8
54	SL	RT E N	14.83	1.09	5	4
55	SL	MO 47 N	49.14	0.69	12	6
56	SL	MO 185	37.12	0.59	4	1
57	SL	MO 185	30.24	0.61	2	2
58	SL	RT NN N	0.07	1.06	5	1
59	SL	MO 47 S	65.02	1.64	40	21
60	SL	MO 47 N	47.14	0.44	13	5
61	SL	RT D S	0.64	0.68	0	1
62	SL	RT D S	1.42	1.00	1	0
63	SW	RT BB S	0.03	1.34	19	3
64	SW	BU 65 N	1.30	0.55	5	7
65	SW	BU 65 N	2.02	0.34	2	3
66	SW	BU 60 E	6.51	0.73	2	3
67	SW	US 160	177.11	0.83	13	16
68	SW	US 160	178.19	0.89	17	11
69	SW	BU 60 E	4.80	0.86	1	2
70	SW	RT CC S	16.61	0.88	1	2
71	SW	RT CC N	0.11	0.63	2	2
72	SW	BU 13 S	0.12	0.98	5	7
73	SW	RT BB S	0.08	0.82	2	2
74	SW	RT BB S	0.95	0.60	0	1
75	SW	MO 96 E	14.92	0.88	3	3
Sum					**365**	**247**
Calibration Factor					**1.478**	

These results indicate that the number of crashes observed in Missouri was higher than the number of crashes predicted by the HSM for this site type. The result of the recalibration in this project is different than the previous calibration performed for the period of 2009 to 2012. The previous calibration factor was 0.84. The main differences were attributed to the crash data processing, fixed objects count, and AADTs. The previous calibration removed all crashes that had intersection identification. Some major driveways have intersection identification numbers (not minor road stop or signalized intersections), so these driveway-related crashes were removed in the previous calibration, reducing the number of observed crashes. In the previous calibration, fixed objects were counted using the ARAN viewer, which was not ideal because image frames are skipped on a regular basis and many sections are not visualized. This issue was solved by using Google Street View along the segments for the recalibration. In addition, light posts along segments generally were without breakaway because the lighting was installed on wood posts. Another difference in data collection was the AADTs. The AADTs were previously collected from the State of the System in TMS, which resulted in higher AADTs (on average 400 vpd). For the recalibration, the AADTs were collected through open database connectivity (ODBC) using TMS intersection node numbers along the segments. Thus, the AADT values were improved from the previous calibration.

6.6.1.2 Severity Distribution Factors

Using the data from the calibration, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 6.13 shows the SDFs for urban two-lane undivided segments.

Table 6.13 Severity distribution factors urban two-lane undivided arterial segments

Severity	MV		SV	
	Crashes	**SDF**	**Crashes**	**SDF**
Fatal	3	0.023	1	0.008
Disabling Injury	3	0.023	2	0.015
Minor Injury	34	0.258	53	0.402
Property Damage Only	92	0.697	178	1.348

6.6.1.3 Crash Type Distribution Factors

The CDFs were used to determine the proportion of predicted crashes according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because Missouri crash types categories differed from those of the HSM. Therefore, different categories were aggregated to provide similar classifications to those recommended by the HSM. The crash types were estimated for all severities only. Table 6.14 provides the CDFs for two-lane undivided arterials based on the classification of crash types in Missouri.

Table 6.14 Crash type distribution factors for urban two-lane undivided arterial segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Rear-end	147	0.665
Head-on	9	0.041
Angle	45	0.204
Sideswipe	13	0.059
Other	7	0.032
Single-Vehicle		
Collision with Animal	34	0.248
Collision with Fixed Object	5	0.036
Collision with Parked Vehicle	5	0.036
Out of Control	83	0.606
Other	10	0.073

6.6.2 Results for Urban Four-Lane Divided Arterial Segments

6.6.2.1 Calibration Factor

The calibration factor for urban four-lane divided arterial segments in Missouri yielded a calibration factor value of 0.91. The IHSDM output is shown in Figure 6.14, and the summary of crash prediction versus observation by sites is presented in Table 6.15. These results indicated that the number of crashes observed in Missouri was fairly consistent with the number of crashes predicted for this site type by the HSM.

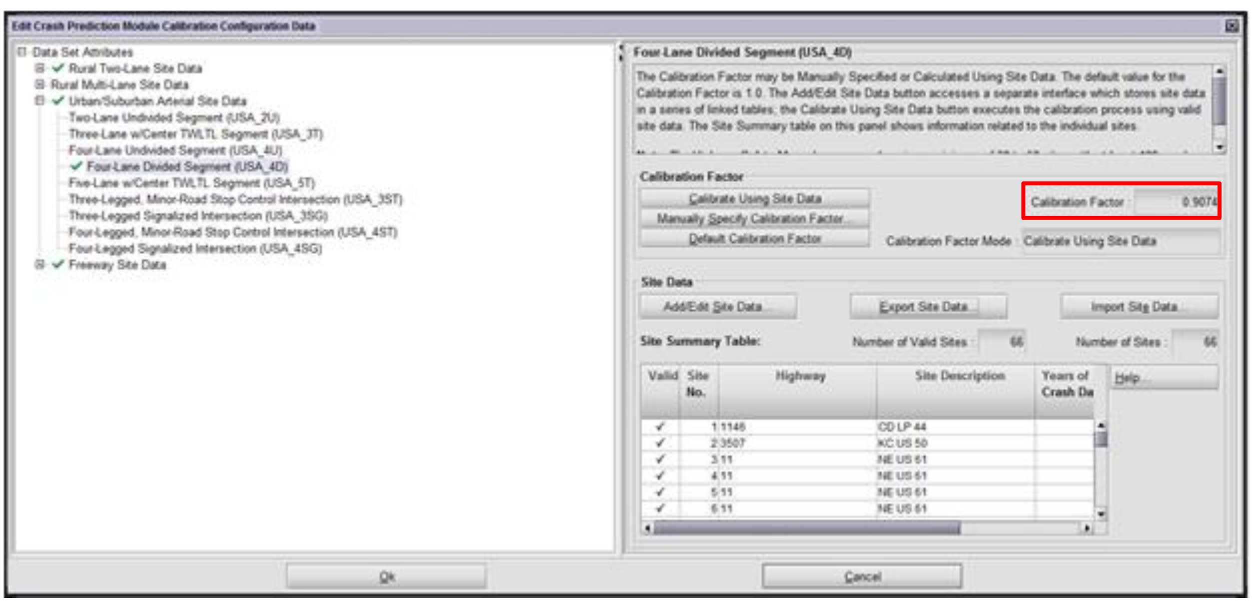

Figure 6.14 Calibration output for urban four-lane divided arterial segments

Table 6.15 Calibration results for urban four-lane divided arterial segments

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
1	CD	LP 44 E	7.621	0.301	15	4.18
2	KC	US 50 E	61.261	0.442	2	2.68
3	KC	MO 291 S	14.894	0.573	4	5.07
4	KC	MO 291 S	16.855	0.268	3	6.58
5	KC	MO 291 S	17.27	0.309	1	7.03
6	KC	MO 291 S	19.769	0.44	22	18.15
7	KC	US 69 N	8.379	0.267	0	1.34
8	KC	US 40 E	15.48	0.365	5	4.6
9	NE	US 61 S	63.954	0.664	6	6.84
10	NE	US 61 S	88.81	0.38	1	2.04
11	NE	US 61 S	120.253	0.49	1	5.03
12	NE	US 61 S	123.471	0.591	8	12.21
13	NE	US 63 N	252.775	0.575	3	3.81
14	NE	US 63 N	250.748	0.733	6	5.18
15	NE	US 36 E	131.644	0.873	6	3.04
16	NW	US 36 E	71.99	0.42	0	2.09
17	NW	US 36 E	73.31	0.495	6	2.07
18	SE	US 61 S	285.517	0.484	13	4.76
19	SE	US 67 N	99.496	0.475	2	2.87
20	SE	US 67 N	106.811	0.407	13	5.22
21	SE	US 67 N	108.169	0.82	9	11.33
22	SE	US 67 N	109.589	2.061	35	26.98
23	SE	MO 25 S	47.771	0.359	1	1.3
24	SE	MO 25 S	49.02	0.404	7	2.19
25	SE	MO 34 E	101.253	0.789	3	9.75
26	SE	MO 34 E	102.271	0.361	3	3.62
27	SE	MO 74 E	7.777	0.417	2	2.25
28	SE	MO 32 E	247.211	0.812	1	2.26
29	SE	MO 232 E	248.783	0.92	2	4.63
30	SE	MO 32 E	254.376	0.256	9	3.43
31	SE	MO 412 W	25.952	0.4	2	2.09
32	SE	US 61 N	101.358	0.631	4	4
33	SE	US 60 E	290.883	0.913	2	4.85
34	SE	US 60 E	314.489	1.391	5	9.34
35	SE	US 60 E	316.203	0.335	1	1.43
36	SE	BU 67 S	4.698	0.316	5	2.27
37	SL	MO 30 E	21.023	0.665	1	4.25
38	SL	MO 30 E	22.262	0.355	4	3.81
39	SL	MO 30 E	22.792	0.303	1	3.25
40	SL	MO 30 E	23.472	0.311	5	3.25
41	SL	MO 30 E	24.618	0.709	0	7.35
42	SL	MO 30 E	25.481	0.953	6	10
43	SL	MO 30 E	26.957	0.373	4	3.76
44	SL	MO 30 E	28.029	1.23	3	18.36
45	SL	MO 30 E	30.177	0.322	1	4.56

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
46	SL	MO 30 E	31.566	0.5	6	14.02
47	SL	MO 30 E	32.333	0.536	11	13.28
48	SL	MO 30 E	33.583	0.545	9	13.5
49	SL	MO 30 E	39.982	0.367	13	12.86
50	SL	MO 30 E	41.108	0.258	3	4.52
51	SL	MO 94 E	100.682	0.439	13	12.76
52	SL	MO 94 E	101.316	0.702	33	21.44
53	SL	MO 141 S	29.281	0.619	7	12.81
54	SL	MO 141 S	28.206	0.728	13	14.01
55	SL	MO 141 S	27.515	0.441	9	9.31
56	SL	MO 141 S	26.025	0.432	13	9.57
57	SL	MO 141 S	24.662	0.598	11	13.06
58	SL	CST MIDLAND BLVD E	2.931	0.473	1	2.95
59	SW	MO 13 S	147.266	0.478	1	3.17
60	SW	RT D E	0.183	1.082	4	2.96
61	SW	MO 59 S	19.655	0.276	3	1.28
62	SW	MO 59 S	20.067	0.633	0	4.08
63	SW	MO 59 S	21.45	0.8	2	3.64
64	SW	MO 59 S	22.37	0.397	1	1.78
65	SW	US 60 E	75.702	0.937	15	13.01
66	SW	US 60 E	77.122	0.277	2	4.99
Sum					403	444.1
Calibration Factor					0.907453276	

6.6.2.2 Severity Distribution Factors

Using the data from the calibration, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 6.16 shows the SDFs obtained for urban four-lane divided segments.

Table 6.16 Severity distribution factors for urban four-lane divided segments

Severity	MV		SV	
	Crashes	SDF	Crashes	SDF
Fatal	0	0	7	0.042
Disabling Injury	9	0.038	6	0.036
Minor Injury	65	0.273	36	0.218
Property Damage Only	164	0.689	116	0.703

6.6.2.3 Crash Type Distribution Factors

The CDFs are used to determine the proportion of crashes from the prediction according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because there are multiple crash type categories. Therefore, different categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were also divided into multiple- and single-vehicle crashes. Table 6.17 shows the CDFs for urban four-lane divided segments.

Table 6.17 Crash type distribution factors for urban four-lane divided segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Rear-end	161	0.399
Head-on	2	0.005
Angle	12	0.029
Sideswipe	43	0.107
Other	16	0.039
Single-Vehicle		
Collision with Animal	47	0.117
Collision with Fixed Object	3	0.007
Collision with Parked Vehicle	4	0.009
Out of Control	85	0.211
Other	30	0.074

6.6.3 Results for Urban Five-Lane Undivided Arterial Segments

6.6.3.1 Calibration Factor

The calibration factor for urban five-lane undivided arterial segments in Missouri yielded a value of 0.84. The IHSDM output is shown in Figure 6.15, and the summary of crash prediction versus observation by site is presented in Table 6.18.

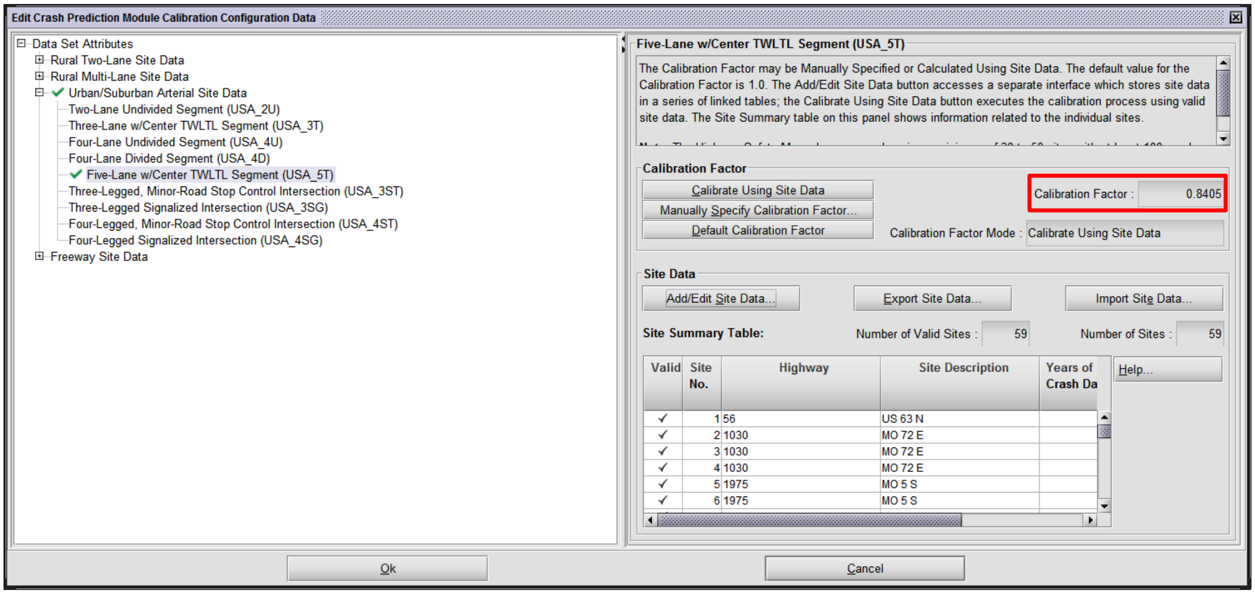

Figure 6.15 Calibration output for urban five-lane undivided arterial segments

Table 6.18 Calibration results for five-lane undivided arterial segments

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	Predicted
1	CD	US 63 N	123.10	1.08	33	40
2	CD	MO 72 E	0.08	0.50	4	11
3	CD	MO 72 E	0.59	1.16	15	24
4	CD	MO 72 E	1.75	0.59	1	6
5	CD	MO 5 S	248.31	0.75	8	14
6	CD	MO 5 S	249.06	0.48	2	7
7	CD	MO 5 S	249.54	0.47	4	10
8	CD	MO 5 S	250.64	0.26	5	9
9	CD	MO 5 S	251.01	0.50	34	29
10	CD	MO 5 S	251.83	0.31	5	10
11	CD	LP 44 E	0.29	0.88	4	14
12	CD	LP 44 E	1.17	0.70	2	12
13	CD	LP 44 E	2.59	0.42	0	6
14	KC	US 65 S	150.28	0.92	48	30
15	KC	US 65 S	151.20	0.91	29	30
16	KC	US 50 E	77.78	0.42	41	10
17	KC	US 50 E	78.55	0.25	16	15
18	KC	US 50 E	79.16	0.38	0	10
19	KC	US 50 E	80.66	0.31	1	8
20	KC	US 50 E	81.09	0.29	1	6
21	KC	US 50 E	81.38	0.63	0	11
22	KC	MO 58 E	6.55	0.47	2	8
23	NW	US 65 S	55.50	1.18	3	6
24	NW	US 65 S	56.69	0.63	3	9
25	NW	US 65 S	57.68	0.48	5	10
26	NW	US 65 S	58.75	0.28	0	9
27	NW	US 65 S	59.02	0.70	9	25
28	NW	US 69 N	55.80	0.29	1	7
29	SE	US 63 N	30.34	0.58	2	11
30	SE	US 63 N	30.93	2.23	6	49
31	SE	BU 67 S	3.90	0.37	13	15
32	SE	BU 60 W	5.45	0.26	39	13
33	SE	BU 60 W	5.71	0.69	88	20
34	SE	BU 60 W	6.40	0.66	31	23
35	SE	MO 32 E	254.84	0.40	8	18
36	SE	MO 32 E	255.43	0.58	5	16
37	SE	MO 32 E	256.01	0.25	1	5
38	SE	MO 32 E	256.26	0.30	4	6
39	SL	LP 44 E	3.08	0.33	4	6
40	SL	US 67 N	137.18	0.38	7	13
41	SL	MO 47 S	70.65	0.31	7	5

No.	District	Segment	Begin Log	Length (mi)	All Crashes	
					Observed	**Predicted**
42	SL	US 50 E	216.15	0.76	7	23
43	SL	US 50 E	215.67	0.48	8	15
44	SW	MO 7 N	107.24	0.25	28	6
45	SW	MO 7 N	111.01	0.74	3	12
46	SW	MO 96 E	13.44	0.25	4	7
47	SW	US 54 E	14.07	0.42	6	9
48	SW	MO 376 W	0.00	1.00	11	7
49	SW	MO 86 W	91.45	1.50	13	26
50	SW	MO 248 E	53.90	1.66	59	49
51	SW	BU 65 S	3.31	0.44	3	5
52	SW	US 60 E	72.62	0.45	6	18
53	SW	US 60 E	71.98	0.47	3	17
54	NE	US 61 S	60.76	0.27	24	13
55	NE	US 61 S	60.05	0.44	25	18
56	NE	US 24 E	135.46	0.34	19	8
57	NE	MO 47 S	33.69	0.35	2	11
58	NE	BU 63 N	7.51	0.83	3	26
59	NE	US 24 E	136.07	0.25	6	5
Sum					**721**	**858**
Calibration Factor					**0.841**	

These results indicated that the number of crashes observed in Missouri was lower than the number of crashes predicted by the HSM for this facility type. The result of the recalibration in this project was different from the previous calibration performed for the period of 2009 to 2012. The previous calibration factor was 0.73. The main differences were attributed to crash data processing, fixed object offset and density, and segment AADTs. The previous calibration removed all crashes that had intersection identification. TMS designates some larger driveways with intersection node identification numbers (some that are stop-controlled and others that are signalized). All intersection crashes were removed in the previous calibration, reducing the number of observed crashes. The intersection nodes in each segment were analyzed, and crashes that were assigned to driveways were included in this calibration effort. In the previous calibration, fixed objects were counted using ARAN viewer, which may not have provided an accurate representation because the viewer can skip several frames along the segment. This issue was solved by using Google Street View along each segment for the recalibration. Another difference in data collection was the AADTs. The AADTs were collected from the current State of the System feature in TMS and resulted in higher AADTs (286 vpd on average). For the recalibration, the AADTs were collected through ODBC using TMS intersection node numbers along the segments. Thus, the AADTs were more accurate than in the earlier calibration effort.

6.6.3.2 Severity Distribution Factors

Using the data from the calibration, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 6.19 shows the SDFs obtained for urban five-lane undivided arterial segments.

Table 6.19 Severity distribution factors for urban five-lane undivided arterial segments

	MV		SV	
Severity	**Crashes**	**SDF**	**Crashes**	**SDF**
Fatal	1	0.002	1	0.016
Disabling Injury	9	0.014	2	0.031
Minor Injury	177	0.269	20	0.313
Property Damage Only	470	0.715	41	0.641

6.6.3.3 Crash Type Distribution Factors

The CDFs were used to determine the proportion of predicted crashes according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because there are multiple crash type categories. Therefore, different categories were aggregated to provide similar classifications to those recommended by the HSM. The crash types were estimated for total crashes to correspond to the calibration factor severity. Table 6.20 provides the CDFs for five-lane undivided arterials based on the classification of crash types in Missouri.

Table 6.20 Crash type distribution factors for urban five-lane undivided arterial segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Rear-end	257	0.394
Head-on	20	0.031
Angle	252	0.386
Sideswipe	102	0.156
Other	22	0.034
Single-Vehicle		
Collision with Animal	9	0.132
Collision with Fixed Object	4	0.059
Collision with Parked Vehicle	4	0.059
Out of Control	43	0.632
Other	8	0.118

CHAPTER 7. FREEWAY SEGMENTS

7.1 Introduction and Scope

Freeway segments require data involving facility-specific population designations, geometric design, operations, protective devices, and surrounding land use. The prediction methodology for freeways appears in Chapter 18 of the HSM Supplement (Bonneson et al. 2012). This chapter contains a detailed description of the data requirements and the HSM prediction methodology for freeway segments. Because some of these freeway segment types are not common in Missouri, this calibration contains only the most relevant freeway types found across the state. New updated calibration factors were obtained for freeway segments for four-lane rural, four-lane urban, and six-lane urban freeway segments.

7.2 Calibration Data Requirements

The IHSDM input data were divided into required and desired data. The required data consisted of site, crash, and traffic data. The desired data were optional and included variables such as inside/outside rumble strips, clear zone, and geometric curve data.

7.2.1. Required Site Data

7.2.1.1. Area Type

The classification of areas depends on the roadway characteristics, surrounding population, and land use. Based on the FHWA guidelines, the HSM defines urban areas as regions with population greater than 5,000 people. Rural areas are designated as regions outside urban areas with a population fewer than 5,000 people. Although the terms metropolitan, urbanized, or suburban refer to urban subcategories, the HSM does not make a distinction among these subgroups and considers all as urban (AASHTO 2010). MoDOT uses the same area classification.

7.2.1.2 Number of Through Lanes

IHSDM calibration requires the total number of through lanes in both directions for urban freeway segments. Add and drop lanes are considered as through lanes after the downstream taper. Figure 7.1 shows an example of through lane counting with add and drop lanes.

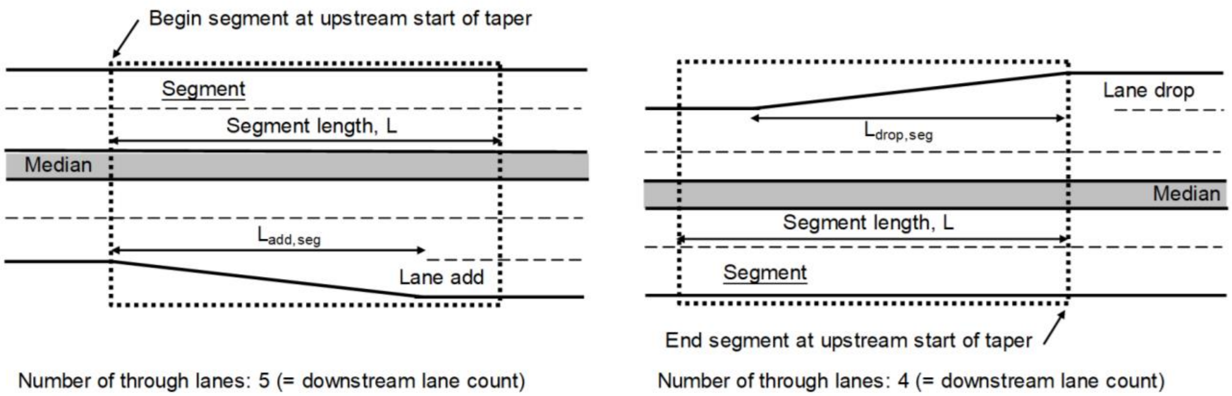

Figure 7.1 Freeway through lanes count with add and drop lanes

If an auxiliary lane exceeded 4,500 ft, the auxiliary lane was treated as a through lane. If an entrance speed change lane exceeded 1,600 ft, the speed change lane was treated as a through lane that began at the ramp entrance gore point and ended at the taper (the same applies to exit speed change lanes) (AASHTO 2010).

7.2.1.3 Segment Length

The segment length is the distance from the beginning to the end of a freeway segment, including the different components that may be part of the segment such as speed change lanes, add and drop lanes, and auxiliary lanes, if they meet the previously mentioned criteria. The units used for the segment length are in miles. No rural or urban four-lane freeway segment sampled was shorter than 0.5 mi. Seven of the 54 urban six-lane freeway segments were slightly shorter than 0.5 mi.

7.2.1.4 Effective Segment Length

The effective segment length is the segment length without the speed change lanes in miles. Figure 7.2 shows how freeway segments are treated within interchanges.

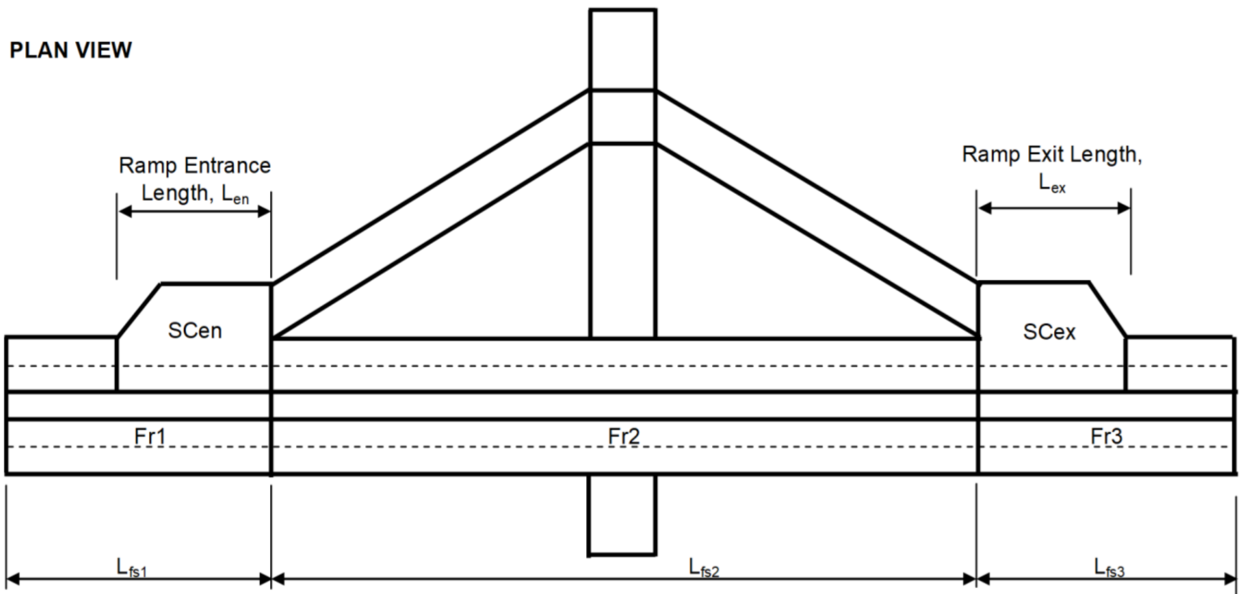

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Figure 7.2 Illustration of segment length with speed change lanes

In Figure 7.2, the segment length is equal to $L_{fs1} + L_{fs2} + L_{fs3}$. Figure 7.2 contains one exit and one entrance speed change lane in one direction of travel of the freeway segment. Thus, the effective length is the total segment minus the speed change lane distance from gore to taper point—note that the speed change lane distances are divided by two to create a homogenous segment in both directions (AASHTO 2010). Figure 7.3 illustrates the process of segmentation and calculation of the effective length.

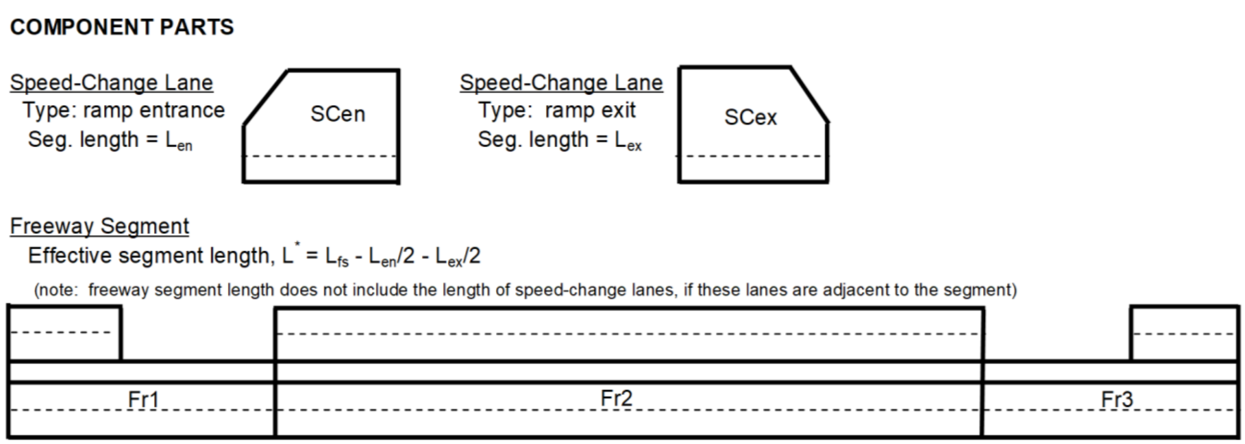

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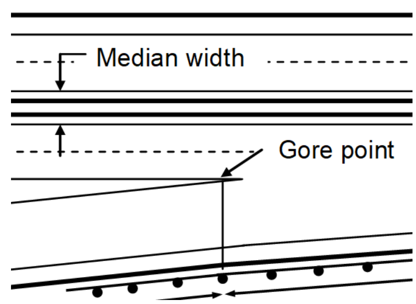
Figure 7.3 Effective segment length example

7.2.1.5 Average Lane Width

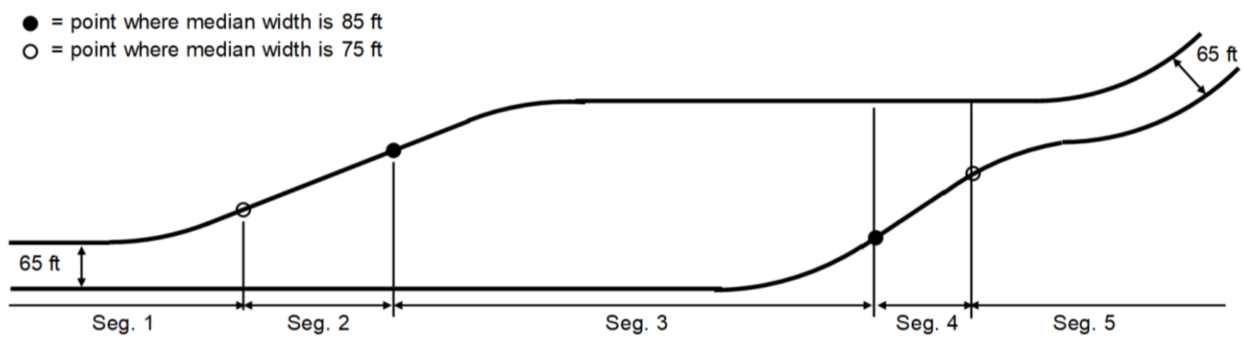
The average lane width is computed by measuring the lane width at different points throughout the freeway segment to compute the average. If necessary, the average lane width is rounded to the nearest 0.5 ft. If there are significant changes in lane width throughout the segment, it should be divided into separate freeway segments (AASHTO 2010).

7.2.1.6 Effective Median Width

The effective median width is the distance between the inside edges of the travelway in both directions (in ft). The edge of the travelway for median width determination is the left edge in each direction of travel. Thus, the effective median includes the inside shoulders. This distance should be measured at different points in the segment to compute the average. Figure 7.4(a) illustrates how to measure the median width. If there are significant changes in the effective median width, the segment should be divided into separate segments (AASHTO 2010). Figure 7.4(b) shows an example of a freeway segment divided into five different segments due to the variations in median width.



(a) Median width



(b) Median width variation and segmentation

Figure 7.4 Median width and variations

7.2.1.7 Proportion of Segment Length with Median Barrier

The length of a barrier is measured along a reference line (in one direction). If the median barrier is present along the entire segment (i.e., cable or concrete), the proportion of the segment with a median barrier is equal to one. When a protective barrier is present along part of the segment, each barrier element should be measured following the reference line. The proportion of the segment with the protective median barrier is then calculated, and it should fall between 0 and 1. If no median barrier is present, the proportion is equal to 0. Therefore, the proportion of segment with a median barrier must have a value between 0 and 1.

7.2.1.8 Average Median Barrier Offset

The offset is measured from the nearest edge of the travelway (including inside shoulder) to the face of the barrier along the reference line (in feet). There may be different barrier components along the segment with different offset lengths, so the average is appropriate when there are not overlapping barriers in the median in both directions of travel (i.e., bridge columns). Figure 7.5 illustrates a case in which barriers in both directions overlap and shows how they can be categorized.

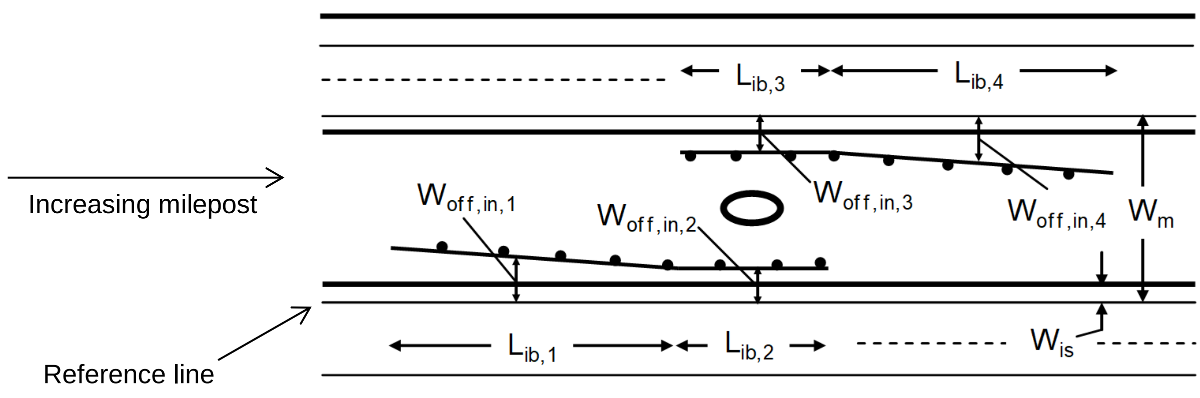


Figure 7.5 Median barrier length and offset

7.2.1.9 Proportion of Segment Length with Outside Barrier

A barrier on the roadside is noted if the offset from the near edge of the travelway is 30 ft or less. The proportion is calculated similarly to the inside median barrier proportion. The proportion should be equal to 1 if the roadside barrier is along the entire segment and 0 when it is not present at all.

7.2.1.10 Average Outside Barrier Offset

The offset of outside barriers is measured from the outside edge of the travelway along the reference line in feet. Because there may be different sections of the segment with outside barriers, the offset distance should be measured at different points along the segment to obtain an average outside barrier offset.

7.2.1.11 Average Inside/Outside Shoulder Width

IHSDM methodology requires both inside and outside shoulder widths. Only paved shoulders (inside and outside) in both directions should be considered. The width of both inside and outside shoulders should be measured throughout the segment and averaged (in feet). The width should be measured for sections in which the width is constant. If the shoulder width varies significantly along the segments, a weighted average of the widths should be computed.

7.2.1.12 Type B Weaving Section Characteristics

A Type B weaving section has the following defining characteristics (AASHTO 2010):

- One of the two weaving movements can be made without making any lane changes.
- The other weaving movement requires one lane change at most.
- Exit and entrance ramps associated with the weaving section are located on the right side of the road.

Figure 7.6 shows typical Type B weaving sections.

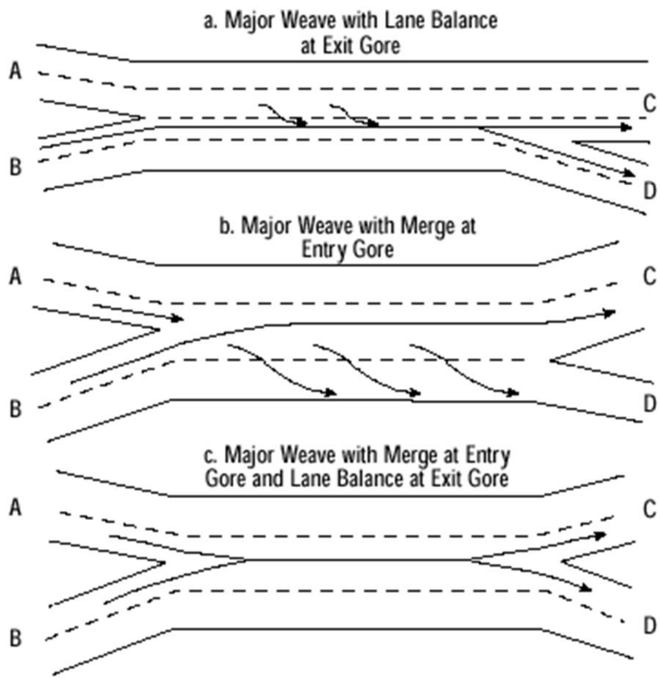
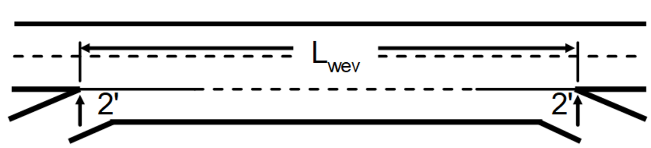


Figure 7.6 Typical Type B weaving sections

7.2.1.13 Length of Weaving Section

The length of a weaving section on the segment is measured along the edge of the travelway from the gore point of the exit ramp to the gore point of the entrance ramp in feet. This length is measured by direction of travel, so two measurements are made. The gore point is the location where the edge markings of the ramp and the freeway meet and are 2 ft apart. It should be noted that the weaving length might exceed the length of the segment under study, so the segment length should be considered as the boundary.

Figure 7.7 shows an example of a weaving section on the increasing milepost with an entrance ramp followed by an exit ramp.



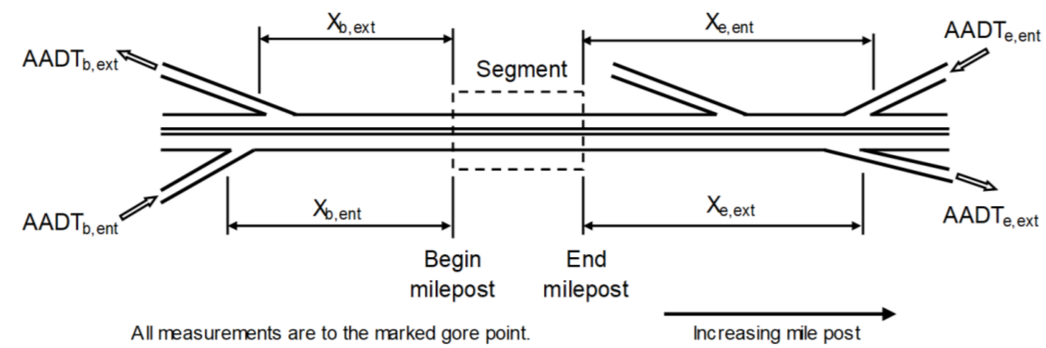
L_{wev} = weaving section length

Figure 7.7 Weaving section length

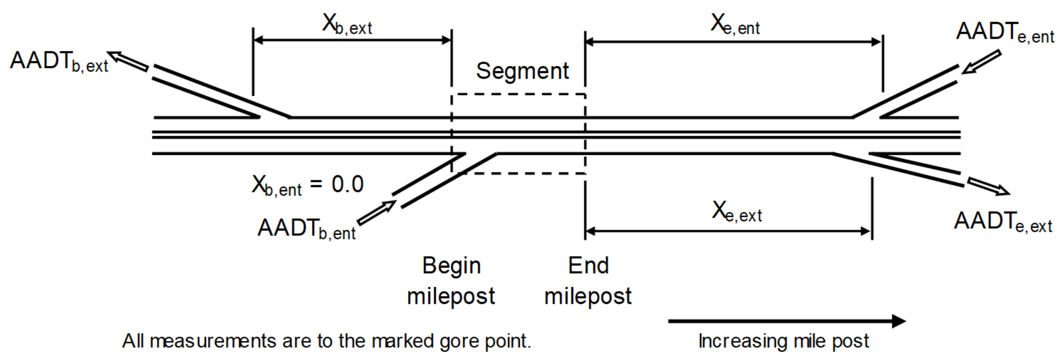
If the length of the weaving section exceeds 0.85 mi (4,500 ft), then the section should no longer be treated as a weaving section. Instead, add/drop lanes should be designated according to the situation (AASHTO 2010).

7.2.1.14 Distance from Segment Beginning/End to Ramps

The segment distances are measured in both directions of travel (increasing or decreasing milepost) and in feet. Figure 7.8(a) shows a segment with spacing to ramps. For the increasing milepost, the distance from the beginning of the segment to the upstream entrance ramp is measured ($X_{b,ent}$), and the distance from the end of the segment to the downstream exit ramp is measured ($X_{e,ext}$). For the decreasing milepost, the same criteria apply, keeping the designated beginning and end of the segment designation. Note that speed change lanes are treated as separate segments. For the entrance ramp, Figure 7.8(b) shows an add lane from the gore point of the entrance ramp to the taper. For the exit ramp, Figure 7.8(b) shows the speed change lane from the taper point to the gore point.



(a) Distances from a segment with spacing to ramps



(b) Distances from a segment starting at the gore point of an entrance ramp

Figure 7.8 Ramp AADTs and distances to beginning/end of segment

7.2.2 Required Crash and Traffic Data

7.2.2.1 Years of Crash Data

The years associated with the calibration need to be specified in IHSDM. The IHSDM considers up to three years of input data.

7.2.2.2 Observed Number of Crashes

Freeway-related crashes involve collisions occurring within the boundaries of a segment. Because freeways often contain speed change lanes near interchange facilities, it is important to distinguish the difference between speed change lane and freeway segment-related crashes. Figure 7.9 shows an example of crash assignment on freeways with speed change lanes. As illustrated in Figure 7.9, crashes within the taper and gore point of speed change lanes are considered speed change-related crashes (A), and crashes occurring outside these boundaries are freeway segment-related crashes (B). The assignment of crashes based on physical location was used as the crash landing criterion for simplicity.

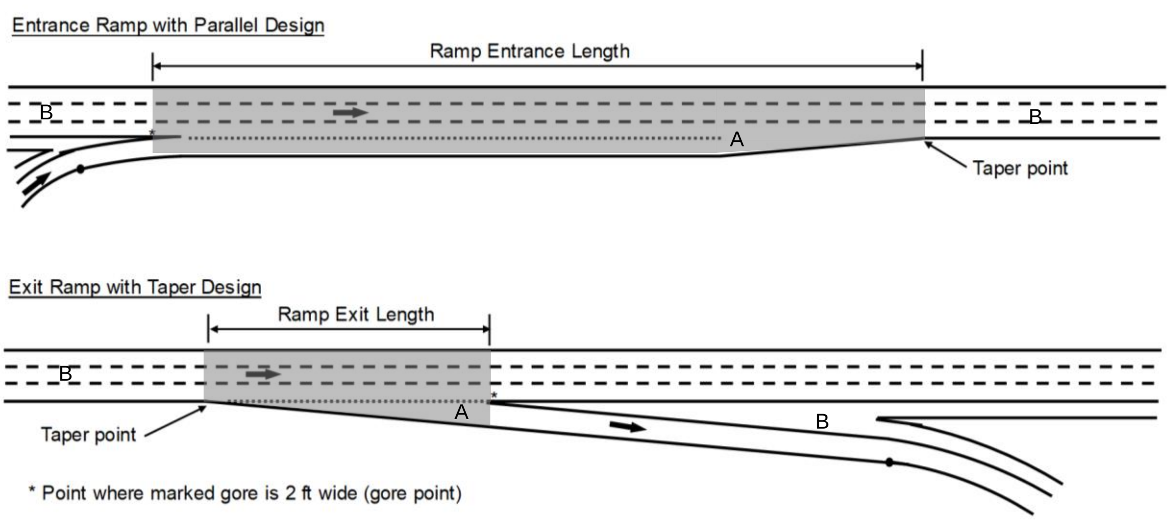


Figure 7.9 Freeway crashes assignment

In theory, with the criterion there could be speed change-related crashes that are incorrectly landed on mainline freeway segments. But, in practice, when the freeway segments were sampled, the interchange was avoided, so the crash landing problem was avoided in practice.

7.2.2.3 Freeway AADT

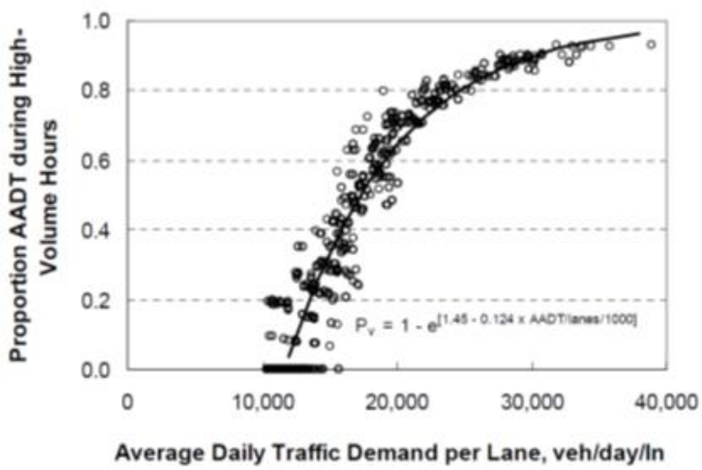
The total AADT in both directions should be collected for all years of analysis.

7.2.2.4 Ramps AADT

The AADT of the nearest ramps, both upstream and downstream of the freeway segment, should be collected for all years of analysis. Similar to Figure 7.8, the AADTs are designated based on the beginning/end of the segment and the increasing/decreasing milepost.

7.2.2.5 Proportion of High Volume

The proportion of high volume introduces the influence of volume concentration in crash frequency prediction. Past research shows that as volume nears capacity, average speed decreases and headway is reduced (Bonneson et al. 2012). Thus, these variations have some influence on freeway segment crashes. The IHSDM defines the proportion of high volume as the proportion of AADT during which the volume exceeds 1,000 vehicles per hour per lane (veh/h/ln). Using data from three different states, the proportion of volume statistic was modeled using regression (Bonneson et al. 2012). Figure 7.10 illustrates data and trend distribution. This CMF was not applied in the previous calibration.



Bonneson et al. 2012

Figure 7.10 Proportion of high volume estimate

7.2.3 Desired Data

7.2.3.1 Proportion of Inside/Outside Rumble Strips

The proportion of the length of freeway segment that contains rumble strips should be estimated. Rumble strips should be measured separately for each shoulder type and direction of travel. The proportion input value must be between 0 and 1.

7.2.3.2 Outside Clear Zone Width

The clear zone distance in feet is measured periodically along the length of the freeway segment from the roadside edge in both directions (including shoulder) to vertical obstructions such as non-traversable slopes, fences, or utility poles. Barriers are not considered within the analysis of clear zone width because they are covered independently in other CMFs. Also, isolated trees are not considered part of the clear zone. Figure 7.11 shows an example of clear zone width measurements of different roadside components. An average is recommended for different components located at different distances.

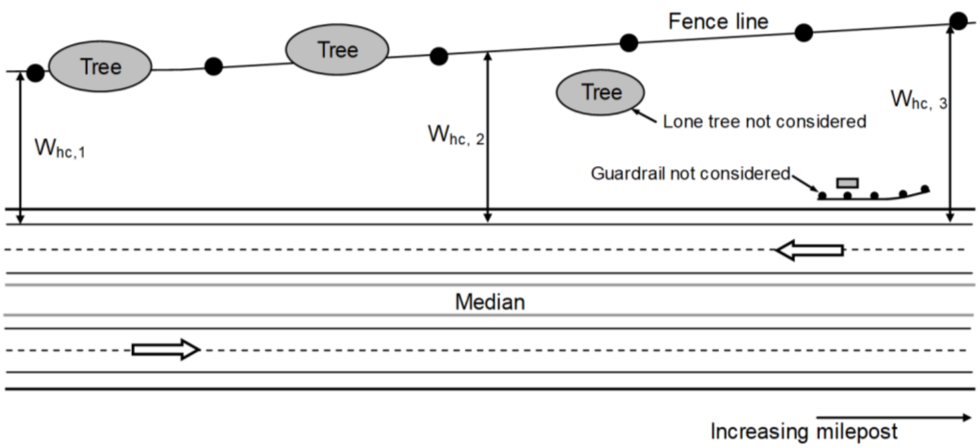


Figure 7.11 Clear zone width measurements

7.2.3.3 Curve Radius

The radius of a curve, in part or in whole, should be measured in feet along the inside edge of the curved travelway. If the roadway is curved in both directions, the equivalent radius of the curve should be computed with the following equation:

$$R^* = \left[\left(\frac{0.5}{R_i^2}\right) + \left(\frac{0.5}{R_j^2}\right)\right]^{-0.5} \quad \textbf{(7.1)}$$

where

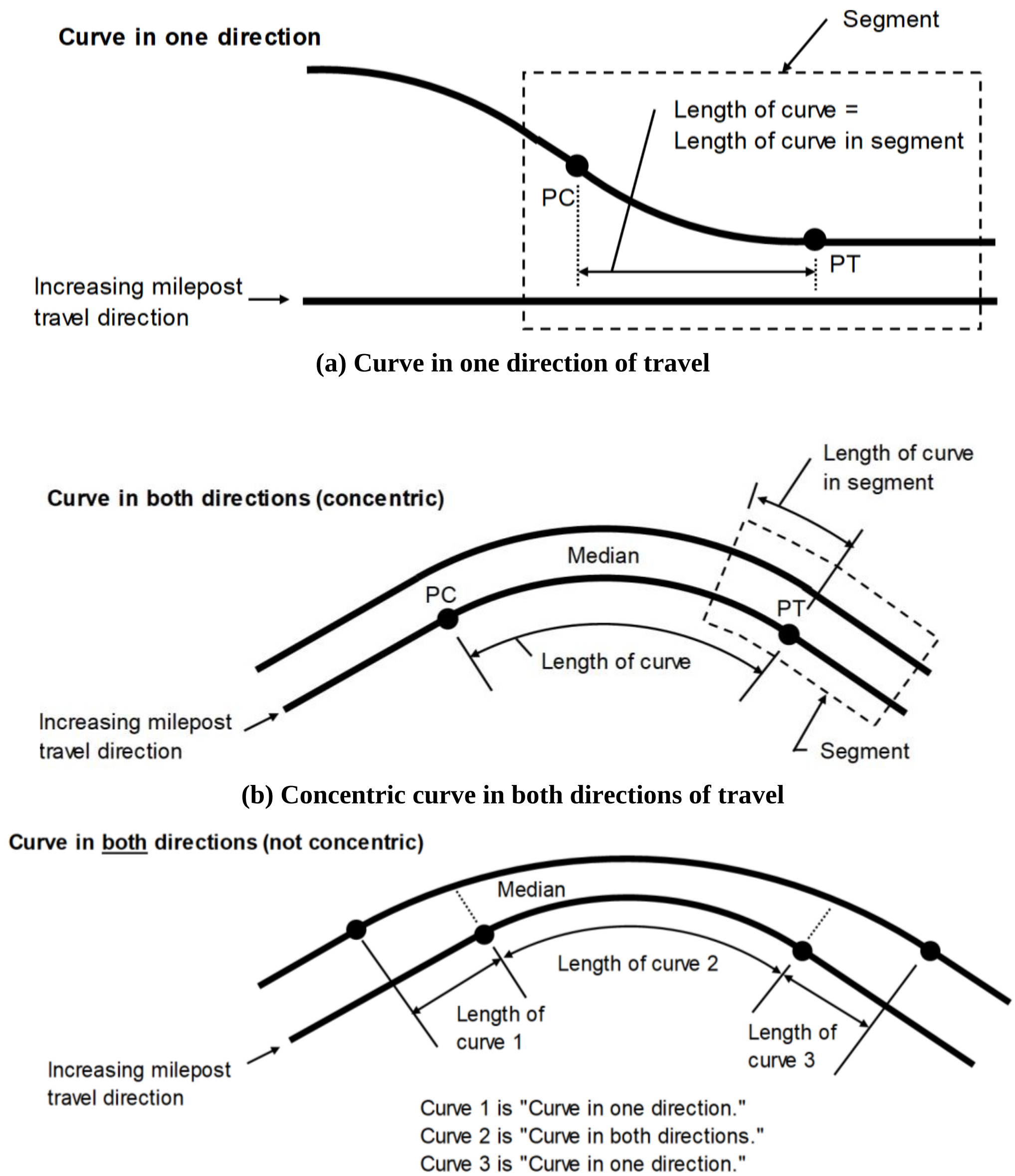
R^* is the equivalent radius of curvature (ft)

R_i is the radius of curvature on roadside *I*

R_j is the radius of curvature on roadside *j*

7.2.3.4 Length of Curve in Segment

The length of the curve within the boundaries of the segment should be recorded. This length should not exceed the length of the segment. Figure 7.12 illustrates different variations of freeway segment curves and shows how the curve length should be measured for each case. The three variations shown are: (1) only one roadside of the segment is curved, (2) both roadsides are curved concentrically, and (3) both roadsides are not curved concentrically.



(c) Not concentric curve in both directions of travel

Figure 7.12 Freeway segment curve length

7.3 HSM Prediction Methodology

As described in Chapter 18 of the supplement to the HSM, the SPFs for freeway segments predict the number of total crashes on the segment per year for the base conditions that are shown in Table 7.1.

Table 7.1 Base conditions for multiple/single-vehicle crashes for freeway segment SPFs

Description	MV Base Condition	SV Base Condition
Horizontal Curve	Not Present	Not Present
Lane Width	12 ft	12 ft
Inside Paved Shoulder Width	6 ft	6 ft
Median Width	60 ft	60 ft
Median Barrier	Not Present	Not Present
Hours with Volume > 1,000veh/h/lane	None	None
Upstream Ramp Entrances	> 0.5 mi from segment	n/a
Downstream Ramp Exits	> 0.5 mi from segment	n/a
Type B Weaving Section	Not Present	n/a
Outside Shoulder Width	n/a	10 ft
Shoulder Rumble Strip	n/a	Not Present
Outside Clearance	n/a	30 ft Clear Zone
Outside Barrier	n/a	Not Present

The SPFs for freeway segments include four models: PDO single-vehicle crashes, PDO multi-vehicle crashes, fatal/injury single-vehicle crashes, and fatal/injury multi-vehicle crashes. The SPFs are based on the AADT and length of the segment. A general form of the SPF equation used to predict average crash frequency for a segment of freeway is shown as Equation 7.2.

$$N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left(CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z} \right) \times C_{w,x,y,z} \qquad \textbf{(7.2)}$$

where

$N_{p,w,x,y,z}$ is the predicted average crash frequency for a specific year for site type *w*, cross-section or control type *x*, crash type *y*, and severity *z* (crashes/year)

$N_{spf,w,x,y,z}$ is the predicted average crash frequency determined for base conditions of the SPF developed for site type *w*, cross-section or control type *x*, crash type *y*, and severity *z* (crashes/year)

$CMF_{m,w,x,y,z}$ is the crash modification factor specific to site type *w*, cross-section or control type *x*, crash type *y*, and severity *z* for specific geometric design and traffic control features *m*

$C_{w,xy,z}$ is the calibration factor to adjust SPF for local conditions for site type *w*, cross-section or control type *x*, crash type *y*, and severity *z*

In order to determine the total average crash frequency of a freeway segment, a sum of the average crash frequencies given by each of the four SPF models must be computed. This summation is shown in Equation 7.3.

$$N_{p,fs,n,at,as} = N_{p,fs,n,mv,fi} + N_{p,fs,n,sv,fi} + N_{p,fs,n,mv,pdo} + N_{p,fs,n,sv,pdo} \tag{7.3}$$

where

$N_{p,fs,n,y,z}$ is the predicted average crash frequency of a freeway segment with *n* lanes

crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types)

severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/year)

$N_{spf,fs,n,y,z}$ is the predicted average crash frequency of a freeway segment with base conditions *n* lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/year)

The general form of each SPF model is given by Equation 7.4. The output of this equation is the average crash frequency given a set of base conditions. This output is then used in the summation within Equation 7.3.

$$N_{spf,fs,n,mv,z} = L^{*} \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{7.4}$$

where

$N_{spf,fs,n,mv,z}$ is the predicted average multiple-vehicle crash frequency of a freeway segment with base conditions, *n* lanes, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/year)

L^{*} is the effective length of freeway segment (mi)

$AADT_{fs}$ is the AADT volume of freeway segment (veh/day)

a, b, c are the regression coefficients

7.4 Sampling Considerations

The sampling process consisted of using the sites from the previous calibration as the calibration starting points (Sun et al. 2014). The previous samples were generated for freeway segments from the lists of all segments for each district and each facility type using Missouri TMS database queries (Sun et al. 2014). Some of these began or ended at interchanges. After several research projects were conducted involving freeway interchange crash data, a number of issues were identified regarding the location and assignment of interchange crashes (Claros et al. 2015, Sun et al. 2016b). In order to avoid crash landing problems and inadvertently including crashes unrelated to freeway segments, the revised samples for this project do not include any segments near interchange facilities. The boundary of interchanges was determined based on the taper point of speed change lanes and a distance of 1,600 ft upstream or downstream from the gore point of add/drop lanes. The 1,600 ft threshold is 100 ft (an extra buffer) beyond the commonly used 1,500 ft influence area (Lu et al. 2013, TRB 2010).

The new samples were based on the previous calibration locations, but the segments were moved upstream or downstream away from interchanges. The segments were separated into urban and rural samples with a minimum length of 0.5 mi and with no interchange facilities. During the sampling process, an attempt was made to obtain a minimum of five samples from each district. However, it was not possible to meet this goal for the urban six-lane freeway segments because most of the samples were located in the St. Louis and Kansas City districts. Freeway segments with significant variation in cross-section, such as a change in median width or median type, were avoided. Specific considerations for each freeway type are described in the next section.

7.4.1 Sampling for Rural Four-Lane Freeway Segments

There were sufficient numbers of rural four-lane freeway samples to obtain at least one sample per district. The sample set for calibration included 45 sites. The general sampling approach involved attempting to obtain 35 at-large samples from the state of Missouri, but more sites were added above the minimum number. This was because rural freeway segments have fewer crashes than urban segments.

A list of samples for rural four-lane freeway segments is shown in Table 7.2. The samples were distributed among the seven MoDOT districts as follows:

- 9 samples from the Central District
- 7 samples from the Kansas City District
- 3 samples from the Northeast District
- 9 samples from the Northwest District
- 7 samples from the Southeast District
- 1 sample from the St. Louis District
- 9 samples from the Southwest District

Table 7.2 List of sites for rural four-lane freeway segments

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
1	CD	IS 44	E	211.188	212.873	1.685	Crawford
2	CD	IS 44	E	204.59	207.126	2.536	Crawford
3	CD	IS 44	E	146.065	148.855	2.79	Pulaski
4	CD	US 40	E	138.93	140.88	1.952	Boone
5	CD	US 40	E	94.344	98.147	3.803	Cooper
6	CD	IS 70	E	106.82	109.745	2.93	Cooper
7	CD	IS 70	E	118.05	120.68	2.625	Boone
8	SW	IS 44	E	67.33	68.25	0.92	Greene
9	SW	IS 44	E	47.45	48.83	1.376	Lawrence
10	SW	IS 44	E	34.04	36.51	2.471	Lawrence
11	SW	IS 44	E	19.022	20.218	1.196	Jasper
12	SW	US 71	S	278.98	279.57	0.586	Newton
13	SW	US 71	S	286.881	288.69	1.809	Newton
14	SW	US 71	S	303.868	304.872	1.004	McDonald
15	KC	US 40	E	47.042	48.888	1.846	Lafayette
16	KC	US 40	E	60.971	62.755	1.784	Lafayette
17	KC	US 40	E	72.979	74.87	1.891	Saline
18	KC	US 71	S	83.685	84.514	0.829	Platte
19	KC	US 71	S	160.785	162.415	1.63	Cass
20	KC	US 71	S	89.532	91.654	2.122	Platte
21	KC	US 40	E	79.968	82.938	2.97	Saline
22	NE	IS 70	E	181.709	183.356	1.647	Montgomery
23	NE	IS 70	E	175.506	177.665	2.159	Montgomery
24	NE	IS 70	E	170.83	174.371	3.541	Montgomery
25	SW	US 71	S	293.461	294.974	1.513	Newton
26	SW	US 71	S	264.06	264.718	0.658	Jasper
27	NW	IS 35	S	8.296	11.262	2.966	Harrison
28	NW	IS 35	S	22.391	24.19	1.799	Harrison
29	NW	US 71	S	78.062	82.50	4.435	Buchanan
30	NW	US 71	S	57.157	57.898	0.741	Andrew
31	NW	IS 229	S	0.851	1.599	0.748	Andrew
32	NW	IS 29	S	56.937	58.385	1.448	Andrew
33	NW	IS 29	S	25.313	26.865	1.552	Holt
34	NW	IS 35	S	14.897	16.18	1.283	Harrison
35	NW	IS 35	S	34.303	35.573	1.27	Daviess
36	SE	IS 55	S	129.384	132.199	2.815	Scott
37	SE	IS 55	S	177.398	179.583	2.185	Pemiscot
38	SE	IS 55	S	202.256	204.123	1.867	Pemiscot
39	SE	US 60	E	322.889	326.586	3.697	Mississippi
40	SE	IS 55	S	152.133	156.676	4.543	New Madrid

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
41	SE	IS 55	S	86.241	89.645	3.404	Perry
42	SE	US 60	E	317.408	320.91	3.502	Mississippi
43	SL	IS 55	S	39.522	40.096	0.574	Jefferson
44	CD	IS 70	E	138.267	141.406	3.139	Callaway
45	CD	IS 70	E	144.602	146.303	1.701	Callaway

The samples were representative of geographic diversity from around Missouri. The sample set consisted mainly of Interstate freeways, although US highways such as US 40, US 71, and US 60 were also represented in the sample set. Most of the major Interstate freeways, including I-44, I-35, I-55, I-29, and I-70 were part of the sample set. The sample set included freeway segments from 26 Missouri counties. All sites from the previous calibration were examined. Some sites were dropped because they included interchange areas, and some new sites were added.

7.4.2 Sampling for Urban Four-Lane Freeway Segments

There were sufficient samples to obtain five samples per district for urban four-lane segments. The sample set for calibration included 41 sites. The general sampling approach involved attempting to obtain 35 at-large samples from Missouri.

A list of samples for urban four-lane freeway segments is shown in Table 7.3. The samples were distributed among the seven MoDOT districts as follows:

- 6 samples from the Central District
- 9 samples from the Kansas City District
- 3 samples from the Northeast District
- 6 samples from the Northwest District
- 4 samples from the Southeast District
- 8 samples from the St. Louis District
- 5 samples from the Southwest District

Table 7.3 List of sites for urban four-lane freeway segments

No.	City	County	District	Description	Primary Dir.	Primary Begin Log	Primary End Log	Length (mi)
1	Laclede	Lebanon	CD	IS 44	E	127.71	128.82	1.10
2	Laclede	Lebanon	CD	IS 44	E	129.38	129.88	0.50
3	Jefferson City	Cole	CD	US 50	E	134.93	135.64	0.71
4	Jefferson City	Cole	CD	US 50	E	136.27	136.99	0.72
5	Sullivan	Crawford	CD	IS 44	E	223.10	224.17	1.07
6	Boonville	Cooper	CD	IS 70	E	102.10	103.18	1.08
7	Harrisonville	Cass	KC	US 71	S	154.00	154.51	0.51
8	Peculiar	Cass	KC	US 71	S	145.18	145.87	0.69
9	Kansas City	Clay	KC	US 169	N	7.66	8.64	0.99
10	Kansas City	Clay	KC	US 169	N	9.37	10.59	1.22
11	Kansas City	Platte	KC	MO 152	E	1.89	3.40	1.51
12	Belton	Cass	KC	US 71	N	176.59	177.71	1.12
13	Lee's Summit	Jackson	KC	MO 291	N	23.69	24.46	0.76
14	Lee's Summit	Jackson	KC	MO 291	N	25.60	26.54	0.94
15	Kansas City	Clay	KC	IS 435	S	22.49	24.85	2.36
16	Hannibal	Marion	NE	US 36	E	189.71	190.30	0.59
17	Warrenton	Warren	NE	IS 70	E	193.83	194.83	1.00
18	Hannibal	Marion	NE	US 36	E	188.28	189.00	0.72
19	St. Joseph	Buchanan	NW	IS 29	N	52.94	54.85	1.91
20	St. Joseph	Buchanan	NW	IS 29	N	51.04	52.22	1.18
21	St. Joseph	Buchanan	NW	IS 229	S	13.36	14.05	0.68
22	St. Joseph	Buchanan	NW	IS 29	N	49.25	50.27	1.02
23	St. Joseph	Buchanan	NW	US 36	E	4.22	4.75	0.53
24	St. Joseph	Buchanan	NW	IS 229	N	7.99	9.14	1.15
25	Cape Girardeau	Scott	SE	IS 55	N	90.22	91.35	1.13
26	Jackson	Cape Girardeau	SE	IS 55	N	100.32	101.80	1.48
27	Sikeston	Scott	SE	IS 55	N	69.77	73.32	3.54
28	Cape Girardeau	Cape Girardeau	SE	IS 55	N	96.85	99.49	2.63
29	Sullivan	Franklin	SL	IS 44	E	224.84	225.53	0.69
30	Wentzville	St. Charles	SL	IS 70	E	205.34	207.83	2.48
31	Lake St. Louis	St. Charles	SL	IS 64	E	1.87	2.89	1.03
32	Lake St. Louis	St. Charles	SL	IS 64	E	4.81	5.89	1.08
33	O'Fallon	St. Charles	SL	IS 64	E	7.05	9.26	2.22
34	St. Clair	Franklin	SL	IS 44	E	240.75	241.86	1.11
35	Villa Ridge	Franklin	SL	IS 44	W	42.54	44.00	1.46
36	Festus	Jefferson	SL	IS 55	N	177.03	178.36	1.33
37	Joplin	Newton	SW	IS 44	E	7.03	8.31	1.28
38	Joplin	Newton	SW	IS 44	E	9.79	11.25	1.46
39	Springfield	Greene	SW	US 160	E	96.12	97.87	1.75
40	Carthage	Jasper	SW	US 71	N	56.16	57.09	0.94
41	Ozark	Christian	SW	US 65	N	38.82	41.16	2.34

The samples were representative of geographic diversity from around Missouri. The sample set consisted mostly of Interstate freeways, although US highways such as US 36, US 50, US 65, US 71, US 160, and US 169 were represented in the sample set. Most of the major Interstate freeways, including I-44 and I-70, were part of the sample set. The sample set included freeway segments from 20 counties in Missouri, as well as segments from large counties such as St. Charles and small counties such as Christian.

7.4.3 Sampling for Urban Six-Lane Freeway Segments

There were sufficient numbers of sites to obtain samples from only three districts: Kansas City, St. Louis, and Southwest. Urban six-lane freeways are not commonly found across Missouri, except in densely populated regions. For this reason, it was not possible to find suitable sites from every single district. The sample set for calibration included 54 sites. Urban interchange spacing tends to be shorter than rural spacing. This led researchers to utilize samples with a minimum of 0.3 mi in length to eliminate excessively short segments.

A list of samples for urban six-lane freeway segments is shown in Table 7.4. The samples were distributed among three MoDOT districts as follows:

- 25 samples from the Kansas City District
- 25 samples from the St. Louis District
- 4 samples from the Southwest District

Table 7.4 List of sites for urban six-lane freeway segments

No.	City	County	District	Descr.	Primary Dir.	Begin Log	End Log	Length (mi)
1	Independence	Jackson	KC	IS 70	E	11.57	12.37	0.80
2	Independence	Jackson	KC	IS 70	E	12.93	13.75	0.82
3	Independence	Jackson	KC	IS 70	E	14.37	14.96	0.59
4	Blue Springs	Jackson	KC	IS 70	E	18.87	19.71	0.84
5	Grandview	Jackson	KC	IS 49	N	174.56	175.22	0.66
6	Grandview	Jackson	KC	IS 49	N	173.86	174.47	0.61
7	Barnhart	Jefferson	SL	IS 55	N	182.47	183.13	0.66
8	Kansas City	Jackson	KC	US 71	N	198.12	198.62	0.50
9	Kansas City	Jackson	KC	IS 70	W	244.97	245.45	0.48
10	Kansas City	Platte	KC	IS 29	N	8.78	9.28	0.50
11	Kansas City	Platte	KC	IS 29	N	9.28	9.83	0.55
12	Platte City	Platte	KC	IS 29	N	20.11	20.65	0.54
13	Platte City	Platte	KC	IS 29	N	20.65	21.49	0.84
14	Kansas City	Clay	KC	IS 35	N	7.21	8.04	0.83
15	Kansas City	Jackson	KC	IS 435	N	6.37	7.00	0.63
16	Kansas City	Jackson	KC	IS 435	N	7.00	7.86	0.86
17	Kansas City	Jackson	KC	IS 470	E	2.41	3.00	0.59
18	Kansas City	Jackson	KC	IS 470	E	3.00	3.66	0.66
19	Lee's Summit	Jackson	KC	IS 470	E	5.77	6.43	0.66
20	Eureka	St. Louis	SL	IS 44	E	266.89	267.40	0.51
21	Bridgeton	St. Louis	SL	IS 70	E	233.43	233.93	0.50
22	Barnhart	Jefferson	SL	IS 55	N	183.20	183.85	0.65
23	St. Louis	St. Louis	SL	IS 70	E	237.00	237.50	0.50
24	St. Charles	St. Charles	SL	MO 370	E	3.07	4.39	1.32
25	St. Charles	St. Charles	SL	MO 370	E	5.54	7.42	1.88
26	Richmond Heights	St. Louis	SL	IS 64	E	33.13	33.67	0.54
27	Chesterfield	St. Louis	SL	IS 64	E	22.31	22.96	0.65
28	Chesterfield	St. Louis	SL	IS 64	E	21.27	21.81	0.54
29	Chesterfield	St. Louis	SL	IS 64	E	17.88	18.52	0.64
30	Chesterfield	St. Louis	SL	IS 64	E	14.94	16.31	1.37
31	Lake St. Louis	St. Charles	SL	IS 70	E	212.27	213.65	1.38
32	O'Fallon	St. Charles	SL	IS 70	E	214.39	215.64	1.25
33	O'Fallon	St. Charles	SL	IS 70	E	223.44	223.92	0.48
34	St. Peters	St. Charles	SL	IS 70	E	224.14	224.82	0.68
35	St. Charles	St. Charles	SL	IS 70	E	225.55	226.64	1.09
36	Bridgeton	St. Louis	SL	IS 70	E	232.33	232.95	0.62
37	St. Louis	St. Louis	SL	IS 70	E	239.91	240.76	0.85
38	St. Louis	St. Louis City	SL	IS 70	E	246.56	246.94	0.38
39	Springfield	Greene	SW	US 65	S	260.08	260.46	0.38
40	Springfield	Greene	SW	US 65	S	263.62	263.98	0.36
41	Springfield	Greene	SW	US 65	S	259.61	259.92	0.31
42	Springfield	Greene	SW	US 65	S	265.77	266.54	0.77
43	Grandview	Jackson	KC	IS 49	N	172.57	173.02	0.45

No.	City	County	District	Descr.	Primary Dir.	Begin Log	End Log	Length (mi)
44	Independence	Jackson	KC	IS 70	E	15.19	15.73	0.54
45	Independence	Jackson	KC	IS 70	E	15.73	16.30	0.57
46	St. Louis	St. Louis City	SL	IS 64	E	37.11	37.58	0.47
47	Independence	Jackson	KC	IS 70	E	16.30	16.83	0.53
48	Blue Springs	Jackson	KC	IS 70	E	17.06	17.66	0.60
49	Blue Springs	Jackson	KC	IS 70	E	17.66	18.22	0.56
50	Eureka	St. Louis	SL	IS 44	E	262.48	263.27	0.79
51	Eureka	St. Louis	SL	IS 44	E	263.27	263.96	0.69
52	Florissant	St. Louis	SL	IS 270	E	28.74	29.40	0.66
53	Florissant	St. Louis	SL	IS 270	E	30.22	30.63	0.41
54	Barnhart	Jefferson	SL	IS 55	N	184.06	184.60	0.54

The samples were representative of geographic diversity around Missouri from among the districts that had six-lane segments. The sample set consisted mostly of Interstate freeways, although US and state highways such as US 71, US 65, and MO 370 were represented in the sample set. Most of the major Interstate freeways, including I-70, I-49, I-29, I-35, I-435, I-270, I-44, I-64, I-270, and I-55, were part of the sample set. The sample set included freeway segments from eight counties in Missouri, mostly from densely populated regions in which six-lane freeways are more prevalent.

7.5 Data Collection

A list of the data types collected for freeway segments and their sources is shown in Table 7.5.

Table 7.5 List of data sources for freeway segments

Data Description	Source
AADT	TMS
Length (mi)	TMS
Effective Length (mi)	TMS/ARAN
Average Lane Width (ft)	TMS
Effective Median Width (ft)	Aerials
Average Inside Shoulder Width (ft)	ARAN
Average Outside Shoulder Width (ft)	ARAN
Proportion of Segment Length with Median Barrier	ARAN
Average Median Barrier Offset	ARAN
Outside Barrier Length (ft)	ARAN
Proportion of Segment Length with Outside Barrier	ARAN
Average Outside Barrier Offset (ft)	ARAN
Outside Clear Zone Width (ft)	HSM Default
Proportion of Segment with Inside Rumble Strips	ARAN
Proportion of Segment with Outside Rumble Strips	ARAN
Proportion of High Volume	HSM Default
Proportion of Weave	ARAN
Length of Weave	ARAN
Distance to Exit or Entrance Ramp	ARAN
Ramp AADT	TMS, Other Sources
Horizontal Curve Radius (ft)	Aerials
Horizontal Curve Length within Site (ft)	ARAN
Number of PDO SV Crashes	TMS
Number of PDO MV Crashes	TMS
Number of FI SV Crashes	TMS
Number of FI MV Crashes	TMS

The TMS map application was used to obtain data on segment length, log miles, and crashes. ARAN and Google Earth were used to derive roadway and geometric data that were not available in the TMS. These included data such as outside shoulder width, inside shoulder width, effective median width, barrier offset, proportion of segment length with median and outside barrier, outside barrier length, proportion of segment with Type B weaving section, proportion of segment with outside and inside rumble strips, and distance to the nearest upstream entrance ramp or downstream exit ramp. The locations of the beginning and end of ramp tapers and ramp gore areas were estimated from the continuous log mile provided in the TMS map application. The ramp log mile locations were used to determine the location of speed change lanes, to calculate the effective segment length, and to calculate the distance to the nearest upstream entrance ramp and nearest downstream ramp. The effective median width was estimated graphically from aerial photographs (Google 2016). The horizontal curve radius and horizontal curve length were estimated using the procedures described in Chapter 3. It should be noted that for freeway segments, the curve length included only the portion of the curve that was within the segment limits. In addition, the curve side of the road (both roadbeds, left roadbed only, or right roadbed only) was a required input. The HSM values for the base conditions were used for the clear zone width and proportion of high volume because these data were not readily available from any sources.

Several important considerations needed to be taken into account when collecting freeway crash data. The first relates to the classification of crashes that occurred within the limits of a speed change lane. HSM mainline freeway models are divided into segments and speed change lanes. A speed change lane is either an entrance or exit area with limits extending from the beginning or end of the taper to the gore point. It is worth noting that these facilities are separate from weaving sections because speed change lanes contain their own taper points while weaving sections typically do not. It is important to consider how crashes that occur on freeway segments adjacent to ramps are to be treated. Such crashes are physically located on a segment and not on a ramp; however, crashes occurring on mainline lanes adjacent to ramps could be the result of ramp traffic and associated with merging or diverging conflicts. In both Missouri and Illinois, crashes located on all lanes associated with ramps were excluded from the segment calibration, consistent with NCHRP 17-45. For example, a crash that occurred between the gore and the taper point would be excluded from segment calibration. Even though this approach identifies all speed change-related crashes, it may also identify some freeway crashes that were not caused by speed change lanes. To avoid the inclusion of such crashes and the inconsistency in the location and assignment of crashes at interchange facilities, the freeway segments considered in this calibration did not include speed change lanes. The segments included were homogenous facilities that were limited by the taper of speed change lanes, if present.

Additionally, it was necessary to separate the number of crashes by severity and the number of vehicles involved in the crash. As discussed in Section 7.3 on HSM methodology, the HSM models single- and multi-vehicle crashes separately. The TMS Accident Browser provides information regarding crash severity in its output. However, it does not provide information regarding the number of vehicles that were involved in a crash. Therefore, all crash reports occurring between 2012 and 2014 that matched the accident browser crash queries were requested from MoDOT to retrieve the required information for the number of vehicles involved in crashes. In other words, for every crash occurring within a freeway segment, the number of vehicles involved was queried using the crash image number. Thus, this was a two-stage crash data querying process where the crashes were identified first, and then the number of vehicles involved was identified. Alternately, the crash data also could have been collected via an ODBC query that joined multiple tables (databases) so that all the relevant crash criteria, such as location, date, severity, and number of vehicles, could be queried simultaneously. This alternate approach was not used due to technical problems with the ODBC connection.

7.5.1 Summary Statistics for Rural Four-Lane Freeway Segments

Descriptive statistics for rural four-lane freeway segments are shown in Table 7.6.

Table 7.6 Sample descriptive statistics for rural four-lane freeway segments

Description	Ave.	Min.	Max.	Std. Dev.
AADT(2013)	21,850	4,336	39,777	8,021
Length (mi)	2.09	0.57	4.54	1.00
Effective Length (mi)	2.09	0.57	4.54	1.00
Average Lane Width (ft)	11.8	11.5	12	0.24
Effective Median Width (ft)	51	30	60	10
Average Inside Shoulder Width (ft)	4.1	3	6	0.8
Average Outside Shoulder Width (ft)	9.5	8	10.5	0.63
Proportion of Segment Length with Median Barrier	0.65	0.0	1.0	0.5
Average Median Barrier Offset	16.87	0.0	31.5	8.92
Outside Barrier Length (ft)	2,253	0	12,033	2,826
Proportion of Segment Length with Outside Barrier	0.10	0.00	0.46	0.10
Average Outside Barrier Offset (ft)	7.6	0.0	12	4
Outside Clear Zone Width (ft)	30	30	30	0
Proportion of Segment with Inside Rumble Strips	1.0	1.0	1.0	0.0
Proportion of Segment with Outside Rumble Strips	1.0	1.0	1.0	0.0
Proportion of High Volume	0	0	0	0
Proportion of Weave Increasing Direction	0	0	0	0
Length of Weave Increasing Direction	0	0	0	0
Proportion of Weave Decreasing Direction	0	0	0	0
Length of Weave Decreasing Direction	0	0	0	0
Distance to Entrance Ramp Increasing Direction (ft)	2,430	776	15,856	2,766
AADT Entrance Ramp Increasing Direction (2013)	891	76	5,082	1,049
Distance to Exit Ramp Increasing Direction (ft)	8,723	1,225	42,451	7,861
AADT Exit Ramp Increasing Direction (2013)	894	102	5,265	11,89
Distance to Entrance Ramp Decreasing Direction (ft)	8,715	1,109	42,541	7,940
AADT Entrance Ramp Decreasing Direction (2013)	877	89	4,885	1,119
Distance to Exit Ramp Decreasing Direction (ft)	2,471	803	15,814	2,733
AADT Exit Ramp Decreasing Direction (2013)	838	94	3,279	780
Horizontal Curve Radius (ft)	6,427	5,896	7,225	704
Horizontal Curve Length within Site (ft)	2,021	1,425	2,999	853
Number of PDO SV Crashes	14	0	47	11.8
Number of PDO MV Crashes	6.7	0	24	6.1
Number of FI SV Crashes	2.4	0	10	2.2
Number of FI MV Crashes	1.6	0	6	1.6

The average AADT was 21,850 vpd, with a standard deviation of 8,021 vpd. Thus, the sample set contained a wide range of AADT values. The average effective length of the segments was 2.09 mi, with a standard deviation of 1 mi. The segments were relatively uniform with respect to lane width, inside shoulder width, and outside shoulder width. The average effective median width was 51 ft, with a standard deviation of 10 ft. Most of the segments contained a median barrier, as indicated by the average value of 0.65 for the proportion of segments with median barrier. Outside barriers were less common, as indicated by the average value of 0.1 for the proportion of segments with outside barrier.

All of the segments contained both inside and outside rumble strips. None of the segments contained a Type B weaving section. The average distance to the nearest upstream entrance ramp or downstream exit ramp varied from around 2,000 to 8,000 ft. The average ramp AADT was approximately 860 vpd. The segments had an average value of 6,427 ft for the horizontal curve radius. The average horizontal curve length within site was 2,021 ft.

7.5.2 Summary Statistics for Urban Four-Lane Freeway Segments

Descriptive statistics for urban four-lane freeway segments are shown in Table 7.7.

Table 7.7 Sample descriptive statistics for urban four-lane freeway segments

Description	Average	Min.	Max.	Std. Dev.
AADT (2012 to 2014)	32,329	5,030	38,383	14,898
Effective Length (mi)	1.27	0.50	3.54	0.66
Average Lane Width (ft)	12.00	12.00	12.50	0.19
Effective Median Width (ft)	51.00	40.00	90.00	11.22
Average Inside Shoulder Width (ft)	4.89	3.00	12.00	1.63
Average Outside Shoulder Width (ft)	9.66	8.00	12.00	0.80
Proportion of Segment Length with Median Barrier	0.77	0.00	1.00	0.41
Average Median Barrier Offset (ft)	18.67	0.00	29.75	8.76
Proportion of Segment Length with Outside Barrier	0.16	0.00	0.53	0.16
Average Outside Barrier Offset (ft)	7.33	0.00	13.00	4.35
Outside Clear Zone Width (ft)	30.00	30.00	30.00	0.00
Proportion of Segment with Inside Rumble Strips	1.00	1.00	1.00	0.00
Proportion of Segment with Outside Rumble Strips	1.00	1.00	1.00	0.00
Proportion of High Volume (2012-2014)	0.04	0.00	0.49	0.12
Proportion of Weave Increasing Direction	0.00	0.00	0.00	0.00
Length of Weave Increasing Direction (ft)	0.00	0.00	0.00	0.00
Proportion of Weave Decreasing Direction	0.00	0.00	0.00	0.00
Length of Weave Decreasing Direction (ft)	0.00	0.00	0.00	0.00
Distance to Entrance Ramp Increasing Direction (ft)	2,371	401	23,237	4,510
AADT Entrance Ramp Increasing Direction (2012-2014)	2,632	146	6,912	1,697
Distance to Exit Ramp Increasing Direction (ft)	2,905	259	39,109	6,847
AADT Exit Ramp Increasing Direction (2012-2014)	2,625	276	6,495	1,800
Distance to Entrance Ramp Decreasing Direction (ft)	4,353	533	58,307	11,042
AADT Entrance Ramp Decreasing Direction (2012-2014)	2,561	262	6,268	1,688
Distance to Exit Ramp Decreasing Direction (ft)	2,247	290	22,994	4,498
AADT Exit Ramp Decreasing Direction (2012-2014)	2,693	135	7,735	1,836
Horizontal Curve Radius (ft)	5,592	1,928	17,024	3,802
Horizontal Curve Length within Site (ft)	2,316	829	7,810	1,743
Number of FI MV Crashes	2.44	0.00	12	2.86
Number of FI SV Crashes	2.32	0.00	7	1.63
Number of PDO MV Crashes	8.85	0.00	43	10.31
Number of PDO SV Crashes	10.59	0.00	37	8.01

The average AADT was 32,329 vpd, with a standard deviation of 14,898 vpd. Thus, the sample set contained a wide range of AADT values. The average effective length of the segments was 1.27 mi, with a standard deviation of 0.66 mi. The segments were relatively uniform with respect to lane width, inside shoulder width, and outside shoulder width. The average effective median width was 51 ft, with a standard deviation of 11.22 ft. Most of the segments contained median barriers, as indicated by the average value of 0.77 for the proportion of segments with median barriers. Outside barriers were less common, as indicated by the average value of 0.16 for the proportion of segments with outside barriers.

All of the segments contained both inside and outside rumble strips. None of the segments contained a Type B weaving section. The average distance to the nearest upstream entrance ramp or downstream exit ramp varied from around 2,000 to 3,000 ft. As expected, the distance to the nearest ramp was shorter for the urban segments than for the rural segments. The average ramp AADT was approximately 2,600 vpd. The segments had an average value of 5,592 ft for the horizontal curve radius.

7.5.3 Summary Statistics for Urban Six-Lane Freeway Segments

Descriptive statistics for urban six-lane freeway segments are shown in Table 7.8.

Table 7.8 Sample descriptive statistics for urban six-lane freeway segments

Description	Average	Min.	Max.	Std. Dev.
Bidirectional AADT (2012 to 2014)	88,875	41,693	177,020	28,380
Effective Length (mi)	0.69	0.31	1.88	0.30
Average Lane Width (ft)	11.81	10.00	12.80	0.63
Effective Median Width (ft)	21.90	10.00	46.50	9.45
Average Inside Shoulder Width (ft)	8.52	4.00	17.50	2.87
Average Outside Shoulder Width (ft)	10.55	5.00	14.30	1.67
Proportion of Segment Length with Median Barrier	1.00	1.00	1.00	0.00
Average Median Barrier Offset (ft)	10.10	3.29	23.00	4.44
Proportion of Segment Length with Outside Barrier	0.30	0.00	1.00	0.27
Average Outside Barrier Offset (ft)	12.16	8.15	49.80	7.15
Outside Clear Zone Width (ft)	54.81	10.00	190.00	34.56
Proportion of Segment with Inside Rumble Strips	0.74	0.00	1.00	0.39
Proportion of Segment with Outside Rumble Strips	0.73	0.00	1.00	0.40
Proportion of High Volume (2012-2014)	0.31	0.00	0.89	0.27
Proportion of Weave Increasing Direction	0.07	0.00	0.94	0.18
Length of Weave Increasing Direction (ft)	203.65	0.00	2,821.00	543.65
Proportion of Weave Decreasing Direction	0.06	0.00	0.84	0.19
Length of Weave Decreasing Direction (ft)	179.85	0.00	2,529.00	538.92
Distance to Entrance Ramp Increasing Direction (ft)	2,779	576	14,974	2,814
AADT Entrance Ramp Increasing Direction (2012-2014)	4,648	353	15,131	3,438
Distance to Exit Ramp Increasing Direction (ft)	2,741	195	9,911	2,328
AADT Exit Ramp Increasing Direction (2012-2014)	5,231	559	13,939	3,010
Distance to Entrance Ramp Decreasing Direction (ft)	3,044	69	13,337	2,747
AADT Entrance Ramp Decreasing Direction (2012-2014)	4,802	472	14,242	2,995
Distance to Exit Ramp Decreasing Direction (ft)	2,946	327	15,074	2,938
AADT Exit Ramp Decreasing Direction (2012-2014)	5,337	222	14,026	3,346
Horizontal Curve Radius (ft)	6,257	1,713	37,262	9,363
Horizontal Curve Length within Site (ft)	1,375	488	2,561	708
Number of Observed FI MV Crashes	7.61	0.00	41.00	7.68
Number of Observed FI SV Crashes	3.50	0.00	10.00	1.99
Number of Observed PDO MV Crashes	23.72	0.00	94.00	20.63
Number of Observed PDO SV Crashes	8.20	0.00	21.00	5.42

The average bidirectional AADT was 88,875 vpd, with a standard deviation of 28,380 vpd. The average effective length of the segments was 0.69 mi, with a standard deviation of 0.30 mi. The segments were relatively uniform with respect to lane width, inside shoulder width, and outside shoulder width, with the exception of one site containing a comparatively large inside shoulder. The average effective median width was 21.90 ft, with a standard deviation of 9.45 ft. This large standard deviation is possibly due to the site containing a large inside shoulder and, in turn, a relatively large effective median when compared to the rest of the sites. All 54 sites contained a median barrier of some sort, as indicated by the descriptive statistics for the proportion of segments with median barriers with an average, minimum, and maximum of 1.00. The presence of outside barriers was less common, as indicated by the average value of 0.30 for the proportion of segments with outside barriers, and was not consistent, as evidenced by the 0.27 standard deviation value.

7.6 Results and Discussion

The original HSM models were developed using data from California, Maine, and Washington state (Bonneson et al. 2012). Some descriptive statistics for the data used to develop the HSM model for freeway segments are shown in Table 7.9.

Table 7.9 Descriptive statistics for HSM freeway data

State	Number of Segments	Total Length (mi)	Minimum AADT (vpd)	Maximum AADT (vpd)
California	533	209	17,000	308,000
Maine	203	101	11,300	83,700
Washington	1,144	200	9,600	197,000

In summary, the HSM freeway data consisted of 1,880 segments covering 510 mi in three different states. The crash data included crashes between 2005 and 2007 for Washington and California, and between 2004 and 2006 for Maine.

7.6.1 Results for Rural Four-Lane Freeway Segments

7.6.1.1 Calibration Factors

The calibration factors for rural four-lane freeway segments are shown in Table 7.10.

Table 7.10 Calibration results for rural four-lane freeway segments

					FI[2]				PDO[3]			
					MV		SV		MV		SV	
No.	Dist[1].	Segment	Begin Log	Length	Obs[4]	Prd[5]	Obs	Prd	Obs	Prd	Obs	Prd
1	CD	IS 44	211.188	1.685	0	2.26	2	5.53	6	4.14	26	12.05
2	CD	IS 44	204.59	2.536	0	2.9	2	6.78	11	5.01	32	16.06
3	CD	IS 44	146.065	2.79	6	3.11	4	6.79	6	5.26	27	17.19
4	CD	US 40	138.93	1.952	1	3.43	3	6.8	19	6.62	22	15.9
5	CD	US 40	94.344	3.803	1	4.03	10	10.28	15	6.7	33	22.68
6	CD	IS 70	106.82	2.93	1	4.26	9	9.28	10	7.98	19	21.28
7	CD	IS 70	118.05	2.625	2	3.98	6	8.13	16	7.62	32	19.29
8	SW	IS 44	67.33	0.92	1	1.89	1	2.97	5	3.94	6	8.04
9	SW	IS 44	47.45	1.376	2	1.61	5	3.99	8	2.89	5	8.57
10	SW	IS 44	34.04	2.471	0	2.56	3	6.81	8	4.43	13	14.3
11	SW	IS 44	19.022	1.196	2	1.41	0	3.35	7	2.54	4	7.43
12	SW	US 71	278.98	0.586	0	0.29	1	1.1	2	0.39	2	2.16
13	SW	US 71	286.881	1.809	0	0.8	1	3.48	0	1.03	5	6.55
14	SW	US 71	303.868	1.004	0	0.19	1	1.25	1	0.19	0	2.11
15	KC	US 40	47.042	1.846	1	2.29	2	5.71	8	4.13	15	12.16
16	KC	US 40	60.971	1.784	2	1.67	0	4.15	3	2.76	15	9.94
17	KC	US 40	72.979	1.891	3	1.6	3	4.19	6	2.53	19	9.65
18	KC	US 71	83.685	0.829	3	0.98	1	2.08	5	1.69	7	5.2
19	KC	US 71	160.785	1.63	0	0.88	2	3.25	2	1.25	2	6.4
20	KC	US 71	89.532	2.122	2	2.57	2	5.5	12	4.53	18	13.46
21	KC	US 40	79.968	2.97	3	3.08	3	7.56	17	5.24	32	17.48
22	NE	IS 70	181.709	1.647	3	2.28	3	4.89	15	4.23	15	11.5
23	NE	IS 70	175.506	2.159	4	3.29	3	6.35	6	6.15	24	15.72
24	NE	IS 70	170.83	3.541	2	3.28	3	8.32	16	5.42	27	19.48
25	SW	US 71	293.461	1.513	0	0.63	1	2.67	0	0.81	0	5.06
26	SW	US 71	264.06	0.658	1	0.3	0	1.12	3	0.39	1	2.3
27	NW	IS 35	8.296	2.966	0	0.93	2	4.36	2	1.14	6	8.45
28	NW	IS 35	22.391	1.799	0	0.65	1	2.71	0	0.82	4	5.54
29	NW	US 71	78.062	4.435	5	5	6	11.3	24	8.8	47	27.41
30	NW	US 71	57.157	0.741	2	0.42	1	1.46	2	0.6	4	3.02
31	NW	IS 229	0.851	0.748	0	0.05	0	0.63	0	0.04	0	0.9
32	NW	IS 29	56.937	1.448	2	0.68	2	2.74	2	0.91	11	5.4
33	NW	IS 29	25.313	1.552	0	0.51	2	2.32	0	0.62	2	4.58
34	NW	IS 35	14.897	1.283	0	0.48	2	2.07	1	0.62	1	4.09
35	NW	IS 35	34.303	1.27	0	0.46	0	2.02	0	0.58	1	3.96
36	SE	IS 55	129.384	2.815	4	1.84	5	5.88	4	2.71	21	12.74
37	SE	IS 55	177.398	2.185	1	1.46	1	4.68	9	2.18	10	9.99
38	SE	IS 55	202.256	1.867	0	0.96	0	3.47	1	1.29	6	7.23
39	SE	US 60	322.889	3.697	5	1.59	1	6.68	4	2.12	13	12.72
40	SE	IS 55	152.133	4.543	3	2.87	3	9.43	10	4.16	23	20.29
41	SE	IS 55	86.241	3.404	1	1.93	3	6.38	6	2.66	21	13.98
42	SE	US 60	317.408	3.502	2	1.65	3	6.62	5	2.26	5	12.76
43	SL	IS 55	39.522	0.574	0	0.42	1	1.26	1	0.64	4	2.69
44	CD	IS 70	138.267	3.139	4	3.05	3	7.75	17	5.11	32	17.76

No.	Dist.[1]	Segment	Begin Log	Length	FI[2]				PDO[3]			
					MV		SV		MV		SV	
					Obs[4]	Prd[5]	Obs	Prd	Obs	Prd	Obs	Prd
45	CD	IS 70	144.602	1.701	1	2.94	3	5.38	7	5.82	19	13.53
Sum					**70**	**83.46**	**110**	**219.47**	**302**	**141**	**631**	**489**
Calibration Factors					**0.839**		**0.501**		**2.143**		**1.290**	

Notes: [1]District, [2]Fatal and Injury, [3]Property Damage Only, [4]Observed crashes, and [5]Predicted crashes.

The IHSDM output is shown in Figures 7.13 to 7.16.

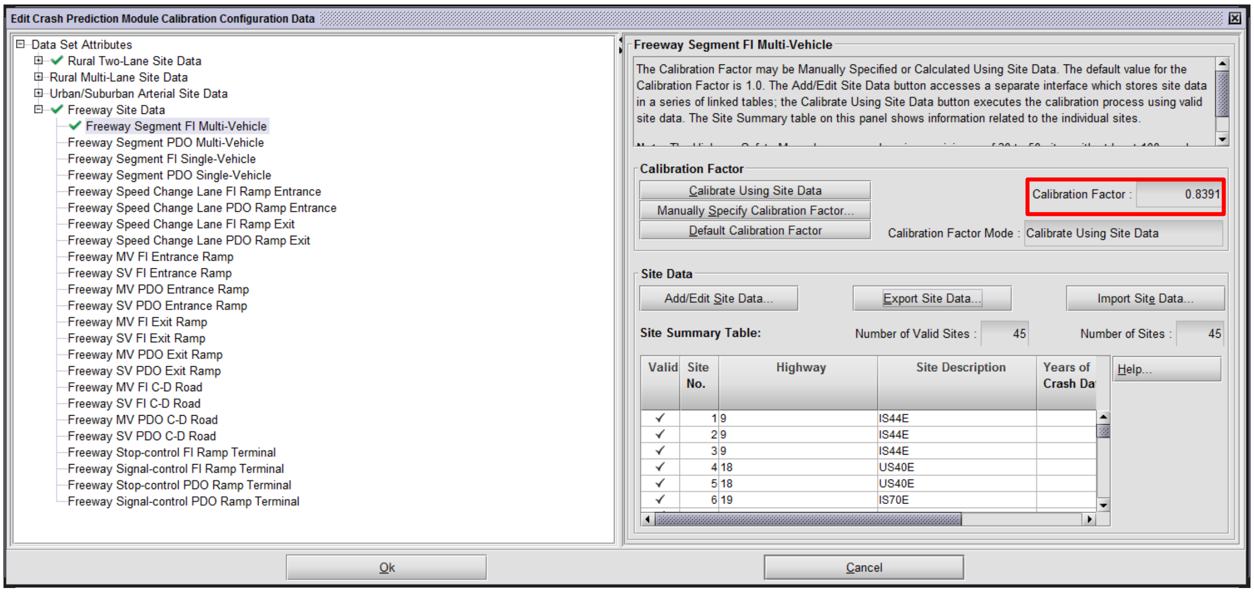


Figure 7.13 Calibration output for rural four-lane freeways (FI multi-vehicle)

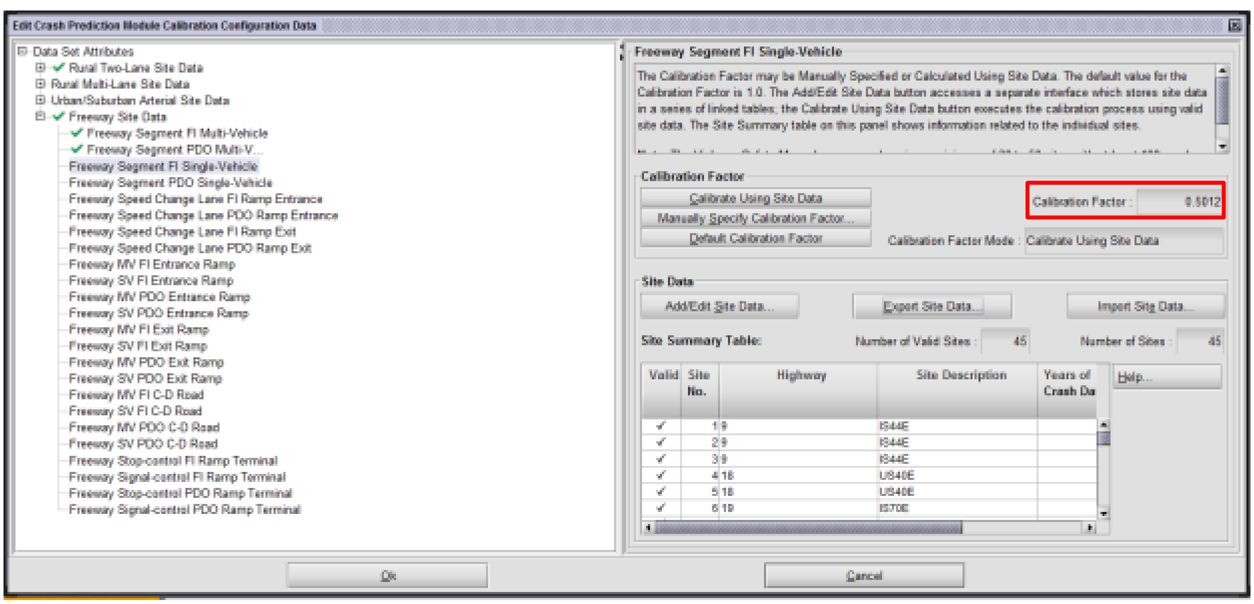


Figure 7.14 Calibration output for rural four-lane freeways (FI single-vehicle)

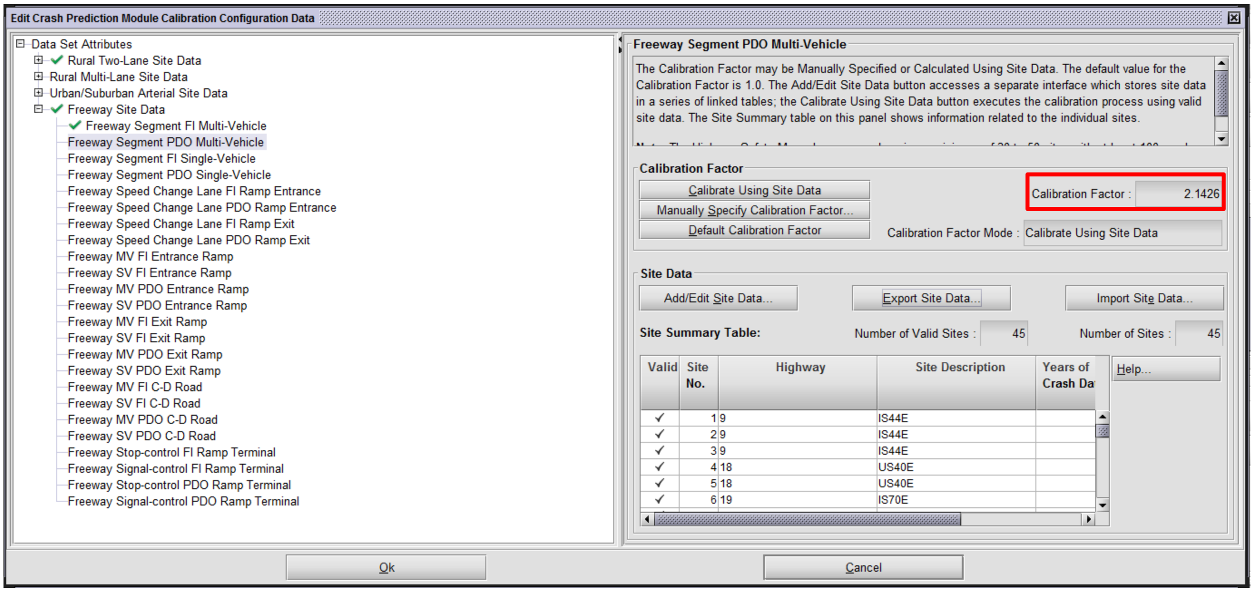


Figure 7.15 Calibration output for rural four-lane freeways (PDO multi-vehicle)

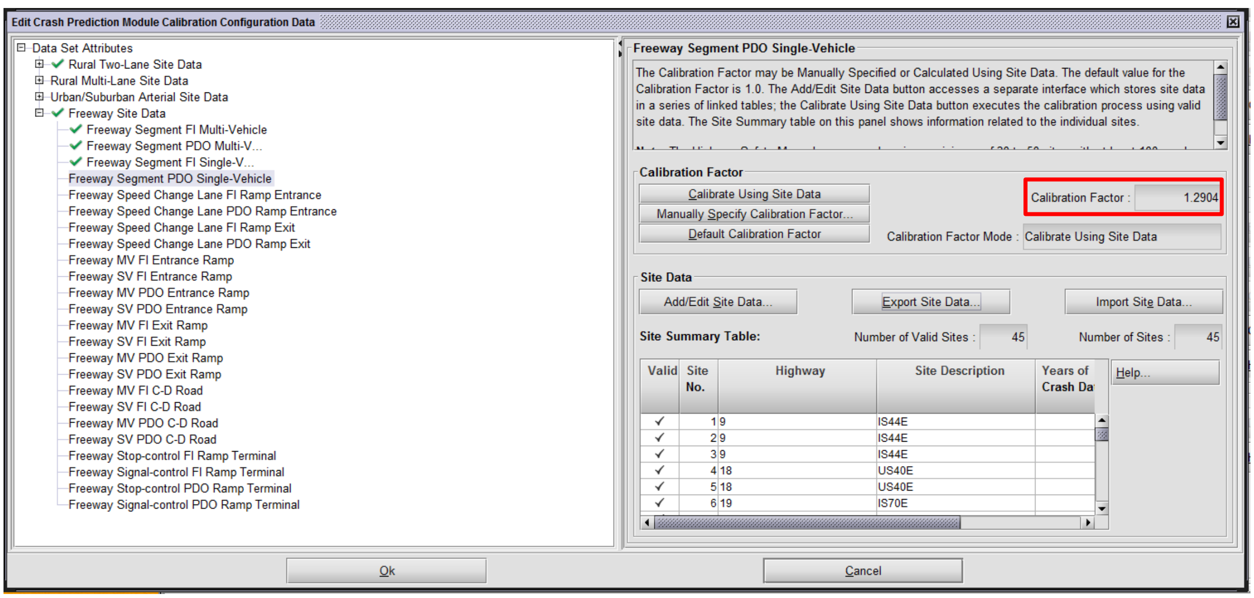


Figure 7.16 Calibration output for rural four-lane freeways (PDO single-vehicle)

These results indicate that the number of property damage only crashes for single/multiple-vehicle crashes observed in Missouri was greater than the number of crashes predicted by the HSM freeway methodology, while the number of fatal/injury crashes for single/multiple-vehicle crashes was lower than the number of crashes predicted by the HSM methodology. Possible reasons for the calibration values deviating from 1.0 included differences in driver behavior, differences in PDO crash reporting, and the sampling of segments with or without speed change lanes. The PDO reporting thresholds for California, Washington, and Maine are all higher than the $500 used in Missouri.

7.6.1.2 Severity Distribution Factors

Using the calibration data, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 7.11 shows the SDFs obtained for rural four-lane freeway segments.

Table 7.11 Severity distribution factors for rural four-lane freeway segments

Severity	MV		SV	
	Crashes	SDF	Crashes	SDF
Fatal	5	0.014	1	0.001
Disabling Injury	11	0.030	19	0.026
Minor Injury	54	0.146	90	0.121
Property Damage Only	300	0.811	633	0.852

7.6.1.3 Crash Type Distribution Factors

The CDFs are used to determine the proportion of predicted crashes according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because HSM and Missouri crash type categories differed. Therefore, different categories were aggregated to provide similar classifications to those recommended by the HSM. The crash types were also divided by multiple- and single-vehicle crashes. Table 7.12 provides the CDFs for rural four-lane freeway segments.

Table 7.12 Crash type distribution factors for rural four-lane freeway segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Head-on	0	0
Angle	1	0.003
Rear-End	151	0.408
Sideswipe	123	0.332
Other	95	0.257
Single-Vehicle		
Crash with Parked Vehicle	0	0
Crash with Fixed Objective	14	0.019
Crash with Animal	89	0.120
Out of Control	536	0.721
Others	104	0.140

7.6.2 Results for Urban Four-Lane Freeway Segments

7.6.2.1 Calibration Factors

The calibration factors for urban four-lane freeway segments are shown in Table 7.13.

Table 7.13 Calibration results for urban four-lane freeway segments

No.	Dist.[1]	Segment	Begin Log	Length (mi)	FI[2] MV Obs[4]	FI[2] MV Prd[5]	FI[2] SV Obs	FI[2] SV Prd	PDO[3] MV Obs	PDO[3] MV Prd	PDO[3] SV Obs	PDO[3] SV Prd
1	CD	IS 44 E	127.71	1.10	1	2	1	3	1	4	5	7
2	CD	IS 44 E	129.38	0.50	0	1	2	1	1	1	3	3
3	CD	US 50 E	134.93	0.71	2	1	1	2	1	1	4	4
4	CD	US 50 E	136.27	0.72	1	2	3	2	5	4	2	7
5	CD	IS 44 E	223.10	1.07	1	2	2	3	5	3	8	7
6	CD	IS 44 E	102.10	1.08	1	2	1	3	3	3	18	7
7	KC	IS 70 E	154.00	0.51	0	1	2	1	5	2	10	4
8	KC	US 71 S	145.18	0.69	1	2	3	2	7	3	8	5
9	KC	US 71 S	7.66	0.99	4	5	2	4	6	11	6	10
10	KC	US 169 N	9.37	1.22	1	4	3	4	3	6	10	10
11	KC	US 169 N	1.89	1.51	0	0	0	2	1	0	8	3
12	KC	MO 152 E	176.59	1.12	3	3	3	4	4	5	11	8
13	KC	US 71 N	23.69	0.76	9	6	1	4	31	13	11	8
14	KC	MO 291 N	25.60	0.94	8	8	5	5	41	17	14	10
15	KC	MO 291 N	22.49	2.36	0	3	0	7	3	4	10	13
16	NE	IS 435 S	189.71	0.59	0	0	2	1	0	0	0	2
17	NE	US 36 E	193.83	1.00	2	3	2	4	7	6	29	9
18	NE	IS 70 E	188.28	0.72	0	0	1	1	0	0	1	2
19	NW	US 36 E	52.94	1.91	0	4	5	6	16	7	24	14
20	NW	IS 70 E	51.04	1.18	2	3	2	4	9	5	13	9
21	NW	IS 64 E	13.36	0.68	1	1	3	1	3	1	8	3
22	NW	IS 64 E	49.25	1.02	1	3	0	3	9	5	10	8
23	NW	IS 64 E	4.22	0.53	0	1	0	1	0	1	2	3
24	NW	IS 29 N	7.99	1.15	0	0	0	1	1	0	1	2
25	SE	IS 29 N	90.22	1.13	5	2	3	3	7	4	5	8
26	SE	IS 229 S	100.32	1.48	4	3	2	4	4	4	12	9
27	SE	IS 29 N	69.77	3.54	3	3	2	7	4	4	23	14
28	SE	US 36 E	96.85	2.63	3	6	4	7	17	9	15	17
29	SL	IS 229 N	224.84	0.69	3	1	1	2	4	2	7	4
30	SL	IS 55 N	205.34	2.48	2	13	5	11	22	24	37	25
31	SL	IS 55 N	1.87	1.03	6	4	2	4	20	8	5	10
32	SL	IS 55 N	4.81	1.08	5	5	1	3	12	9	11	9
33	SL	IS 55 N	7.05	2.22	12	14	4	9	43	28	24	20
34	SL	IS 44 E	240.75	1.11	0	3	1	3	4	4	9	8
35	SL	IS 44 W	42.54	1.46	3	5	3	5	13	8	22	13
36	SL	IS 55 N	177.03	1.33	6	6	4	5	20	11	9	13
37	SW	IS 44 E	7.03	1.28	0	3	5	4	3	4	11	9
38	SW	IS 44 E	9.79	1.46	0	2	3	4	8	4	6	8
39	SW	US 160 E	96.12	1.75	7	5	7	6	4	8	8	15
40	SW	US 71 N	56.16	0.94	0	1	1	2	2	1	3	4
41	SW	US 65 N	38.82	2.34	3	7	3	8	14	13	11	19
Sum					**100**	**141**	**95**	**158**	**363**	**248**	**434**	**362**
Calibration Factors					**0.708**		**0.603**		**1.461**		**1.200**	

Notes: [1]District, [2]Fatal and Injury, [3]Property Damage Only, [4]Observed crashes, and [5]Predicted crashes.

The IHSDM output is shown in Figures 7.17 to 7.20.

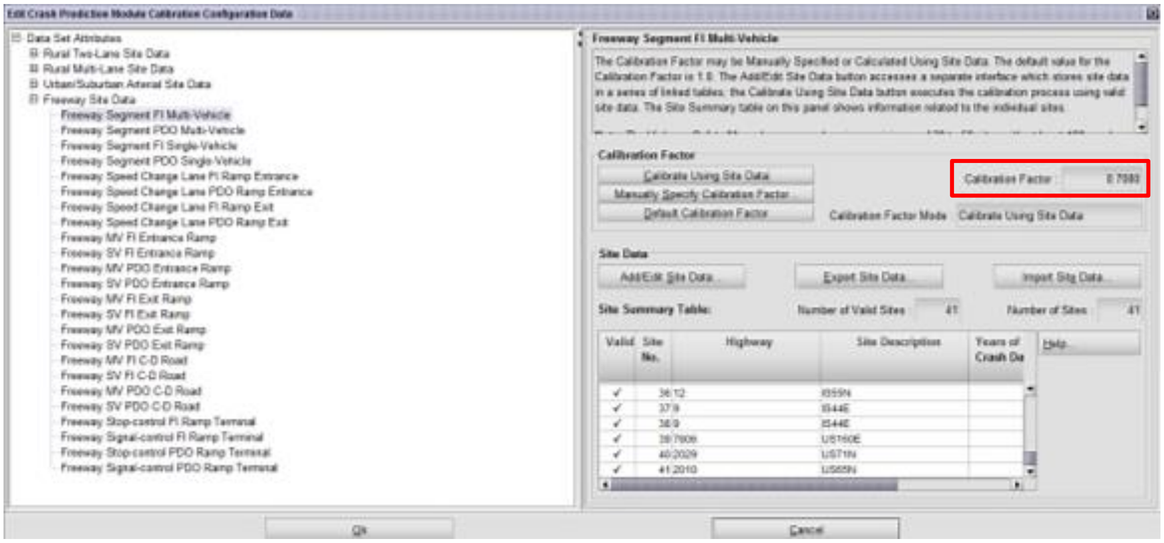


Figure 7.17 Calibration output for urban four-lane freeways (FI multi-vehicle)

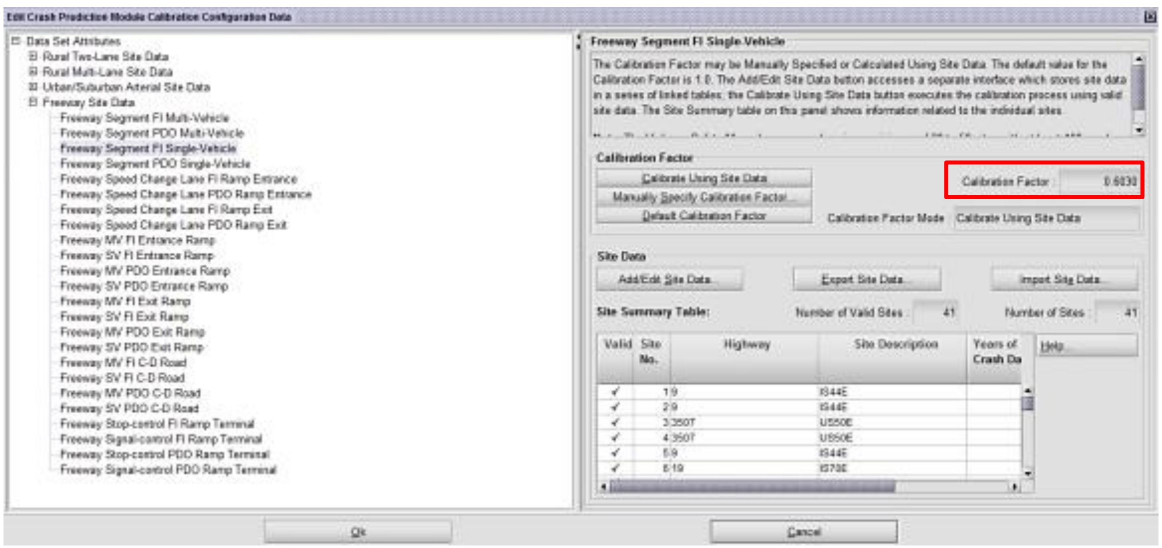


Figure 7.18 Calibration output for urban four-lane freeways (FI single-vehicle)

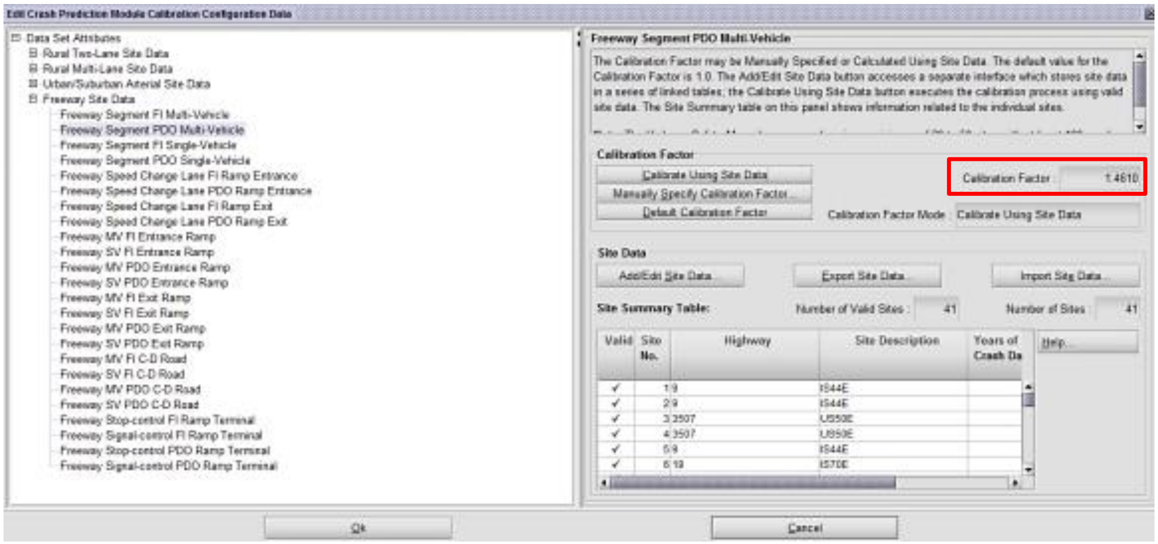


Figure 7.19 Calibration output for urban four-lane freeways (PDO multi-vehicle)

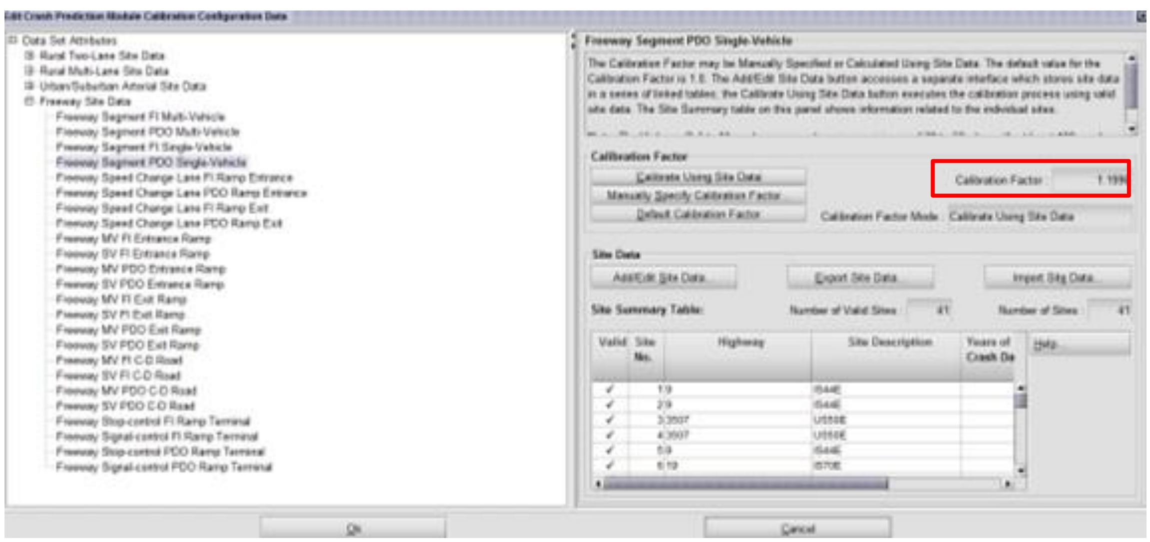


Figure 7.20 Calibration output for urban four-lane freeways (PDO single-vehicle)

These results indicate that the number of property damage only crashes observed in Missouri, both single- and multiple-vehicle, was greater than the number of crashes predicted by the HSM freeway methodology. Meanwhile, the number of fatal/injury crashes, both single and multiple vehicle, was lower than the number of crashes predicted by the HSM methodology. Possible reasons for the calibration values deviating from 1.0 include differences in driver behavior, differences in PDO crash reporting, and the sampling of segments with or without speed change lanes. Again, the higher PDO reporting thresholds used for the HSM model states is one explanation for the PDO calibration factors being greater than 1.0.

7.6.2.2 Severity Distribution Factors

Using the calibration data, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 7.14 shows the obtained SDFs for urban four-lane freeway segments.

Table 7.14 Severity Distribution Factors for urban four-lane freeway segments

Severity	MV		SV	
	Crashes	**SDF**	**Crashes**	**SDF**
Fatal	4	0.009	6	0.011
Disabling Injury	14	0.030	17	0.032
Minor Injury	82	0.177	72	0.136
Property Damage Only	363	0.784	434	0.820

7.6.2.3 Crash Type Distribution Factors

The CDFs are used to determine the proportion of crashes from the prediction according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because HSM and Missouri crash type categories differed. Therefore, different categories were aggregated to provide similar classifications to those recommended by the HSM. The crash types also were divided by multiple- and single-vehicle crashes. Table 7.15 provides the CDFs for urban four-lane freeway segments.

Table 7.15 Crash type distribution factors for urban four-lane freeway segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Angle	2	0.004
Head-on	7	0.016
Sideswipe	105	0.233
Rear-end	252	0.560
Other	84	0.187
Single-Vehicle		
Crash with Parked Vehicle	13	0.024
Crash with Fixed Object	16	0.030
Crash with Animal	83	0.154
Out of Control	370	0.688
Other	56	0.104

7.6.3 Results for Urban Six-Lane Freeway Segments

7.6.3.1 Calibration Factors

The calibration factors for urban six-lane freeway segments are shown in Table 7.16.

Table 7.16 Calibration results for urban six-lane freeway segments

No.	Dist.[1]	Segment	Begin Log	Length (mi)	FI[2]				PDO[3]			
					MV		SV		MV		SV	
					Obs4	Prd5	Obs	Prd	Obs	Prd	Obs	Prd
1	KC	IS 70 E	11.57	0.80	10	14	6	4	30	32	7	12
2	KC	IS 70 E	12.93	0.82	18	16	5	5	29	36	2	13
3	KC	IS 70 E	14.37	0.59	7	8	5	3	15	18	1	9
4	KC	IS 70 E	18.87	0.84	3	4	7	3	17	8	11	10
5	KC	IS 49 N	174.56	0.66	8	6	5	4	31	12	12	10
6	KC	IS 49 N	173.86	0.61	3	6	5	3	14	10	8	9
7	SL	IS 55 N	182.47	0.66	4	3	4	3	10	6	3	7
8	KC	US 71 N	198.12	0.50	12	5	2	3	34	10	10	8
9	KC	IS 70 W	244.97	0.48	12	9	2	4	29	14	1	10
10	KC	IS 29 N	8.78	0.50	2	12	1	3	15	22	7	7
11	KC	IS 29 N	9.28	0.55	3	9	4	3	11	20	7	8
12	KC	IS 29 N	20.11	0.54	0	2	0	2	4	3	3	4
13	KC	IS 29 N	20.65	0.84	0	2	1	2	4	3	6	5
14	KC	IS 35 N	7.21	0.83	8	6	5	5	32	12	10	10
15	KC	IS 435 N	6.37	0.63	7	4	3	3	4	9	12	8
16	KC	IS 435 N	7.00	0.86	4	7	5	7	5	14	12	15
17	KC	IS 470 E	2.41	0.59	0	6	2	2	2	12	3	8
18	KC	IS 470 E	3.00	0.66	1	7	1	3	11	14	2	9
19	KC	IS 470 E	5.77	0.66	5	6	4	3	27	11	12	9
20	SL	IS 44 E	266.89	0.51	5	4	1	2	13	7	1	8
21	SL	IS 70 E	233.43	0.50	4	10	2	4	11	25	4	9
22	SL	IS 55 N	183.20	0.65	1	3	2	3	10	6	8	7
23	SL	IS 70 E	237.00	0.50	13	11	3	3	17	26	7	7
24	SL	MO 370 E	3.07	1.32	3	6	1	4	8	9	7	13
25	SL	MO 370 E	5.54	1.88	1	9	5	6	13	16	8	21
26	SL	IS 64 E	33.13	0.54	11	32	6	6	43	79	7	11
27	SL	IS 64 E	22.31	0.65	41	16	3	4	88	38	5	11
28	SL	IS 64 E	21.27	0.54	34	12	4	3	94	29	5	9
29	SL	IS 64 E	17.88	0.64	7	7	2	3	19	15	2	8
30	SL	IS 64 E	14.94	1.37	9	14	2	6	29	31	4	17
31	SL	IS 70 E	212.27	1.38	2	16	2	6	19	33	10	20
32	SL	IS 70 E	214.39	1.25	5	18	5	8	24	37	17	18
33	SL	IS 70 E	223.44	0.48	4	18	2	7	33	40	13	17
34	SL	IS 70 E	224.14	0.68	6	10	2	4	26	22	4	10
35	SL	IS 70 E	225.55	1.09	14	20	2	7	63	48	11	17
36	SL	IS 70 E	232.33	0.62	23	16	7	4	82	40	21	10
37	SL	IS 70 E	239.91	0.85	14	19	6	6	29	47	15	13
38	SL	IS 70 E	246.56	0.38	13	12	10	3	24	21	21	7
39	SW	US 65 S	260.08	0.38	1	2	0	2	0	3	0	4
40	SW	US 65 S	263.62	0.36	6	2	4	2	24	4	12	4
41	SW	US 65 S	259.61	0.31	7	1	3	1	17	2	8	3
42	SW	US 65 S	265.77	0.77	4	4	2	4	2	8	4	9

No.	Dist.[1]	Segment	Begin Log	Length (mi)	FI[2]				PDO[3]			
					MV		SV		MV		SV	
					Obs4	Prd5	Obs	Prd	Obs	Prd	Obs	Prd
43	KC	IS 49 N	172.57	0.45	8	4	3	3	51	7	19	6
44	KC	IS 70 E	15.19	0.54	7	12	6	2	22	22	5	8
45	KC	IS 70 E	15.73	0.57	4	10	3	3	11	20	3	7
46	SL	IS 64 E	37.11	0.47	14	7	3	4	56	15	6	8
47	KC	IS 70 E	16.30	0.53	13	6	3	2	24	14	8	7
48	KC	IS 70 E	17.06	0.60	6	7	4	3	16	16	18	8
49	KC	IS 70 E	17.66	0.56	6	7	6	3	19	15	19	7
50	SL	IS 44 E	262.48	0.79	2	4	2	3	8	7	6	9
51	SL	IS 44 E	263.27	0.69	3	3	5	4	6	6	16	9
52	SL	IS 270 E	28.74	0.66	3	19	3	5	18	47	6	11
53	SL	IS 270 E	30.22	0.41	7	11	5	3	30	23	4	7
54	SL	IS 55 N	184.06	0.54	3	3	3	2	8	5	10	6
Sum					**411**	**486**	**189**	**196**	**1,281**	**1,050**	**443**	**519**
Calibration Factors					**0.846**		**0.964**		**1.22**		**0.854**	

Notes: [1]District, [2]Fatal and Injury, [3]Property Damage Only, [4]Observed crashes, and [5]Predicted crashes.

The IHSDM output is shown in Figures 7.21 to 7.24.

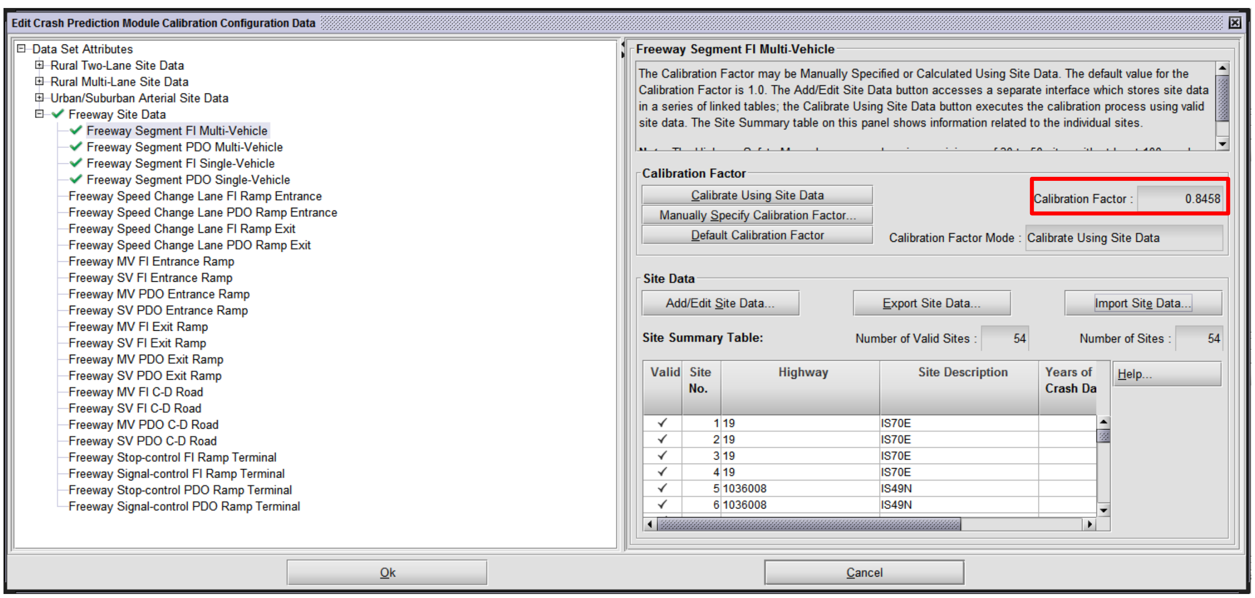


Figure 7.21 Calibration output for urban six-lane freeways (FI multi-vehicle)

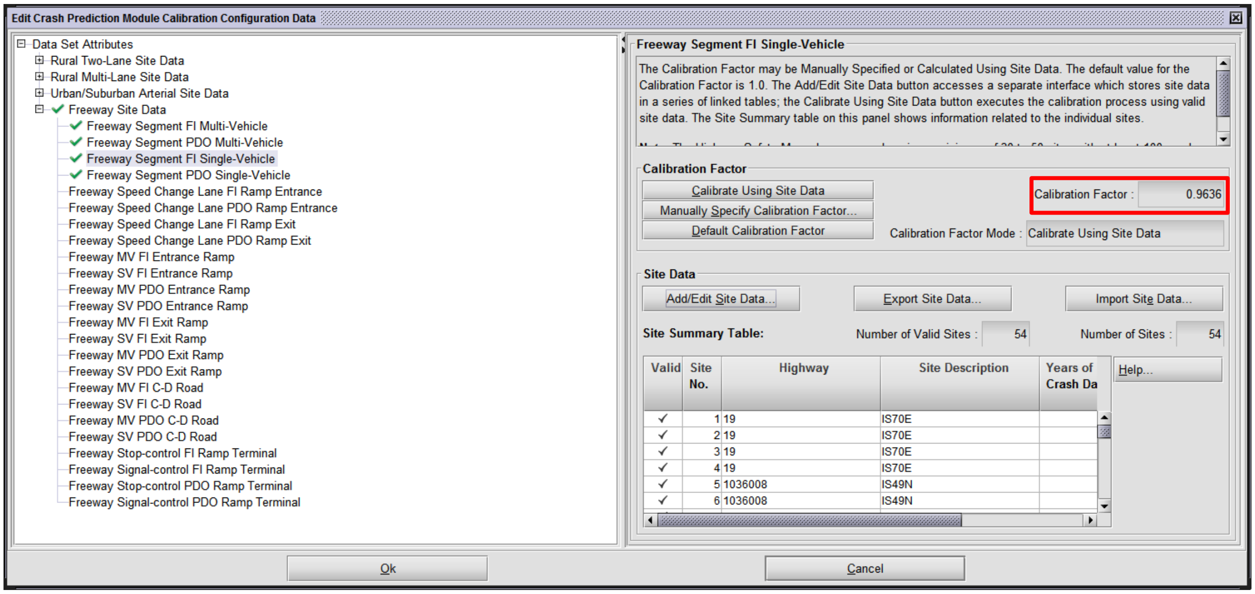


Figure 7.22 Calibration output for urban six-lane freeways (FI single-vehicle)

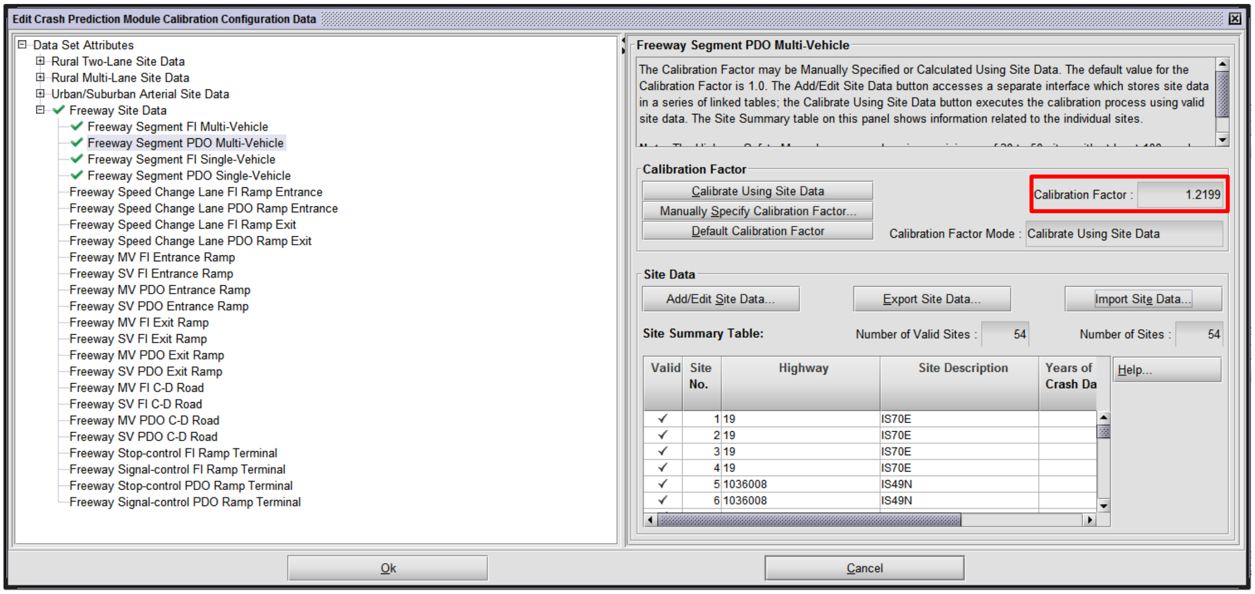


Figure 7.23 Calibration output for urban six-lane freeways (PDO multi-vehicle)

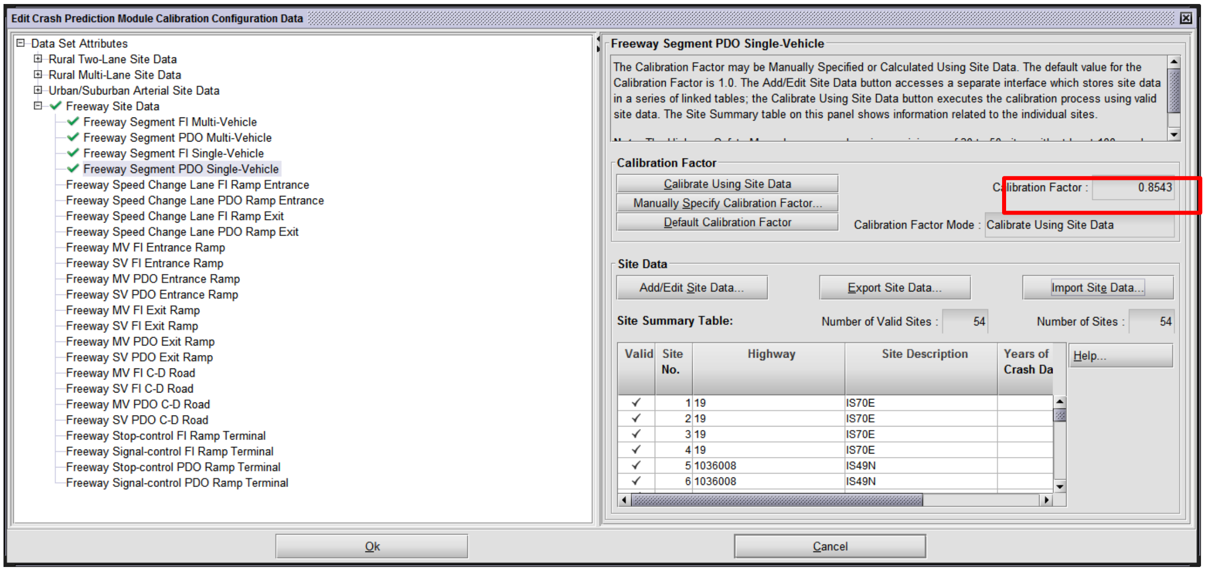


Figure 7.24 Calibration output for urban six-lane freeways (PDO single-vehicle)

These results indicate that the number of property damage only multiple-vehicle crashes observed in Missouri was greater than the number of crashes predicted by the HSM freeway methodology. Meanwhile, the number of property damage only single-vehicle crashes, fatal/injury single-vehicle crashes, and fatal/injury multiple-vehicle crashes was lower than the number of crashes predicted by the HSM methodology. There could be many reasons for these differences, as discussed previously in the section detailing the results for four-lane freeways. However, it is important to note that the sites for this HSM calibration did not contain any speed change lane facilities and on average contained longer freeway segments compared to the previous calibration efforts. Additionally, the introduction of the high volume proportion parameter was new to this calibration and contributed to the difference in results for this facility type.

7.6.3.2 Severity Distribution Factors

Using the calibration data, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only for both multi-vehicle and single-vehicle crashes. Table 7.17 shows the SDFs obtained for urban six-lane freeway segments.

Table 7.17 Severity distribution factor for urban six-leg freeway segments

	MV		SV	
Severity	**Crashes**	**SDF**	**Crashes**	**SDF**
Fatal	4	0.002	9	0.014
Disabling Injury	31	0.018	23	0.036
Minor Injury	376	0.222	157	0.248
Property Damage Only	1281	0.757	443	0.701

7.6.3.3 Crash Type Distribution Factors

The CDFs are used to determine the proportion of crashes from the prediction according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required because there are multiple crash type categories included in the crash reports. For example, crashes that were classified as “Left-Turn Right Angle” or “Right-Turn Right Angle” collisions were included as “Right Angle” crashes in the CDF distribution. Therefore, different categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were also divided by multiple- and single-vehicle crashes. It should be noted that the crash query results returned crashes with parked cars as multi-vehicle crashes while the HSM classifies them as single-vehicle crashes. For this reason, parked vehicle crashes were reclassified as single-vehicle crashes to calculate the CDF. Table 7.18 provides the CDFs for urban six-leg freeway segments.

Table 7.18 Crash type distribution factors for urban six-leg freeway segments

Collision Type	Crashes	CDF
Multiple-Vehicle		
Angle	9	0.005
Head-on	22	0.013
Sideswipe	437	0.261
Rear-end	1,024	0.612
Other	181	0.108
Single-Vehicle		
Crash with Parked Vehicle	19	0.029
Crash with Fixed Object	39	0.060
Crash with Animal	33	0.051
Out of Control	466	0.716
Other	94	0.144

CHAPTER 8. URBAN SIGNALIZED INTERSECTIONS

8.1 Introduction

Urban signalized intersections have facility-specific geometric, operational, and surrounding area conditions. Chapter 12 of the HSM describes the methodology for crash prediction for signalized intersections, including both three-leg and four-leg signalized intersections. This chapter contains a detailed description of the data requirements, the HSM prediction methodology, and the calibration results.

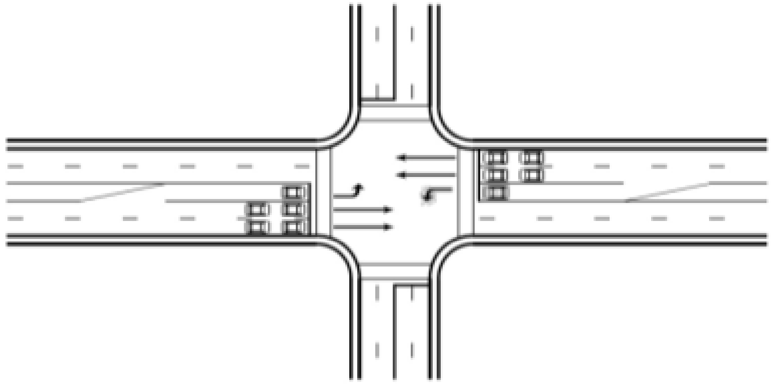
8.2 Calibration Data Requirements

The input data in the IHSDM were divided into required and desired data. The required data consisted of site, crash, and traffic data. The desired data were optional and included variables such as pedestrian facilities, bus stops, alcohol sales establishments, and educational facilities.

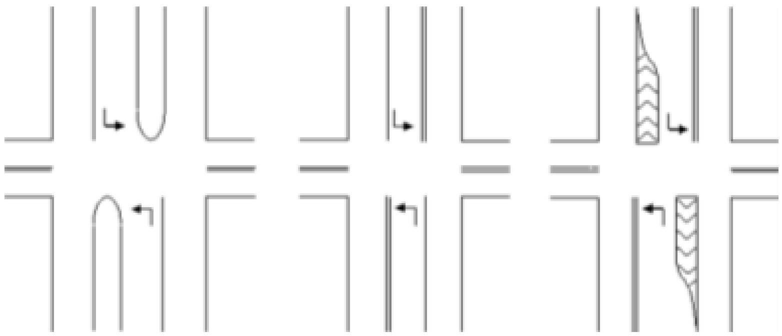
8.2.1 Required Site Data

8.2.1.1 Number of Approaches with Left-Turn Lanes

Left-turn lanes at a signalized intersection are defined as exclusive lanes for left-turn operations and exist in addition to through lanes. An exclusive left-turn lane includes an entering taper with sufficient storage length to accommodate queued vehicles. Figure 8.1(a) shows a conventional left-turn configuration at a four-leg signalized intersection. There are variations of offsets between opposing left-turns. Negative offsets and positive offsets may be located in approaches with sufficient median separation to accommodate left turns. Figure 8.1(b) shows a negative offset and Figure 8.1(d) shows a positive offset. Some intersections have through lanes converted to left-turn lanes with no offset, as illustrated in Figure 8.1(c).



(a) Diagram of major road left turns



(b) Negative offset **(c) No offset** **(d) Positive offset**

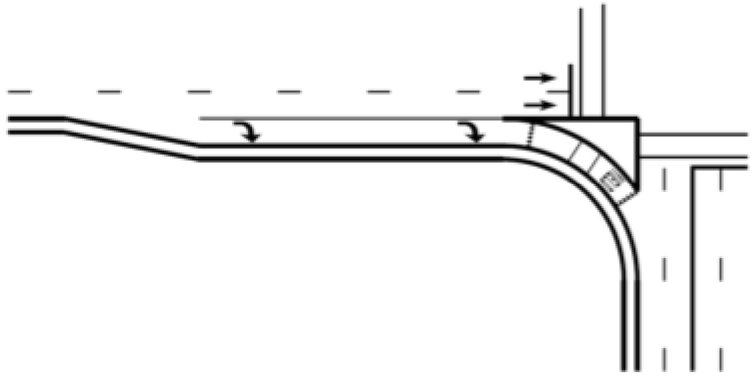
ODOT 2012; Chandler et al. 2013

Figure 8.1 Diagrams for left-turn movements

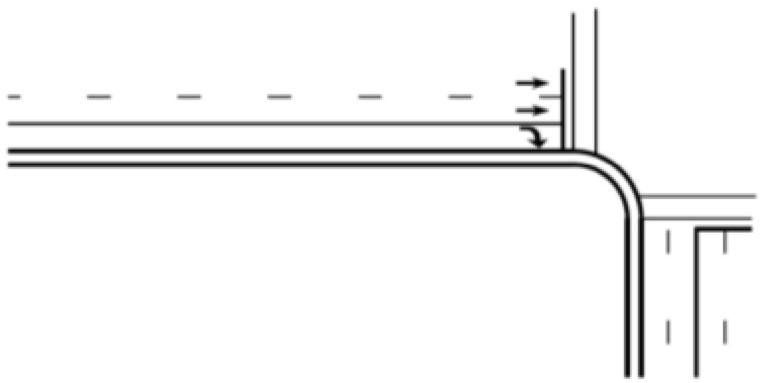
For the purposes of the IHSDM data input for urban signalized intersections, the number of approaches with left-turn lanes was counted. The input value for four-leg signalized intersections should be between 0 and 4 and between 0 and 2 for three-leg signalized intersections.

8.2.1.2 Number of Approaches with Right-Turn Lanes

Right-turn lanes at a signalized intersection are defined as exclusive lanes for right-turn operations at intersections. A right-turn lane with higher speeds may exist with an entering taper, sufficient lane queue storage, and channelization, as illustrated in Figure 8.2(a). For lower speed designs, shown in Figure 8.2(b), a through lane may be designated as a right-turn lane with a smaller turn radius and without channelization.



(a) Right turn higher speed design



(b) Right turn lower speed design

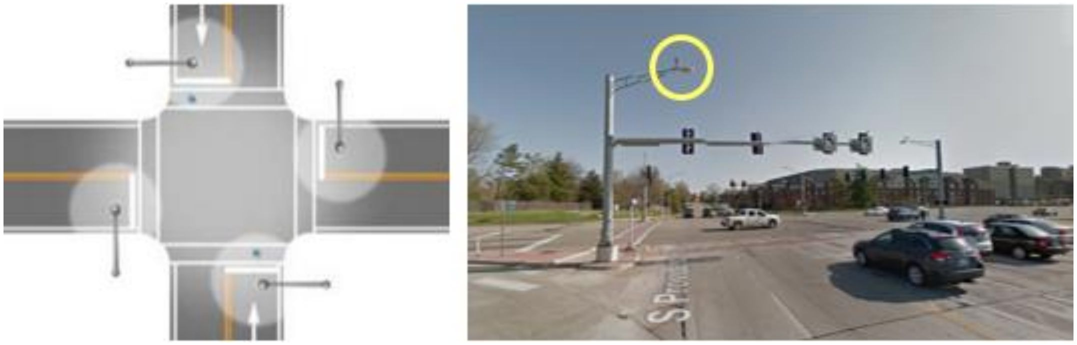
ODOT 2012

Figure 8.2 Common right turn configurations

In the IHSDM data input for urban signalized intersections, the number of approaches with right-turn lanes is counted. The input value should be between 0 and 4 for four-leg signalized intersections and 0 to 2 for three-leg signalized intersections.

8.2.1.3 Presence of Lighting

Illumination close to the intersection is considered lighting. The IHSDM data input requires specifying only whether or not there is lighting at the intersection (i.e., yes or no). Figure 8.3 shows common lighting configurations.



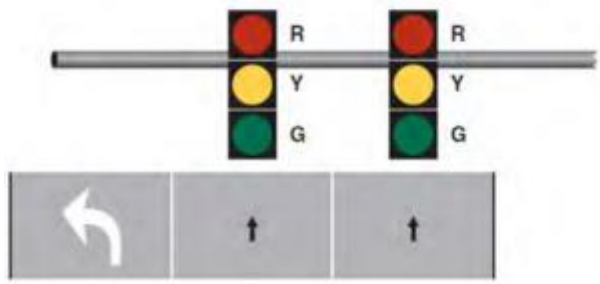
(a) Common intersection lighting layout **(b) Street view of intersection with lighting**

Gibbons et al. 2008, © Google 2016

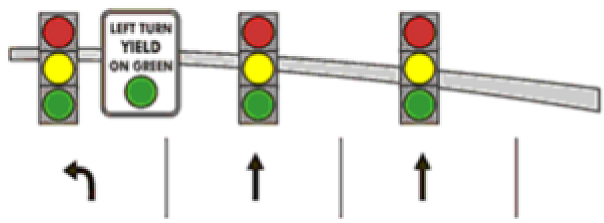
Figure 8.3 Intersection lighting

8.2.1.4 Number of Approaches with Permissive Left Turns

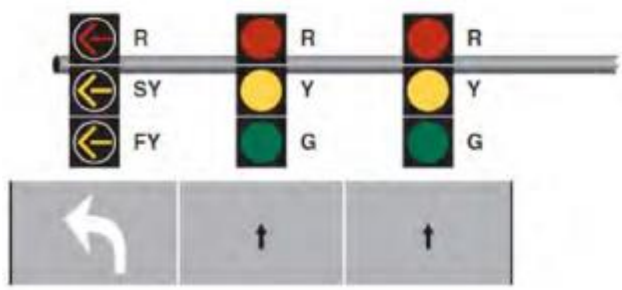
Permissive left-turn phasing refers to two opposing approaches operating simultaneously with left turns allowed but yielding to opposing traffic and pedestrians. Figure 8.4 shows common signal head configurations for permissive left turns.



(a) Signals heads over the through lanes



(b) Signals heads over though lanes and left-turn lane



(c) Signal head over left-turn lane with flashing yellow

Chandler et al. 2013, MUTCD 2009

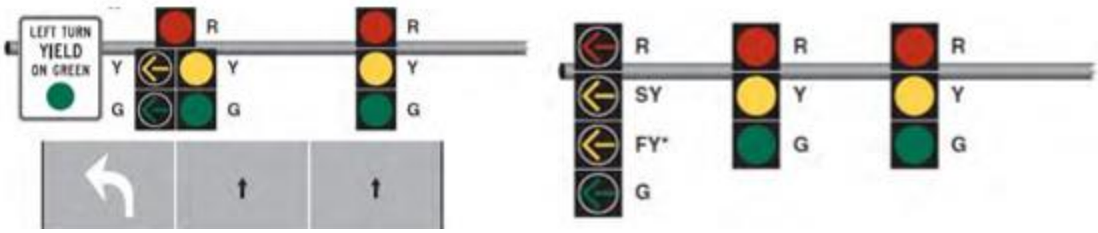
Figure 8.4 Common permissive left-turn signals

In the IHSDM data input for urban signalized intersections, the number of approaches with permissive left-turn phasing is counted. The input value should be between 0 and 4 for four-leg signalized intersections and between 0 and 2 for three-leg signalized intersections.

8.2.1.5 Number of Approaches with Permissive/Protective Left Turns

A combination of a protected only left-turn phasing with permissive left-turn phasing is referred to as protected/permissive. According to the MUTCD (2009), the two signal head configurations are (1) left-turn lane and adjacent through lane sharing same signal head and (2) separate signal head(s) exclusively for left turn(s).

The first configuration is illustrated in Figure 8.5(a). A five-signal head configuration is commonly used for dual signalization for the left and adjacent through lane. This signal configuration is also known as "dog house." The second signal configuration provides a signal head for exclusive signalization of the left-turn protected/permissive phase, as illustrated in Figure 8.5(b).



(a) Dog house with accompanying sign **(b) Four vertical signal head over left-turn lane**

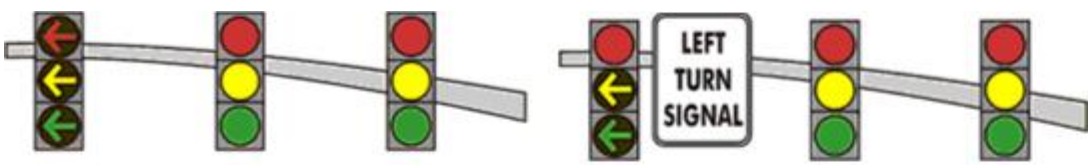
Chandler et al. 2013

Figure 8.5 Permissive/protected left-turn signals

In the IHSDM data input for urban signalized intersections, the number of approaches with protected/permissive left-turn phasing is counted. The input value for four-leg signalized intersections should be between 0 and 4 and between 0 and 2 for three-leg signalized intersections.

8.2.1.6 Number of Approaches with Protected Left Turn

Protected left-turn phasing provides a separate phase for left-turning movements with left-turn arrow signalization. No pedestrian or vehicular traffic is allowed to conflict with the protected left-turn movements (Chandler et al. 2013). Figure 8.6 shows commonly used protected only left-turn signal configurations.



(a) Signal head with left-turn arrows **(b) Signal with arrows and sign**

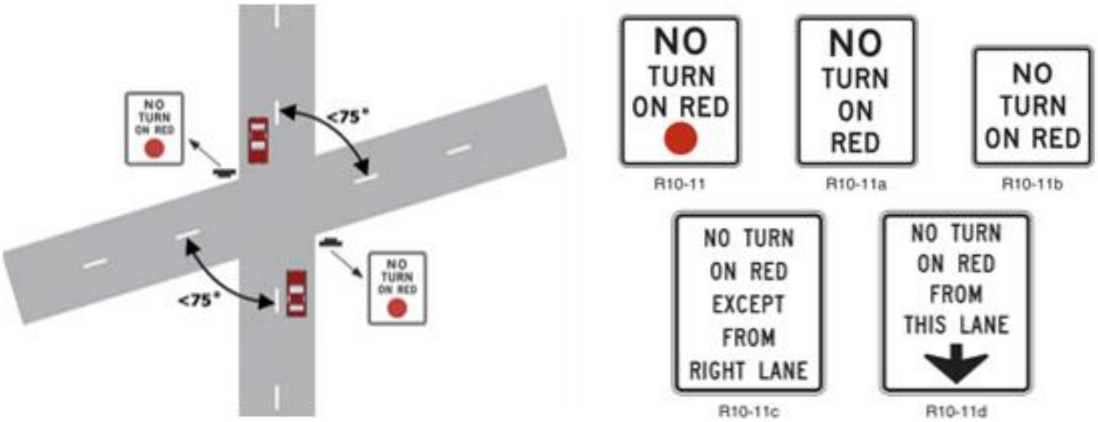
MUTCD 2009

Figure 8.6 Protected only left-turn signals

In the IHSDM data input for urban signalized intersections, the number of approaches with protected only left-turn phasing is counted. The input value for four-leg signalized intersections should be between 0 and 4 and between 0 and 2 for three-leg signalized intersections.

8.2.1.7 Number of Approaches on which Right Turn on Red is Prohibited

Some signalized intersections may have inadequate sight distance to vehicles approaching from the left. Geometry, pedestrian exclusive phase, and a skew angle less than 75 degrees may also contribute to inadequate visibility and operation of right turns (Harkey et al. 2014). Therefore, right-turn movement on red may be prohibited. Figure 8.7(a) shows an example of an intersection with skew angle and Figure 8.7(b) shows the different signs recommended by the MUTCD (2009).



(a) Right turn on red prohibited **(b) No turn on red signs**

Harkey et al. 2014, MUTCD 2009

Figure 8.7 Right turn on red prohibited

8.2.1.8 Presence of Red Light Cameras

Red light cameras are automated enforcement devices at signalized intersections that capture images and record information to enforce red light running violations. The IHSDM data input requires specifying only whether or not there is a red light camera at the intersection (i.e., yes or no). Figure 8.8 shows an example of a red light camera.

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Figure 8.8 Red light camera

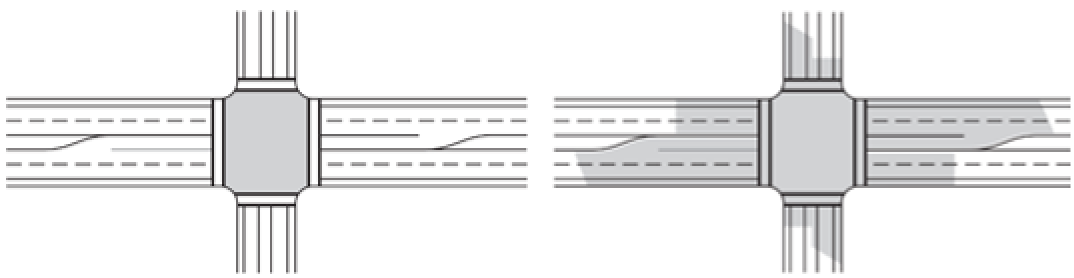
8.2.2 Required Crash and Traffic Data

8.2.2.1 Years of Crash Data

The years associated with the calibration should be specified. The IHSDM considers up to three years for the input data.

8.2.2.2 Observed Number of Crashes

The observed number of crashes at an intersection refers to the crashes attributed to the geometry and operation of signalized intersections. The HSM provides guidance for crash assignment based on intersection physical and functional areas (AASHTO 2010). The Green Book (AASHTO 2011) defines an intersection as “the general area where two or more roadways join or cross, including the roadway and roadside facilities for traffic movements within the area.” An at-grade intersection is defined “by both its physical and functional areas.” The functional area “extends both upstream and downstream from the physical intersection area and includes any auxiliary lanes and their associated channelization.” The functional area on each approach to an intersection consists of (1) decision distance, (2) maneuver distance, and (3) queue storage distance. Figure 8.9 illustrates both physical and functional areas, with the intersection area colored in gray. MoDOT assigns a crash to an intersection if the crash occurred within 132 ft of the intersection.



(a) Physical area **(b) Functional area**

Figure 8.9 Intersection physical and functional areas

In the IHSDM data input for urban signalized intersections, the total number of observed crashes for the years specified in the calibration should be used (i.e., 3 years).

8.2.2.3 Major Road AADT

The major road at an intersection may be determined by considering the road classification hierarchy and AADT. Usually, the major road experiences higher AADT than the minor road. However, when the AADT of both approaching roads is similar, the highest road classification hierarchy should be designated as the major road. The major road AADT for every year specified in the calibration is inputted into the IHSDM.

8.2.2.4 Minor Road AADT

The minor road is designated as the road that holds less traffic and has a lesser position in the hierarchy compared to the other road. The minor road AADT for every year specified in the calibration is inputted in the IHSDM.

8.2.3 Desired Site Data

8.2.3.1 Pedestrian Volumes Crossing All Intersection Legs

Pedestrian volumes are used to estimate vehicle-pedestrian collisions. Based on an observation of the surroundings and pedestrian facilities at intersections, the level of pedestrian activity can be estimated. The estimate is made in terms of pedestrian crossings per day. In Table 8.1, the different level of pedestrian activity for input in the IHSDM data are provided for three- and four-leg intersections.

Table 8.1 Estimates of pedestrian volumes

General Level of Pedestrian Activity	**Estimate of PedVol (pedestrians/day) for Use in Equation 12-29**	
	3SG Intersections	**4SG Intersections**
High	1,700	3,200
Medium-High	750	1,500
Medium	400	700
Medium-Low	120	240
Low	20	50

Source: AASHTO 2010

8.2.3.2 Maximum Number of Lanes Crossed by Pedestrians

According to the HSM (AASHTO 2010):

The maximum number of traffic lanes that a pedestrian must cross in any crossing maneuver at the intersection should be counted. Both through and turning lanes that are crossed by a pedestrian along the crossing path are considered. If the crossing path is broken by an island that provides a suitable refuge for the pedestrian so that the crossing may be accomplished in two (or more) stages, then the number of lanes crossed in each stage is considered separately. To be considered as a suitable refuge, an island must be raised or depressed; a flush or painted island is not treated as a refuge.

It should be noted that only the longest crossing path (one crossing path) is considered and not the sum of all approaching legs or paths (AASHTO 2010). Figure 8.10 illustrates the procedure to count the maximum number of lanes crossed.

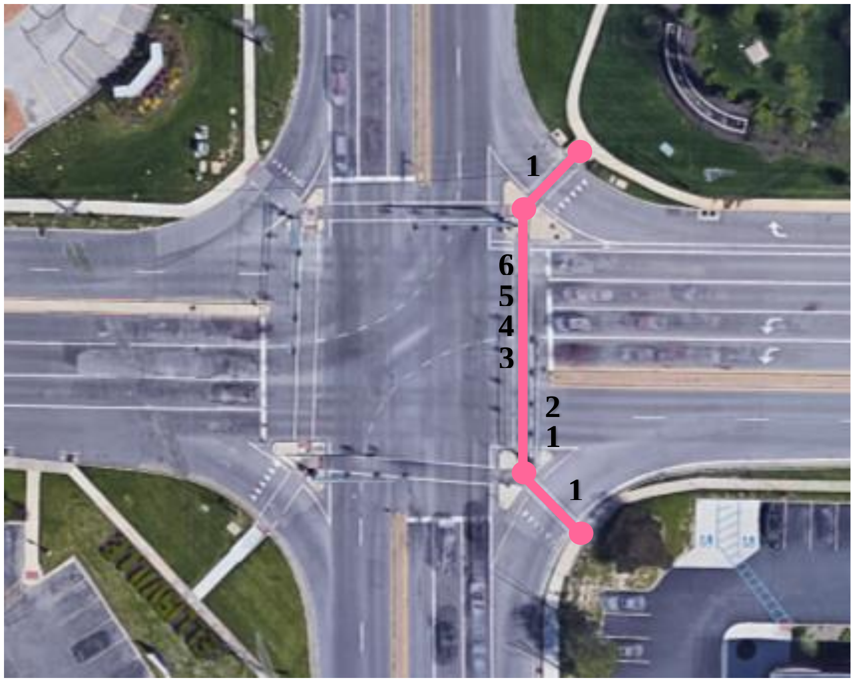


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Figure 8.10 Example of maximum number of lanes crossed

In this example, the maximum number of lanes crossed is six. The right-turn lanes were not counted because there were islands that provided appropriate refuge for pedestrians to cross at different stages.

8.2.3.3 Number of Bus Stops within 1,000 ft of Intersection

According to the HSM (AASHTO 2010),

> [m]ultiple bus stops at the same intersection (i.e., bus stops in different intersection quadrants or located some distance apart along the same intersection leg) are counted separately. Bus stops located at adjacent intersections would also be counted as long as any portion of the bus stop is located within 1,000 ft of the intersection being evaluated.

HSM recommends that local transit bus stop records be used to determine the number of stops within the 1,000 ft threshold at an intersection. If no records are available, aerial photographs could be used. It should be noted that the bus stops could be relocated or replaced over time. Figure 8.11 shows an example of three bus stops within 1,000 ft from the center of an intersection.

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Figure 8.11 Intersection bus stops

8.2.3.4 Number of Schools within 1,000 ft of Intersection

According to the HSM (AASHTO 2010), "[a] school may be counted if any portion of the school grounds is within 1,000 ft of the intersection." Figure 8.12 shows an example of school next to an intersection.

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Figure 8.12 Educational facility close to intersection

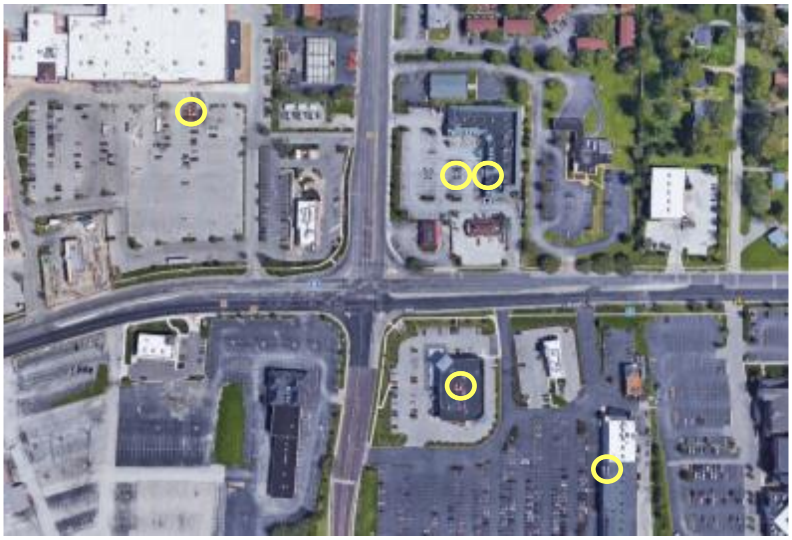
The use of local school registration data is desirable. However, aerial photographs could be used if no other data are available. It should be noted that the educational facilities might not have been present during the period of analysis of the calibration.

8.2.3.5 Number of Alcohol Sales Establishments within 1,000 ft of Intersection

According to the HSM (AASHTO 2010),

> [a]ny alcohol sales establishment wholly or partly within 1,000 ft of the intersection may be counted. The CMF includes any alcohol sales establishment, which may include liquor stores, bars, restaurants, convenience stores, or grocery stores. Alcohol sales establishments are counted if they are on any intersection leg or even on another street, as long as they are within 1,000 ft of the intersection being evaluated.

The use of local business registration data is desirable. However, aerial photographs could be used if no other data are available. It should be noted that the alcohol sales establishments might not have been present during the period of analysis of the calibration. Figure 8.13 shows an example of alcohol sales establishments identified near an intersection. The establishments were verified individually because not all businesses sell alcohol (e.g., fast food restaurants).



© Google 2016

Figure 8.13 Alcohol sale establishments close to an intersection

8.3 HSM Prediction Methodology

As described in Chapter 12 of the HSM (AASHTO 2010), the SPFs for urban signalized intersections predict the number of total crashes at the intersection per year for base conditions. The SPF is based on the major and minor AADTs of the intersection. The SPFs include four functions in order to predict all possible crash frequencies. These functions include N_{bimv}, N_{bisv}, N_{pedi}, and N_{bikei}. The N_{bimv} term is the predicted average number of multiple-vehicle crashes for base conditions, N_{bisv} is the predicted average number of single-vehicle crashes for base conditions, N_{pedi} is the predicted average number of pedestrian-involved crashes for base conditions, and N_{bikei} is the predicted average number of bicyclist-involved crashes for base conditions.

In order to predict the number of crashes that may occur within an urban or suburban arterial intersection, the following equations are applied:

$$N_{\text{predicted } int} = C_i \text{ x } (N_{bi} + N_{pedi} + N_{bikei}) \quad \textbf{(8.1)}$$

$$N_{bi} = N_{spf\ int} \text{ x } (CMF_{1i} \text{ x } CMF_{2i} \text{ x } \ldots \text{ x } CMF_{6i}) \quad \textbf{(8.2)}$$

where

$N_{\text{predicted } int}$ is the total predicted average crash frequency within an intersection for a selected year

$N_{spf\ int}$ is the predicted number of total intersection crashes per year for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions)

N_{bi} is the predicted average crash frequency within an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions)

The general form of the SPF is given by the following:

$$N_{spf\ int} = N_{bimv} + N_{bisv} \quad \textbf{(8.3)}$$

$$N_{bimv} = exp[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min})] \quad \textbf{(8.4)}$$

$$N_{bisv} = exp[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min})] \quad \textbf{(8.5)}$$

where

N_{bimv} is the number of multiple-vehicle crashes

N_{bisv} is the number of single-vehicle crashes

$AADT_{maj}$ is the annual average daily traffic (vehicles/day) for major roads (both directions of travel combined)

$AADT_{min}$ is the annual average daily traffic (vehicles/day) for minor roads (both directions of travel combined)

a, *b*, *c* are regression coefficients

The number of vehicle-pedestrian crashes predicted for an intersection during a given year was determined with an SPF and a set of CMFs. The number of vehicle-bicycle crashes was predicted in a similar fashion. The following shows the model used for vehicle-pedestrian crashes within signalized intersections:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p} \quad \textbf{(8.6)}$$

where

$N_{pedbase}$ is the predicted number of vehicle-pedestrian collisions per year for base conditions at signalized intersections

$CMF_{1p} \ldots CMF_{3p}$ are the crash modification factors for vehicle-pedestrian collisions at signalized intersections

Values for $N_{pedbase}$ depend on total AADT, minor AADT, major AADT, pedestrian volume, and maximum number of lanes crossed by pedestrian.

The predicted number of vehicle-bicycle crashes at signalized intersections over a given year was determined by the following:

$$N_{bikei} = N_{bi} \times f_{bikei} \qquad \textbf{(8.6)}$$

where f_{bikei} is the bicycle crash adjustment factor.

CMFs introduce facility traits into the prediction. Thus, the HSM prediction models have specific base condition for each CMF. Table 8.2 shows the base conditions used as crash modification factors for signalized intersections.

Table 8.2 Base conditions used for intersection crash predictions

Crash Modification Factor	Base Condition
Intersection Left-Turn Lanes	Not Present
Intersection Left-Turn Signal Phasing	Permissive Left-Turn Phasing
Intersection Right-Turn Lanes	Not Present
Right Turn on Red	Permitting
Lighting	Not Present
Red-Light Cameras	Not Present
Bus Stops within 1,000 ft of the Intersection	Not Present
School within 1,000 ft of the Intersection	Not Present
Alcohol Sales Establishments within 1,000 ft of the Intersection	Not Present

8.4 Sampling

Most samples from the previous calibration were used. The samples dropped from the previous sample set were sites that experienced significant changes in geometry, operations, and/or classification. In addition, some intersections were dropped because the sites did not meet the urban signalized intersection classification criteria (e.g., ramp terminals). Because some facilities had to be dropped, additional samples were selected to fulfill the HSM minimum requirements for calibration. The sampling process used random selection from the intersection list generated in the previous calibration project (Sun et al. 2014).

The list of samples for urban three-leg signalized intersections is shown in Table 8.3.

Table 8.3 List of sites for urban three-leg signalized intersections

No.	District	Description	Int. No.	City	County
1	CD	RT B/MO 87 (Main St.) and MO 87 (Bingham Rd.)	188779	Boonville	Cooper
2	CD	US 63 (N Bishop Ave.) and RT E (University Ave.)	409359	Rolla	Phelps
3	CD	LP 44 and MO 17	431017	Waynesville	Pulaski
4	CD	BU 50 (Missouri Blvd.) and Seay Place - Walmart (724 W Stadium Blvd)	651041	Jefferson City	Cole
5	CD	BU 50 and Stoneridge Blvd (Kohls entrance)	302396	Jefferson City	Cole
6	KC	MO 291 (NE Cookingham Dr.) and N Stark Ave.	121469	Kansas City	Clay
7	KC	US 40 and East 47th St. S	168735	Kansas City	Jackson
8	KC	MO 291 (NE Cookingham Dr.) and N Flintlock Road	123483	Liberty	Clay
9	KC	US 40 and Entrance to Blue Ridge Crossing	929297	Kansas City	Jackson
10*	KC	US 69 and Indiana Ave.	137412	Kansas City	Clay
11	NE	MO 15 and Boulevard St.	143089	Mexico	Audrain
12	NW	RT YY (Mitchell Ave.) and Woodbine Dr.	68340	St. Joseph	Buchanan
13	SE	US 61 and Old Orchard Rd.	489147	Jackson	Cape Girardeau
14	SE	RT K and Siemers Dr.	496486	Cape Girardeau	Cape Girardeau
15	SE	US 61 and Smith Ave.	574289	Sikeston	Scott
16	SE	Business 60 and Walmart Entrance	588152	Dexter	Stoddard
17*	SE	BU 60 (N Westwood Blvd.) and Valley Plaza Entrance	651105	Poplar Bluff	Butler
18	SL	MO 100 and Woodgate Dr.	288254	St. Louis	St. Louis
19	SL	MO 231 (Telegraph Rd.) and Black Forest Dr.	324301	St. Louis	St. Louis
20	SL	RT B (Natural Bridge Rd.) and Fee Fee Rd.	928641	St. Louis	St. Louis
21	SL	MO 180 and Stop n Save (St. John Crossing)	251803	St. John	St. Louis
22	SL	MO 267 (Lemay Ferry Rd.) and Victory Dr.	313246	St. Louis	St. Louis
23	SL	MO 47(W. Gravois Ave.) and MO 30 (Commercial Ave.)	347423	St. Clair	Franklin
24	SL	RT D and Page Industrial Blvd.	257667	St. Louis	St. Louis
25*	SL	MO 100 and Holloway Rd.	291512	Ballwin	St. Louis
26*	SL	N Hanley Rd. and University PI DR.	249780	St. Louis	St. Louis
27*	SL	Marine Ave. and Dorsett Rd.	253124	Maryland Heights	St. Louis
28	SL	Big Bend Rd. and New Ballwin Rd.	299708	Ballwin	St. Louis
29	SW	LP 49B/BU 60/BU 71 (N Rangeline Rd.) and Turkey Creek Road (North Park Ln)	543380	Joplin	Jasper
30	SW	RT D (Sunshine St.) and Lone Pine Ave.	523828	Springfield	Greene
31	SW	MO 744 (E Kearney St.) and N Cresthaven Ave.	932947	Springfield	Greene
32	SW	MO 744 (E Kearney St.) and N Neergard Ave.	512492	Springfield	Greene
33	SW	US 60 and Lowe's Ln	963973	Monett	Barry
34	SW	MO 66 (7th St.) and Walmart (2623 W. 7th St.)	963880	Joplin	Jasper
35	SW	MO 571 (S Grand Ave.) and Walmart Entrance	963860	Carthage	Jasper

* Indicates a new site replacing a site used in the previous calibration.

There was only one sample each for the Northeast and Northwest districts. The sample set included five samples from the Southeast District, seven samples from the Southwest District, and ten samples from the St. Louis District. Each of the remaining districts had five samples. The intersections included public road intersections as well as commercial driveway entrances that were signalized. Intersections from the major metropolitan areas of St. Louis, Kansas City, and

Springfield were included in the sample set. In addition, smaller communities such as Boonville and Mexico were represented in the sample set.

A list of samples for urban four-leg signalized intersections is shown in Table 8.4. The sample set included five samples from each district. Intersections from the major metropolitan areas of St. Louis, Kansas City, Springfield, and St. Joseph were included in the sample set. In addition, smaller communities such as Cape Girardeau and Moberly were represented in the sample set.

Table 8.4 List of sites for urban four-leg signalized intersections

No.	District	Description	Int. No.	City	County
1	CD	MO 32 and MO 19 (Main St.)	458532	Salem	Dent
2	CD	MO 64 (N Jefferson Ave.) and MO 5 (W 7th St.)	452499	Lebanon	Laclede
3	CD	MO 32 and RT J/HH	458516	Salem	Dent
4	CD	BU 50 (Missouri Blvd.) and St. Mary's Blvd./W Stadium Blvd.	302287	Jefferson City	Cole
5	CD	US 63 (N. Bishop Ave.) and 10th St.	409975	Rolla	Phelps
6	KC	US 50 (E Broadway Blvd.) and Engineer Ave.	262974	Sedalia	Pettis
7	KC	MO 152 and Shoal Creek Pkwy.	924806	Kansas City	Clay
8	KC	MO 7 and Clark Rd./Keystone Dr.	178087	Blue Springs	Jackson
9	KC	US 40 and Sterling Ave.	165662	Kansas City	Jackson
10	KC	MO 7 and US 40	175906	Blue Springs	Jackson
11	NE	US 63 (N Missouri St.) and Vine St.	73685	Macon	Macon
12	NE	BU 63 (S Morley St.) and RT EE (E Rollins St.)	106134	Moberly	Randolph
13	NE	US 24 and BU 63 (N Morley St.)	102590	Moberly	Randolph
14	NE	MO 47 and Old US 40 (E Veterans Memorial Pkwy.)	219337	Warrenton	Warren
15	NE	MO 47 and Main St. (Sydnorville Rd.)	179534	Troy	Lincoln
16	NW	US 169 (N Belt Hwy.) and MO 6/LP 29 (Frederick Ave.)	64653	St. Joseph	Buchanan
17	NW	US 169 (N Belt Hwy.) and Faraon St.	66131	St. Joseph	Buchanan
18	NW	US 169 (S Belt Hwy.) and RT YY (Mitchell Ave.)	68315	St. Joseph	Buchanan
19	NW	MO 6 (E 9th St.) and Harris Ave.	41614	Trenton	Grundy
20*	NW	MO 752 and King Hill Ave.	75399	St. Joseph	Buchanan
21	SE	BU 60 (W Pine St.) and N 5th St.	597292	Poplar Bluff	Butler
22	SE	US 61 (N Kingshighway St.) and MO 51 (N Perryville Blvd.)	439049	Perryville	Perry
23	SE	US 61 (S Kingshighway St.) and RT K (William St.)	496355	Cape Girardeau	Cape Girardeau
24	SE	MO 53 and MO 142/RT WW	599957	Poplar Bluff	Butler
25	SE	MO 47 and Berry Rd.	412009	Bonne Terre	St. Francois
26	SL	MO 115 (Natural Bridge Ave.) and Goodfellow Blvd.	258418	St. Louis	St. Louis City
27	SL	MO 185 and Springfield Ave.	368007	Sullivan	Franklin
28	SL	MO 47 (N Main St.) and Commercial Ave.	345142	St. Clair	Franklin
29	SL	MO 30 (Gravois Ave.) and Holly Hills Blvd.	295564	St. Louis	St. Louis City
30	SL	MO 115 (Natural Bridge Ave.) and Marcus Ave.	262408	St. Louis	St. Louis City
31	SW	MO 744 and Summit Ave.	512290	Springfield	Greene
32	SW	US 60 and RT P/S Main Ave.	540602	Republic	Greene
33	SW	MO 18 (Ohio St.) and BU 13 (S 2nd St.)	345687	Clinton	Henry
34	SW	MO 14 (W Mt. Vernon St.) and RT M (N Nicholas Rd.)	554723	Nixa	Christian
35*	SW	MO 14 and RT M	523287	Nixa	Christian

* Indicates a new site replacing a site used in the previous calibration

8.5 Data Collection

A list of the data types collected for urban signalized intersections and their sources is shown in Table 8.5.

Table 8.5 List of data sources for urban signalized intersections

Data Description	Source
AADT	TMS
No. of Approaches with Left-Turn Lanes	Aerials
No. of Approaches with Right-Turn Lanes	Aerials
No. of Approaches with Permissive LT Phasing	MoDOT
No. of Approaches with Protected/Permissive LT Phasing	MoDOT
No. of Approaches with Protected LT Phasing	MoDOT
Pedestrian Volumes (Crossings/Day)	Estimated pedestrian activity
Max. Number of Lanes Crossed by Pedestrians	Aerials
Number of Bus Stops within 1,000 ft	Aerials
Number of Schools within 1,000 ft	Aerials
Number of Alcohol Sales Establishments within 1,000 ft	Aerials
Presence of Lighting	ARAN and Street View
Presence of Red Light Running Cameras	MoDOT
No. of Crashes	TMS

Aerial photographs were used to determine the number of approaches with turn lanes, the maximum number of lanes crossed by pedestrians, and the number of bus stops, schools, and alcohol sales establishments within 1,000 ft. ARAN and aerial and street view photographs were used to determine the presence of lighting at intersections. MoDOT districts provided information regarding left-turn phasing and the number of approaches with prohibited right turn on red movements. A list of signalized intersections with red light running cameras was provided by MoDOT. Pedestrian volumes were estimated with street view and aerial imaging according to the presence of pedestrian facilities and paths.

8.5.1 Summary Statistics

8.5.1.1 Urban Three-Leg Signalized Intersections

Descriptive statistics for urban three-leg signalized intersections are shown in Table 8.6.

Table 8.6 Descriptive statistics for urban three-leg signalized intersections

Description	Average	Min.	Max.	Std. Dev.
Major AADT (2014)	17,451	4,007	44,280	9,206
Minor AADT (2014)	2,946	188	7,035	1,735
No. of Approaches with Left-Turn lanes	1.8	1	2	0.4
No. of Approaches with Right-Turn lanes	1.3	0	2	0.8
No. of Approaches with Permissive Left-Turn Phasing	0.1	0	1	0.3
No. of Approaches with Protected/Permissive Left-Turn Phasing	0.6	0	1	0.5
No. of Approaches with Protected Left-Turn Phasing	1.3	1	2	0.4
No. of Approaches with Prohibited RTOR	0.1	0	1	0.2
Pedestrian Volumes Crossing All Intersection Legs	119.7	20	750	140.8
Max. Number of Lanes Crossed by Pedestrians	4.4	3	6	0.9
No. of Bus Stops within 1,000 ft	1	0	5	1.5
No. of Schools within 1,000 ft	0.2	0	1	0.4
No. of Alcohol Sales Establishments within 1,000 ft	1.6	0	4	1.3
Number of Crashes	15.1	1	55	13.3
Description	**No. of Intersections**			
Presence of Lighting	33			
Presence of Red Light Running Cameras	0			

The average AADT for the major approaches was 17,451 vpd, and the average AADT for the minor approach was 2,946 vpd. The average number of approaches with left-turn lanes was 1.8, and the average number of approaches with right-turn lanes was 1.3, indicating that the presence of turn lanes was common at these intersections. The most common type of left-turn phasing for the intersection approaches was protected phasing followed by protected and permissive phasing. The prohibition of right turn on red was not very common at these intersections, as shown by the average value of 0.1 for the number of approaches with prohibited right turn on red (at two intersections). The average pedestrian volume was 119.7 and the maximum number of lanes crossed was 4.4, indicating that many of these intersections were located on multilane arterials. The average values for the number of bus stops, schools, and alcohol sales establishments were all less than 1.6. The average number of crashes was 15.1. The standard deviation was 13.3, indicating that the number of crashes at these intersections varied considerably. The total number of crashes for these intersections was 529, which was greater than the minimum of 300 crashes recommended by the HSM. Thirty-three of these intersections had lighting, while none of the intersections had red light running cameras.

8.5.1.2 Urban Four-Leg Signalized Intersections

Descriptive statistics for urban four-leg signalized intersections are shown in Table 8.7.

Table 8.7 Descriptive statistics for urban four-leg signalized intersections

Description	Average	Min.	Max.	Std. Dev.
Major AADT (2014)	16,183	5,202	44,834	8,761
Minor AADT (2014)	7,549	1,421	25,521	6,138
No. of Approaches with Left-Turn lanes	3.3	1	4	1
No. of Approaches with Right-Turn Lanes	1.8	0	4	1.6
No. of Approaches with Permissive Left-Turn Phasing	0.9	0	4	1.4
No. of Approaches with Protected/Permissive Left-Turn Phasing	1.6	0	4	1.6
No. of Approaches with Protected Left-Turn Phasing	1.5	0	4	1.7
No. of Approaches with Prohibited RTOR	0	0	1	0.2
Pedestrian Volumes Crossing All Intersection Legs	294	50	700	219.1
Max. Number of Lanes Crossed by Pedestrians	4.6	3	6	1.1
No. of Bus Stops within 1,000 ft	0.9	0	8	1.8
No. of Schools within 1,000 ft	0.3	0	5	0.9
No. of Alcohol Sales Establishments within 1,000 ft	2	0	4	1.5
Number of Crashes	39.2	4	118	29.7
Description	**No. of Intersections**			
Lighting	35			
Presence of Red Light Running Cameras	1			

The average AADT for the major approaches was 16,183 vpd, similar to urban three-leg intersections, and the average AADT for the minor approaches was 7,549 vpd. The average number of approaches with left-turn lanes was 3.3 (1.8 times greater than for three-leg intersections), and the average number of approaches with right-turn lanes was 1.8, indicating that the presence of turn lanes was common at these intersections. The sampled intersections had some variation in left-turn phasing, with protected permissive left-turn phasing being the most common. There was only one intersection approach at which a right turn on red was prohibited. The average value for the maximum number of lanes crossed by pedestrians was 4.6, indicating that many of these intersections were located on multilane arterials. The average values for the number of bus stops, schools, and alcohol sales establishments were all less than or equal to 2.0. The average number of crashes was 39.2, indicating that four-leg intersections experienced more crashes than three-leg intersections. The standard deviation for the number of crashes was 29.7, indicating that the number of crashes at these intersections varied considerably. The total number of crashes was 1,372, which was greater than the minimum of 300 crashes recommended by the HSM. All of these intersections had lighting, while only one had red light running cameras.

8.6 Results and Discussion

The results presented in this section include calibration factors, severity distribution factors, and crash type distribution factors for urban signalized intersections.

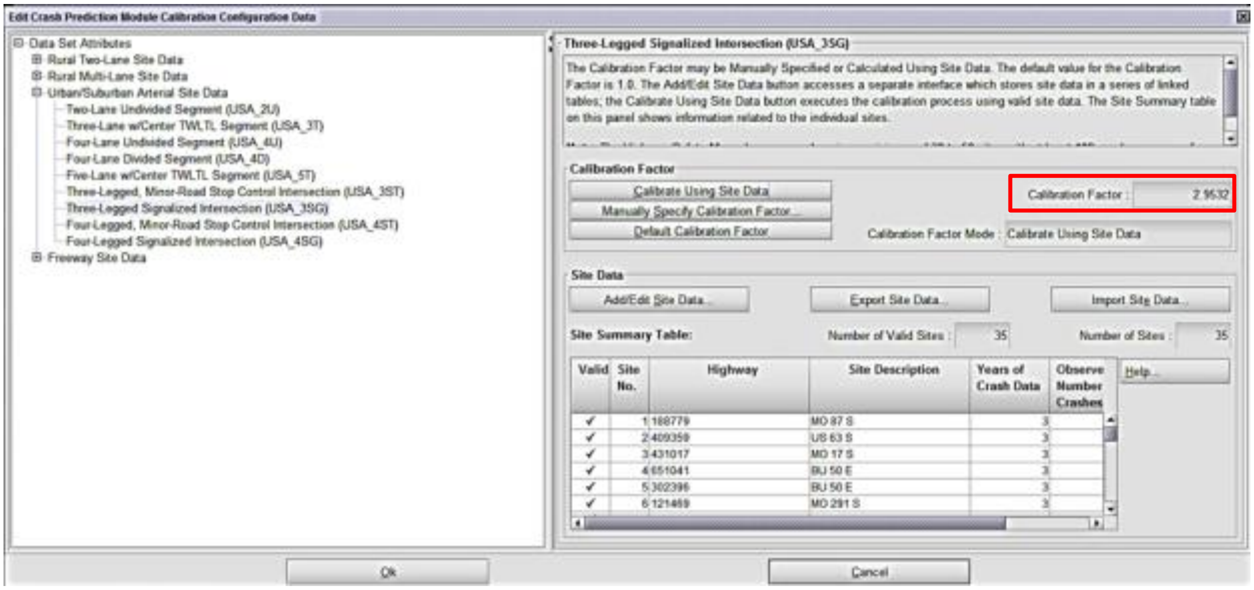
8.6.1 Calibration Factors

The calibration factor for urban three-leg signalized intersections is 2.95 and for urban four-leg signalized intersections is 5.21. The number of observed and predicted crashes by facility is presented in Table 8.8.

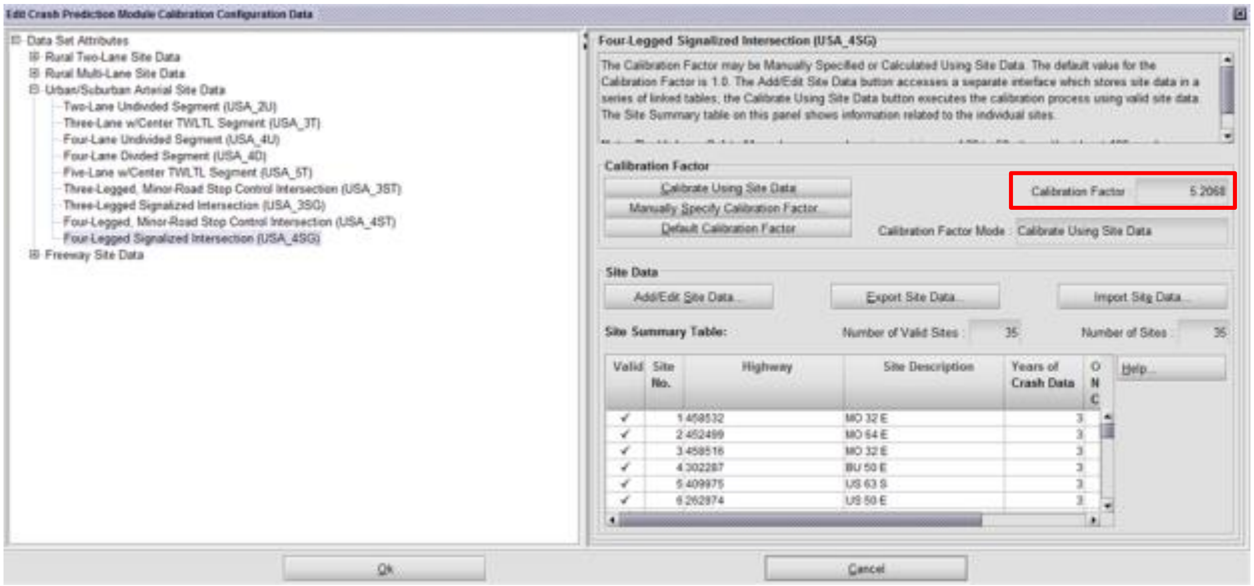
Table 8.8 Calibration results for urban signalized intersections

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Observed	Predicted	No.	Int. No.	Observed	Predicted
1	188779	7	2	1	458532	21	5
2	409359	21	5	2	452499	73	6
3	431017	12	3	3	458516	17	4
4	651041	4	3	4	302287	43	5
5	302396	18	4	5	409975	31	9
6	121469	8	5	6	262974	22	7
7	168735	16	7	7	924806	76	15
8	123483	23	6	8	178087	29	9
9	929297	14	4	9	165662	58	7
10	143089	19	3	10	175906	88	13
11	68340	9	3	11	73685	10	5
12	288254	5	9	12	106134	26	4
13	324301	15	16	13	102590	54	4
14	489147	36	3	14	219337	26	10
15	496486	55	2	15	179534	12	7
16	574289	33	4	16	64653	56	12
17	588152	9	1	17	66131	67	10
18	928641	1	2	18	68315	55	12
19	251803	9	6	19	41614	4	4
20	313246	7	7	20	597292	19	6
21	347423	28	4	21	439049	19	3
22	651105	5	8	22	496355	99	9
23	543380	16	6	23	599957	32	3
24	257667	8	11	24	258418	98	12
25	523828	25	10	25	368007	6	2
26	932947	14	4	26	345142	21	4
27	512492	8	4	27	295564	11	12
28	963973	3	2	28	262408	41	11
29	963880	27	3	29	512290	23	13
30	963860	2	3	30	540602	45	10
31	137412	3	4	31	345687	17	2
32	291512	53	13	32	554723	15	6
33	249780	3	5	33	75399	34	6
34	253124	3	2	34	412009	6	2
35	299708	10	5	35	523287	118	15
Sum		**529**	**179**	**Sum**		**1,372**	**263**
Calibration Factor		**2.95**		**Calibration Factor**		**5.21**	

In addition, the IHSDM output is shown in Figure 8.14. These results indicate that the number of crashes observed at three-leg and four-leg signalized intersections in Missouri was greater than the number of crashes predicted by the HSM for these facility types.



(a) IHSDM calibration output for urban three-leg signalized intersection



(b) IHSDM calibration output for urban four-leg signalized intersection

Figure 8.14 IHSDM calibration output for urban signalized intersections

Calibration results for a few other states are shown in Table 8.9.

Table 8.9 Calibration results for urban signalized intersections

State	Facility	Years of Data	Calibration Factor
Florida (Srinivasan et al. 2011)	U3SG KABC	2005	1.98
		2006	1.90
		2007	2.10
		2008	1.87
		2009	1.41
	U4SG KABC	2005	2.05
		2006	1.91
		2007	1.82
		2008	1.79
		2009	1.84
Maryland (Shin et al. 2014)	U3SG	2008-2010	0.40
	U4SG		0.48
North Carolina (Srinivasan and Carter 2011)	U3SG	2007-2009	2.47
	U4SG		2.79
Oregon (Dixon et al. 2012)	U3SG	2004-2006	0.75
	U4SG		1.10
Ohio (ODOT 2014)	U3SG	N/A	1.92
	U4SG		2.01

In comparison to the calibration factors for these other states, Missouri had larger calibration factors, which is consistent with the previous calibration (Sun et al. 2014). However, other states also had large calibration factors. For example, Florida had values of 2.10 and 2.05 for urban three-leg and four-leg signalized intersections, respectively. North Carolina had values of 2.47 and 2.79 for urban three-leg and four-leg signalized intersections, respectively. Ohio had values of 1.92 and 2.01 for urban three-leg and four-leg signalized intersections, respectively.

As explained in the previous report (Sun et al. 2014), possible explanations for the larger Missouri calibration values are the differences in the Missouri and HSM definitions of intersection crashes, data differences between Missouri and the sites used to develop the HSM predictive models, and recent changes in driver behavior, such as the increase in mobile device use. An example of a data difference is the difference in property damage thresholds used for crash reporting in various states. Some states, such as Minnesota, North Carolina, Oregon, Washington, and California, have much higher thresholds than the $500 Missouri threshold. Because of these differences, it is recommended that Missouri develop its own SPFs for urban four-legged and three-legged signalized intersections. Other possible reasons for the high calibration factors are explored in more detail in the following sections.

8.6.1.1 Differences in Definition of Intersection Crash

One possible factor contributing to the higher calibration factor is the difference between how Missouri and the HSM define an intersection crash. According to the version of the Missouri Statewide Traffic Accident Records System (STARS) Manual that was in effect when the recalibration data were collected, an officer is to enter “AT” if an accident occurred in an intersection for the “DISTANCE FROM” field and the “LOCATION” field (MTRC 2002). Note that the Missouri Uniform Accident Records (MUAR) form, unlike similar forms for some other states, does not have a checkbox for an officer to indicate that the crash was “intersection-related.” A revised STARS Manual (MSC 2012) went into effect on January 1, 2012 and therefore was not applicable to the data collected before that date. The revised manual has similar instructions for marking “AT” for the “LOCATION” field, with a slightly different description instructing the officer to indicate “if the crash occurred within the confines of the intersection.” According to Myrna Tucker from MoDOT TMS, if a crash occurred within 132 ft of an intersection, the crash was assigned an intersection number. Ms. Tucker explained that the distance was determined by MoDOT traffic engineers many years ago. This was confirmed by Michael Curtit and John Miller, MoDOT Highway Safety and Traffic. However, this 132 ft threshold does not appear to be applied uniformly. When crash reports were reviewed manually for a diverging diamond interchange (DDI) terminal study, crashes outside this distance were still assigned to intersections (Claros et al. 2015).

The HSM SPFs for signalized intersections were developed in the NCHRP 17-26 project and reported in NCHRP 129 (Harwood et al. 2007). The intersection criteria were the same as those used in the IHSDM and are as follows:

1. An accident classified by the investigating officer was coded as “at intersection.”
2. An accident on an intersection leg within 250 ft of the intersection was assigned to the intersection if the investigating officer or coder classified it as “intersection-related.”

The purpose of these criteria was to ensure that only accidents that occurred because of intersection characteristics were assigned to the intersection. It is clear that the Missouri criteria for an intersection crash differ from those used for HSM SPF development. The two main differences are the “intersection-related” checkbox and the difference in the distance thresholds. Nevertheless, it is unclear how much of the large calibration factor can be attributed to the intersection criteria difference. The omission of “intersection-related” crashes means that Missouri over-classifies some crashes, because not all crashes within 132 ft are intersection-related. For example, driveway-related crashes within 132 ft would be wrongly classified as intersection crashes. Conversely, Missouri’s threshold is smaller, so it would under-classify intersection-related crashes that occurred between 132 and 250 ft. For example, a queue-related rear end crash could be misclassified. But, as previously discussed, the 132 ft threshold was not consistently applied.

8.6.1.2 Differences in Data

In addition to differences in the definition of an intersection crash, there were differences between the data used for SPF development in the HSM and in the calibration of the HSM for Missouri. The data used for SPF development of signalized intersections came from Minnesota and North Carolina (Harwood et al. 2007). The Minnesota urban and suburban intersections were on state routes and were all located in the Twin Cities metropolitan area. The North Carolina intersections were located in Charlotte and were recommended by city traffic engineers. The totals of 96 and 108 intersections represent a significant, but not very large, number of intersections. The Minnesota crash data were from 1998 to 2002, and the North Carolina crash data were from 1997 to 2003.

The use of Charlotte and the Twin Cities for HSM SPF development points to some possible explanations for the high Missouri calibration factor. First, the HSM models were based on data from highly populated urban areas. The HSM definition of urban areas is much broader and is based on FHWA guidelines, which define urban areas as having a population greater than 5,000. The HSM also gives the user discretion in making the determination of whether an area is urban. The calibration data set for the Missouri study included a broader range in the sizes of urban areas. In addition, the AADT ranges for the samples from the Twin Cities and Charlotte may be higher than the AADT ranges in the Missouri study because the Missouri data set included samples from smaller urban areas. The HSM models did not include some of the characteristics of signalized intersections, such as turn lane lengths, lengths of all-red intervals, sizes of signal heads, and presence of flashing yellow arrows, all factors that could have increased crash values.

Finally, there may not be much variation in some of the traffic signal characteristics of the Twin Cities and Charlotte. For example, the Twin Cities and/or the Minnesota Department of Transportation (MnDOT) may have certain standards for signalized intersections that they incorporate into most of their designs. The Missouri calibration data set included intersections from many different cities that may display more differences with regard to signalization.

It is unclear to what degree differences between Missouri and Minnesota and North Carolina contributed to the large calibration factor. It is unlikely that the Twin Cities and Charlotte were exceptionally safe cities in terms of driver behavior, geometric design, and signal timing because they were chosen as candidate sites for SPF development.

8.6.1.3 Changes in Driver Behavior over Time

Another possible explanation for the higher calibration factor in Missouri could be changes in driver behavior. The HSM models for signalized intersections were based on crash data from 1997 to 2003. It is likely that many aspects of driver behavior have changed since that time. For example, distracted driving seems to have become more prevalent, especially for drivers who text and talk on cell phones. Distracted driving could be a significant factor in rear end crashes at intersections.

8.6.2 Severity Distribution Factors

Using the calibration data, SDFs were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 8.10 shows the obtained SDFs for urban signalized intersections. Although the factors for three- and four-leg intersections are similar, using the appropriate factor for each facility type is recommended.

Table 8.10 Severity Distribution Factors

Severity	Three-Leg		Four-Leg	
	Crashes	**SDF**	**Crashes**	**SDF**
Fatal	1	0.002	3	0.002
Disabling Injury	10	0.019	34	0.025
Minor Injury	107	0.202	300	0.219
Property Damage Only	411	0.777	1,035	0.754

8.6.3 Crash Type Distribution Factors

CDFs are used to determine the proportion of predicted crashes according to the type of crash. The data available from the calibration were used to estimate these factors. Some data processing was required in order to match Missouri crash type categories to the HSM categories. Therefore, different categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were also divided into multiple- and single-vehicle crashes. Pedestrian and cyclist crashes were not considered for these factors because specific SPFs exist for those types of crashes. Table 8.11 provides the CDFs for urban signalized intersections.

Table 8.11 Crash type distribution factors

Collision Type	Three-Leg		Four-Leg	
	Crashes	**CDF**	**Crashes**	**CDF**
Multiple-Vehicle				
Rear End	255	0.520	732	0.574
Angle	155	0.316	319	0.250
Sideswipe	48	0.098	146	0.115
Head-on	22	0.045	74	0.058
Other	10	0.020	4	0.003
Single-Vehicle				
Out of Control	23	0.719	62	0.747
Deer	4	0.125	2	0.024
Parking or Parked Car	2	0.063	6	0.072
Fixed Object	1	0.031	6	0.072
Other	2	0.063	7	0.084

CHAPTER 9. UNSIGNALIZED INTERSECTIONS

9.1 Introduction and Scope

Multiple chapters of the HSM describe the methodology for crash prediction on different types of unsignalized intersections. All of the following unsignalized intersection types were calibrated as part of this project:

- Rural Two-Lane Three-Leg Unsignalized Intersections (Chapter 10 of HSM)
- Rural Two-Lane Four-Leg Unsignalized Intersections (Chapter 10 of HSM)
- Rural Multilane Three-Leg Unsignalized Intersections (Chapter 11 of HSM)
- Rural Multilane Four-Leg Unsignalized Intersections (Chapter 11 of HSM)
- Urban Three-Leg Unsignalized Intersections (Chapter 12 of HSM)
- Urban Four-Leg Unsignalized Intersections (Chapter 12 of HSM)

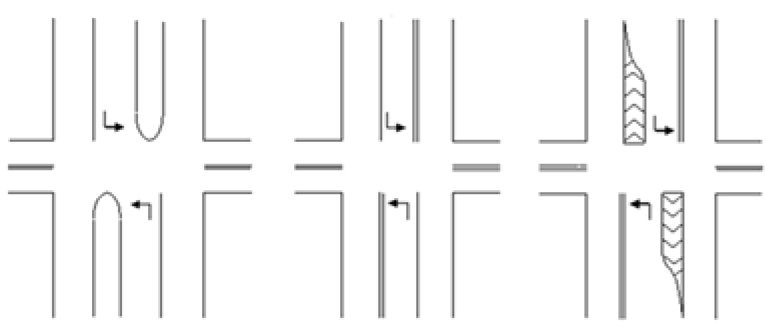
9.2 Calibration Data Requirement

For this calibration project, the results produced from three-leg and four-leg stop-controlled intersections are applicable to rural two-lane roads, rural multilane roads, and urban/suburban arterials. For each of these facilities, a number of CMFs are applicable. This chapter will discuss how the values for these CMFs were determined for the Missouri calibration.

9.2.1 Required Site Data

9.2.1.1 Number of Approaches with Left-Turn Lanes

A left-turn lane is the lane used for left turn movements. There is zero or one left-turn lane for a three-leg stop-controlled intersection. There are zero, one, or two left-turn lanes for a four-leg stop-controlled intersection. The HSM applies a CMF for left-turn lanes only on the uncontrolled major road approaches to stop-controlled intersections. Figure 9.1 shows different left-turn lane configurations at intersections.



Chandler et al. 2013

Figure 9.1 Left-turn lane configurations

Figure 9.2 shows examples of aerial and street view images of a three-leg stop-controlled intersection.

(a) Aerial view

(b) A major approach

(c) The minor approach

Figure 9.2 Example of three-leg stop-controlled intersection

The north/south road in Figure 9.2(a) is the major road, and the east/west road in Figure 9.2(a) is a minor road. The reason for the major/minor road determination is that, as shown in Figure 9.2(b) and 9.2(c), the major road does not have a stop sign while the minor road does. Only the left-turn lane(s) on the major road need to be counted. As the example in Figures 9.2(a) and (b) shows, the intersection has only one left-turn lane for HSM purposes.

Figure 9.3 shows aerial and street view images of a four-leg stop-controlled intersection.

(a) Aerial view

(b) A major approach

(c) A minor approach

Figure 9.3 Example of a four-leg stop-controlled intersection

The north/south road in Figure 9.3(a) is a major road, and the east/west road in Figure 9.3(a) is a minor road. The reason for the major/minor road designation is that the major road does not have a stop sign while the minor road does, as shown in Figure 9.3(b) and (c). Again, only the left turn on the major road needs to be counted. As Figure 9.3(a) shows, the intersection has two left-turn lanes for HSM purposes, one in each north/south direction.

9.2.1.2 Number of Approaches with Right-Turn Lanes

A right-turn lane is an exclusive lane for right turns. There can be zero or one right-turn lane for a three-leg stop-controlled intersection. There can be up to four right-turn lanes for a four-leg stop-controlled intersection, but the HSM applies a CMF for right-turn lanes only on the uncontrolled major road approaches to stop-controlled intersections.

Figure 9.4 shows aerial and street view images of a three-leg stop-controlled intersection.

(a) Aerial view

(b) A major approach

(c) The minor approach

Figure 9.4 Example of a three-leg stop-controlled intersection

The north/south road in Figure 9.4(a) is the major road, and the east/west road in the Figure 9.4(a) is a minor road. The reason for the major/minor determination is that, as shown in Figure 9.4(b), the major road does not have a stop sign, but the minor road does, as shown in Figure 9.4(c). Only the right–turn lane on the major road needs to be counted. As Figure 9.4(a) and (b) show, the intersection has only one right-turn lane for HSM purposes

9.2.1.3 Presence of Light

Illumination close to the intersection is considered lighting. Street view and ARAN images were used to verify the presence of lighting (i.e., yes or no). Figure 9.5 shows an example of a light pole close to an intersection.

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Figure 9.5 Example of street view image of presence of light

9.2.1.4 Intersection Skew Angle

Skew angle for an intersection is defined as the absolute value of the deviation from an intersection angle of 90 degrees. The absolute value is used in the definition of skew angle because positive and negative skew angles are considered to have similar effects. Reducing the skew angle of three- or four-leg stop-controlled intersections on rural multilane highways reduces total intersection crashes. Figure 9.6 illustrates skew angle.

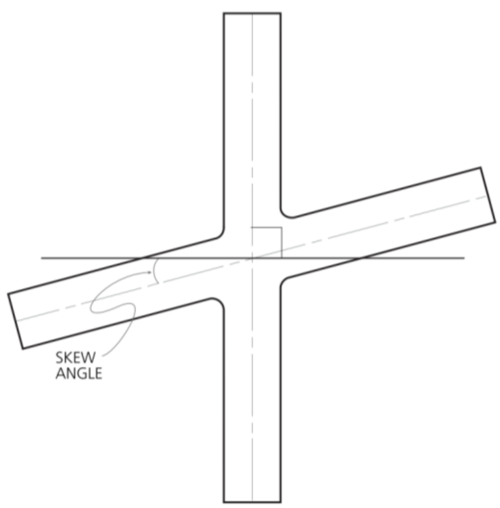

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Figure 9.6 Skew angle

In the following example, aerial images of a three-leg and a four-leg stop-controlled intersection were reviewed. This was accomplished by using the “compass tool” image overlay, an option available for Google Earth. The major road was reoriented in the north/south direction to align with the compass tool. Then the deviation of the minor road can be measured from the east/west direction in degrees. Figure 9.7 shows that the skew angle for the sample minor road on a three-leg intersection is approximately 30 degrees. Figure 9.8 shows that the skew angle for the sample minor road on a four-leg intersection is approximately 30 degrees.

Figure 9.7 Skew angle measurement for a three-leg stop-controlled intersection

Figure 9.8 Skew angle measurement for a four-leg stop-controlled intersection

9.2.2 Required Traffic Data

9.2.2.1 AADT

Both the major road entering AADTs and minor road entering AADTs are needed. The following default HSM rules should be followed:

- If AADT data are available for only a single year, the same value is assumed to apply to all years of the before period.
- If two or more years of AADT data are available, the AADT for intervening years are computed by interpolation.
- The AADT for the years before the first year for which data are available is assumed to be equal to the AADT for the first year.
- The AADT for the years after the last year for which data are available is assumed to be equal to the last year.

In the following example, the AADT of a three-leg stop-controlled intersection was collected. In Figure 9.9(a), the east/west road is the minor road and the north/south road is the major road. The queries were conducted using ODBC. The intersection identification number (SS_INTRSC_NUMBER) and years (SS_INTRSC_YEAR) of data were used, as shown in Figure 9.9(b). The resulting AADT table is shown in Figure 9.9(c). The direction in column three of Figure 9.9(c) refers to the entering direction.

(a)Aerial view

SS_INTRSC_NUMBER	CONTROL_IN_OVERLA	SS_INTRSC_YEAR
TMS_SS_INTERSECTIOI	TMS_SS_INTERSECTIOI	TMS_SS_INTERSECTIOI
☑	☑	☑
305939		2012
305939		2013
305939		2014

(b) TMS query for AADT

SS_INTRSC_Y	LEG_DESIGN	LEG_TRAVELWAY_NAME	LEG_DIRECTI	LEG_CONTIN	LEG_AADT
2012	CST	SWIFTS HWY	E	0.213	426
2013	CST	SWIFTS HWY	E	0.213	471
2014	CST	SWIFTS HWY	E	0.213	497
2012	CST	SOUTHWEST BLVD	N	1.194	5273
2013	CST	SOUTHWEST BLVD	N	1.194	5820
2014	CST	SOUTHWEST BLVD	N	1.194	6146
2012	CST	SOUTHWEST BLVD	S	0.84	4866
2013	CST	SOUTHWEST BLVD	S	0.84	5388
2014	CST	SOUTHWEST BLVD	S	0.84	5698
2013	CST	SWIFTS HWY	W	0	471
2014	CST	SWIFTS HWY	W	0	497

(c) AADT query results

Figure 9.9 Aerial view and AADT of a three-leg stop-controlled intersection

There are three directions: east, north, and south. There is no west approach to the three-leg stop-controlled intersection. In this case, the major road AADT should be the sum of the northbound and southbound AADTs. The minor road AADT is the eastbound AADT. Figure 9.9(c) shows the major road AADT as 10,139 (sum of both approaches) in 2012 and the minor road AADT as 426 in 2012.

In the following example, the AADT of a four-leg stop-controlled intersection was collected. In Figure 9.10(a), the east/west road is the minor road and the north/south road is the major road. The resulting AADT table is shown in Figure 9.10(b). The direction in column three of Figure 9.10(b) refers to the entering direction.

(a) Aerial view

SS_INTRSC_Y	LEG_DESIGN	LEG_TRAVELWAY_NAME	LEG_DIRECTI	LEG_CONTIN	LEG_AADT
2012	CST	38TH ST	E	0.256	432
2013	CST	38TH ST	E	0.256	399
2014	CST	38TH ST	E	0.256	412
2012	CST	MAIN ST	N	1.122	5283
2013	CST	MAIN ST	N	1.122	4992
2014	CST	MAIN ST	N	1.122	5008
2012	CST	MAIN ST	S	3.327	5008
2013	CST	MAIN ST	S	3.327	4499
2014	CST	MAIN ST	S	3.327	4805
2012	CST	38TH ST	W	0.308	432
2013	CST	38TH ST	W	0.308	399
2014	CST	38TH ST	W	0.308	412

(b) AADT query results

Figure 9.10 Aerial view and AADTs of a four-leg stop-controlled intersection

There are four directions: east, west, north, and south. In this case, the major road AADT is the sum of the northbound and southbound AADTs. The minor road AADT is the sum of the eastbound and westbound AADTs. As shown in Figure 9.10(b), the major road AADT was 10,291 in 2012, and the minor road AADT was 864 in 2012.

9.3 HSM Methodology

As described in the HSM, the SPFs for unsignalized intersections predict the number of total crashes per year for the base conditions. The SPF was based on different considerations for each intersection type. Therefore, the methodology is described separately for each intersection type.

9.3.1 Rural Two-Lane Three- and Four-Leg Unsignalized Intersections

Chapter 10 of the HSM presents the SPFs for rural two-lane three- and four-leg unsignalized intersections. Major and minor stop-controlled road traffic volumes (AADT) are used for the prediction of average crash frequency for intersection related crashes within the limits of a particular intersection. The SPFs consider rural two-way road intersections with two through lanes only, in both the major and minor road legs, without including the turning lanes.

The SPFs for both intersection types are given by the following:

$$N_{spf\ 3ST} = \exp\left[-9.86 + 0.79 \times \ln\left(AADT_{maj}\right) + 0.49 \times \ln(AADT_{min})\right] \quad \textbf{(9.1)}$$

$$N_{spf\ 4ST} = \exp\left[-8.56 + 0.60 \times \ln\left(AADT_{maj}\right) + 0.61 \times \ln(AADT_{min})\right] \quad \textbf{(9.2)}$$

where

$N_{spf\ 3ST}$ is the predicted intersection related crash frequency for base conditions for rural three-leg stop-controlled intersections

$N_{spf\ 4ST}$ is the predicted intersection related crash frequency for base conditions for rural four-leg stop-controlled intersections

$AADT_{maj}$ is the AADT (vehicles per day) on the major road

$AADT_{min}$ is the AADT (vehicles per day) on the minor road

Table 9.1 presents the parameters applicable for both three-leg and four-leg intersection equations. The AADT ranges shown in Figure 9.1 for major and minor approaches are common for rural areas.

Table 9.1 SPFs rural unsignalized three/four-leg stop-controlled intersection parameters

	Rural Unsignalized	
Intersection Type	**Three-Leg Stop-Controlled**	**Four-Leg Stop-Controlled**
Overdispersion Parameter (k)	0.54	0.24
$AADT_{maj}$	0 to 19,500 vehicles per day	0 to 14,700 vehicles per day
$AADT_{min}$	0 to 4,300 vehicles per day	0 to 3,500 vehicles per day

The base conditions assumed for both three-leg and four-leg intersection SPFs are presented in Table 9.2. The base conditions represent a perpendicular intersection with stop control in all directions.

Table 9.2 SPFs rural unsignalized three/four-leg stop-controlled intersection base conditions

Base Conditions	Description
Intersection Skew Angle	0°
Intersection Left-Turn Lanes	None of the approaches without stop control
Intersection Right-Turn Lanes	None of the approaches without stop control
Lighting	None

9.3.2 Rural Multilane Three- and Four-Leg Unsignalized Intersections

Chapter 11 of the HSM presents the SPFs for rural multilane three- and four-leg unsignalized intersections. Major and minor stop-controlled road traffic volumes (AADT) are used for the prediction of average crash frequency for intersection-related crashes within the limits of a particular intersection. The SPFs are applicable to rural multilane highway facilities with four through lanes and stop control on minor road approaches. The SPFs for both three- and four-leg intersection types are given by the following:

$$N_{spf\ 3ST} = \exp\left[-12.526 + 1.204 \times \ln\left(AADT_{maj}\right) + 0.236 \times \ln(AADT_{min})\right] \quad (9.3)$$

$$N_{spf\ 4ST} = \exp\left[-10.008 + 0.848 \times \ln\left(AADT_{maj}\right) + 0.448 \times \ln(AADT_{min})\right] \quad (9.4)$$

where

$N_{spf\ 3ST}$ is the predicted intersection-related crash frequency for base conditions for multilane three-leg stop-controlled intersections

$N_{spf\ 4ST}$ is the predicted intersection-related crash frequency for base conditions for multilane four-leg stop-controlled intersections,

$AADT_{maj}$ is the AADT (vehicles per day) on the major road

$AADT_{min}$ is the AADT (vehicles per day) on the minor road

Table 9.3 shows the parameters applicable to the three- and four-leg stop-controlled intersection equations.

Table 9.3 Rural multilane three/four-leg stop-controlled intersection SPF parameters

Intersection Type	Rural Unsignalized Multilane	
	Three-Leg Stop-Controlled	**Four-Leg Stop-Controlled**
Overdispersion Parameter (k)	0.460	0.494
$AADT_{maj}$	0 to 78,300 vehicles per day	0 to 78,300 vehicles per day
$AADT_{min}$	0 to 23,000 vehicles per day	0 to 7,400 vehicles per day

Table 9.4 shows the base conditions for both SPF equations.

Table 9.4 Multilane three/four-leg stop-controlled intersection SPF base conditions

Base Conditions	Description
Intersection Skew Angle	0°
Intersection Left-Turn Lanes	0, except on stop-control approaches
Intersection Right-Turn Lanes	0, except on stop-control approaches
Lighting	None

9.3.3 Urban Three- and Four-Leg Unsignalized Intersections

Chapter 11 of the HSM presents the SPFs for urban three- and four-leg unsignalized intersections. Major and minor road traffic volumes (AADT) are used for the prediction of average crash frequency for intersection-related crashes within the limits of a particular intersection. The SPFs are applicable for intersections on urban and suburban arterials with stop control on minor road approaches. The SPF is divided into two components, accounting for multiple-vehicle collisions and single-vehicle collisions for the base conditions. The total crash frequency is the sum of the multi-vehicle and single-vehicle collisions, as follows:

$$N_{spf\ int} = N_{bimv} + N_{bisv} \quad \textbf{(9.5)}$$

where

$N_{spf\ int}$ is the predicted total average crash frequency of intersection-related crashes for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions)

N_{bimv} is the predicted average number of multiple-vehicle collisions for base conditions

N_{bisc} is the predicted average number of single-vehicle collisions for base conditions

Multiple-Vehicle Collisions:

$$N_{bimv\ 3ST} = \exp\left[-13.36 + 1.11 \times \ln\left(AADT_{maj}\right) + 0.41 \times \ln(AADT_{min})\right] \quad \textbf{(9.6)}$$

$$N_{bimv\ 4ST} = \exp\left[-8.90 + 0.82 \times \ln\left(AADT_{maj}\right) + 0.25 \times \ln(AADT_{min})\right] \quad \textbf{(9.7)}$$

where

$N_{bimv\ int}$ is the predicted average number of multiple-vehicle collisions for base conditions

$AADT_{maj}$ is the AADT (vehicles per day) on the major road

$AADT_{min}$ is the AADT (vehicles per day) on the minor road

Single-Vehicle Crashes:

$$N_{bisv\ 3ST} = \exp\left[-6.81 + 0.16 \times \ln\left(AADT_{maj}\right) + 0.51 \times \ln(AADT_{min})\right] \quad \textbf{(9.8)}$$

$$N_{bisv\ 4ST} = \exp\left[-5.33 + 0.33 \times \ln\left(AADT_{maj}\right) + 0.12 \times \ln(AADT_{min})\right] \quad \textbf{(9.9)}$$

where

$N_{bisv\ int}$ is the predicted average number of single-vehicle collisions for base conditions

$AADT_{maj}$ is the AADT (vehicles per day) on the major road

$AADT_{min}$ is the AADT (vehicles per day) on the minor road

Table 9.5 shows the overdispersion parameters that are applicable for the three- and four-leg intersection equations.

Table 9.5 SPFs Urban unsignalized multiple-vehicle collision overdispersion parameters

	Urban Unsignalized	
Overdispersion Parameter (k)	**Three-Leg Stop-Controlled**	**Four-Leg Stop-Controlled**
Multiple-Vehicle Collisions	0.80	0.40
Single-Vehicle Collisions	1.14	0.65

Table 9.6 shows the AADT ranges that are applicable to the SPFs.

Table 9.6 SPFs applicable AADT ranges

Intersection Type	Urban Unsignalized	
	Three-Leg Stop-Controlled	Four-Leg Stop-Controlled
$AADT_{maj}$	0 to 45,700 vehicles per day	0 to 46,800 vehicles per day
$AADT_{min}$	0 to 9,300 vehicles per day	0 to 5,900 vehicles per day

9.4 Sampling

Because this project is a recalibration, an attempt was made to use the same sites sampled in previous calibration efforts. However, it was necessary to verify that a site had not undergone geometric or other changes that would disqualify the site. Each site was examined for the multiple attributes needed to be classified as a certain type of intersection. These attributes included the number of undivided lanes on the major roadway segment, the presence of three or four approach legs, and the existence of stop control on the minor road only. Of particular note were the addition of lanes, work zone areas that disrupted traffic, changes in control type, and changes in rural/urban classification.

Different challenges were encountered during the sampling of unsignalized intersections. Initially, visual identification was used to verify the existence of stop control on the minor road, but it was difficult to perform stop control verification for certain rural areas because neither ARAN records nor street view images existed. Therefore, these samples were not included. In general, sampling for unsignalized intersections in rural areas was more difficult than in urban areas due to the problems in obtaining information related to leg names, locations, and specific intersections.

Another challenge encountered during intersection sampling was difficulty in finding samples for rural multilane three/four-leg unsignalized intersections. Many attempts were made to obtain samples following the basic criteria of randomness and consistency with intersection type characteristics. The first consideration was to examine major facilities only. Unfortunately, no samples were found. Therefore, instead of sampling intersections directly, the sampling was based on the rural multilane highway segments, as discussed in Chapter 5. Because some districts did not have a large set of intersections along a facility within the district's region, it was difficult to find rural multilane unsignalized three-leg intersections. Researchers compensated for the lack of samples by using available samples from other districts. Because of the challenges of the sampling process, a total of 416 unsignalized intersections were sampled.

The lists of intersections are found in Tables 9.7 to 9.12. The tables contain the intersection number that was used for the identification and collection of data. The locations (county and district) of intersections are also included. The lists display 10 intersections that were collected for each district. As mentioned previously, when a district lacked sufficient samples for rural multilane intersections, samples from other districts were used to compensate for the deficit.

Table 9.7 is the list of rural two-lane three-leg unsignalized intersections.

Table 9.7 List of sites for rural two-lane three-leg unsignalized intersections

Site No	District	Description	Intersection No.	County
1	CD	Grand Av, Hwy H, Moniteau, MO 65025	277931	Moniteau
2	CD	County Road 4029, Hwy 94, Summit, Callaway, MO 65043	301833	Callaway
3	CD	Bottom Diggins Rd, Hwy E, Union, Washington, MO 63630	398249	Washington
4	CD	County Road 240A, Hwy 32, Spring Creek West, Missouri 65560	462095	Dent
5	CD	Blank Rd, Hwy Hh, Vanpool Rd, Moniteau, MO 65074	313734	Moniteau
6	CD	County Road 432, Hwy 240, Howard, MO 65274	165855	Howard
7	CD	Cannon Mines Rd, Hwy 21, Union, Washington, MO 63630	395691	Washington
8	CD	Jim Henry Road, Hwy 17, Jim Henry, Miller, MO 65032	358162	Miller
9	CD	James Rd, Hwy Ff, Richland, Laclede, MO 65556	437012	Laclede
10	CD	5th St, Hwy 50, Rosebud, Gasconade, MO 63091	341235	Gasconade
11	KC	Top Water Street, Hwy Z, Bates City, Lafayette, MO 64011	1024754	Lafayette
12	KC	Slusher School Rd, Hwy 13, Lexington, Lafayette, MO 64067	148501	Lafayette
13	KC	Bell Rd, Hwy 13, Davis, Lafayette, MO 64037	183496	Lafayette
14	KC	Goose Creek Rd, Hwy Pp, Concordia, Lafayette, MO 64020	194504	Lafayette
15	KC	Boyer Rd, Hwy 210, Fishing River, Clay, MO 64024	128338	Clay
16	KC	Main Street Road, Hwy 127, Sedalia, Pettis, MO 65301	257933	Pettis
17	KC	State Hwy Z, Bainbridge Rd, Bates City, Lafayette, MO 64011	182234	Lafayette
18	KC	State Hwy Kk, W 196th St, Polk, Ray, MO 64062	101512	Ray
19	KC	State Hwy Hh, Shippy Rd, Sni-A-Bar, Lafayette, MO	199141	Lafayette
20	KC	12th St, S Main St, Holden, Johnson, MO 64040	259956	Johnson
21	NE	Hwy V, CRD 15, Clark, MO 63453	117	Clark
22	NE	County Road 557, Hwy P, Vandalia, Audrain, MO 63382	119371	Audrain
23	NE	State Hwy Dd, County road 84, Revere, Clark, MO 63465	5567	Clark
24	NE	County Road 283, Hwy U, Warren, Marion, Missouri 63461	73147	Marion
25	NE	County Road 439, Hwy Ww, Shelbina, Shelby, Missouri 63468	81668	Shelby
26	NE	County Road 931, Hwy M Union, Monroe, Missouri 65263	111199	Monroe
27	NE	Dragonfly Pl, Hwy 149, Walnut Creek, Macon, MO 63539	56428	Macon
28	NE	County Road 229, Hwy C, Warren, Marion, MO 63456	66821	Marion
29	NE	Lackland St, Hwy Ww, New Florence, Montgomery, MO 63363	200260	Montgomery
30	NE	Pike 57, Pike 58, RA, Pike, MO 63441	98338	Pike
31	NW	S 185 Street, Missouri DD, Marion, Daviess, MO 64647	49142	Daviess
32	NW	W 185 Street, Missouri DD, Marion, Daviess, MO 64647	49076	Daviess
33	NW	Hwy 129, Hwy J, New Boston, Linn, MO 63557	51127	Linn
34	NW	Hwy H, McCurry Grove Rd, MO 64438	30409	Gentry
35	NW	West North Street, Hwy Y, Plattsburg, Clinton, MO 64477	89124	Clinton
36	NW	State Hwy A, Hwy 190, Chillicothe, Livingston, MO 64601	59129	Livingston
37	NW	Garden Dr, Hwy Hh, Union, Sullivan, MO 63545	30013	Sullivan
38	NW	11th St, E McPherson St, Hwy 246, Nodaway, MO 64461	2101	Nodaway
39	NW	370 St, Hwy H, Cooper, Gentry, MO 64438	31927	Gentry
40	NW	332 Street, Hwy 190, Jackson, Daviess, MO 64648	56702	Daviess
41	SE	Midvale Rd, Hwy 17, Carroll, Texas, MO 65571	516183	Texas
42	SE	Bowden Drive, Hwy Y, Doniphan, Ripley, MO 63935	616858	Ripley
43	SE	County Road 76-221, Hwy 76, Ava, Douglas, MO 65608	569355	Douglas
44	SE	Emma St, Mc Kinley Ave, Hwy DD, Fisk, Butler, MO 63940	592827	Butler
45	SE	7 Falls Dr, State Rd C, Ste. Genevieve, MO 63670	925236	Genevieve
46	SE	State Hwy U, Hwy 76, Miller, Douglas, MO	563643	Douglas
47	SE	Hwy 160, 3rd St, Ozark, MO 65655	659340	Ozark

Site No	District	Description	Intersection No.	County
48	SE	County Road 223, Hwy M, Stoddard, MO 63825	564661	Stoddard
49	SE	County Road 95-142, Hwy 95, Douglas County, MO 65711	564170	Douglas
50	SE	Garfield St, US 60 Bus, Willow Springs, Howell, MO 65793	563127	Howell
51	SL	Hyfield School Rd, Hwy P, De Soto, Jefferson, MO 63020	373777	Jefferson
52	SL	Lynch Rd, St. Josephs Rd, Hwy F, Jefferson, MO 63051	334130	Jefferson
53	SL	Grafton Ferry Rd, Hwy 94, St. Charles, MO 63301	197233	St. Charles
54	SL	Hwy V, Hwy 94, St. Charles, MO 63301	199154	St. Charles
55	SL	Rolling Stone Ln, John MacKeever Rd, Jefferson, MO 63069	333345	Jefferson
56	SL	Big Pine Pl, State Road H, Big River, Jefferson, MO 63020	377213	Jefferson
57	SL	Plass Rd, Buckeye Rd, Festus, Jefferson, MO 63028	360531	Jefferson
58	SL	Hwy V, Marais Becket Rd, St. Charles, MO 63301	199192	St. Charles
59	SL	Klondike Rd, Hwy B, Hillsboro, Jefferson, MO 63050	354737	Jefferson
61	SW	19th St, Cassville, Hwy 37, Main St, Barry, MO 65625	1010106	Barry
62	SW	Fr 1195, Hwy 248, Mineral, Barry, MO	602021	Barry
63	SW	State Hwy Dd, 951Rd, Cedar, MO 64744	423141	Cedar
64	SW	County Road 2130, Missouri T, Lawrence, MO 65610	547167	Lawrence
65	SW	Poppy Ln, Hwy 14, Lincoln, Christian, MO 65610	555567	Christian
66	SW	East 405th Road, Hwy Aa, Northeast Marion, Polk, MO	455897	Polk
67	SW	Osage Rd, Hwy DD, Niangua, Webster, MO 65713	498873	Webster
68	SW	Glen Oaks Dr, Hwy 86, Blue Eye, Stone, MO 65611	636407	Stone
69	SW	South Ward Street, Hwy 39, Stockton, Cedar, MO 65785	452012	Cedar
70	SW	Wilson Rd, Hwy Zz, Lincoln, Christian, MO 65631	548004	Christian

Table 9.8 is the list of rural two-lane four-leg unsignalized intersections.

Table 9.8 List of sites for rural two-lane four-leg unsignalized intersections

Site No.	District	Description	Intersection No.	County
1	CD	Rasa Dr, N Pine Rd, Hwy 135, Stover, Morgan, MO 65078	309234	Morgan
2	CD	Pigeon Dr (County Rd Bb-225), Route BB, Laclede, MO 65536	439001	Laclede
3	CD	Normandy Dr, Hwy 32, Lebanon, Laclede, MO 65536	459214	Laclede
4	CD	Elkstown Road, Hwy 5, Lebanon, Cooper, MO	249169	Cooper
5	CD	Hwy 32, State Hwy P, County Rd 418, Dent County, MO 65560	457991	Dent
6	CD	County Line Rd, Hwy Aa, Saline, Miller, MO	337073	Miller
7	CD	Scott Ave, Hwy K, Blackwater, Cooper, MO 65322	185659	Cooper
8	CD	County Road 404, 406, Hwy A, Moniteau, Howard, MO 65248	150348	Howard
9	CD	Strassner Rd, Hwy F, Hwy W, Gasconade, MO 65041	941340	Gasconade
10	CD	Humphrey Creek Road, Hwy A, Osage, Miller, MO	376560	Miller
11	KC	Hwy 58, Third St, Holden, Johnson, MO 64040	257488	Johnson
12	KC	SW 701st Rd, SW County Road VV, Johnson, MO	247971	Johnson
13	KC	Marshall School Rd, Hwy 24, Lexington, Lafayette, MO 64067	144057	Lafayette
14	KC	Market St, Hwy 371, Dearborn, Platte, MO 64439	94741	Platte
15	KC	Egypt Rd, Hwy 210, Orrick, Ray, MO 64077	131307	Ray
16	KC	Stillhouse RD, Mize Rd, Co Hwy 4s, Jackson, MO 64075	179272	Jackson
17	KC	Florence Rd, Hwy 135, Hwy 50, Smithton, Pettis, MO 65350	266798	Pettis
18	KC	Hwy 224, 10th St, Lexington, Lafayette, MO 64067	139264	Lafayette
19	KC	East 237th Street, SE Bend Ln, Hwy 291, Cass, MO 64701	265534	Cass
20	KC	State Hwy Zz, Hwy 52, Hwy E, Washington, Pettis, MO	314183	Pettis
21	NE	County Road 155, 154, State Hwy Aa, Knox, MO 63537	31011	Knox
22	NE	Hwy B, CRD 960 958, Scotland, MO	498	Scotland
23	NE	Cherry St, Clow St, Hwy C, Ewing, Lewis, MO 63440	1029271	Lewis
24	NE	County Road 457, Hwy J, Prairie, Audrain, MO	122384	Audrain
25	NE	W Missouri Ave, Maple St, Vandalia, Audrain, MO 63382	1037510	Audrain
26	NE	North 1st Street, W Cedar Ave, Clarence, Shelby, MO 63437	72647	Shelby
27	NE	5th St, Hwy 61, Lewis, MO	43610	Lewis
28	NE	East Maple Street, State Hwy E, Curryville, Pike, MO 63339	114079	Pike
29	NE	Tennessee Street, N 3rd St, Hwy 79, Louisiana, Pike, MO	1026494	Pike
30	NE	Henderson Street, Hwy 61, Route B, Canton, Lewis, MO 63435	35796	Lewis
31	NW	Main St, 8th St, Eagleville, Harrison, MO 64442	8607	Harrison
32	NW	Mike Rd, Hwy 5, Missouri D, Salt Creek, Chariton, MO 64676	87502	Chariton
33	NW	Washington St, N 22nd St, Hwy 5, Putnam, MO 63565	8111	Putnam
34	NW	6th Street, Hwy 246, Sheridan, Worth, MO 64486	4139	Worth
35	NW	West Truman Street, Kansas Ave, Route JJ, Linn, MO 64658	76413	Linn
36	NW	Jade Pl, Karma Ave, State Hwy D, Madison, Mercer, MO 64679	22531	Mercer
37	NW	North Van Buren Street, Hwy 136, Albany, Gentry, MO 64402	26276	Gentry
38	NW	Vawter Rd, Vawter Rd, Rte DD, Taylor, Sullivan County, MO	41297	Sullivan
39	NW	Talc Ln, State Hwy Y, Franklin, Grundy, MO 64679	27746	Grundy
40	NW	State Hwy M, Hwy C, Worth, MO 64499	14176	Worth
41	SE	State Hwy F, Luyster St (School), Koshkonong, MO 65692	626406	Oregon
42	SE	Pcr 452, Hwy A, Church St, Brazeau, Perry, MO	453325	Perry
43	SE	County Road 738, 702, Hwy Y, Bollinger, MO 63787	513096	Bollinger
44	SE	County Road 3250, Route W, Sisson, Howell, MO	587463	Howell
45	SE	County Road 613, 612, Hwy V, Girardeau, MO 63701	478407	Cape Girardeau
46	SE	S 10th St, Hwy 19, Oregon County, MO	637405	Oregon
47	SE	County Road 40, Missouri O, Iron, MO 63623	447271	Iron
48	SE	County Road 324, Hwy 61, New Madrid, MO 63873	640131	New Madrid

Site No.	District	Description	Intersection No.	County
49	SE	State Hwy W, Rose St, Oran, Scott, MO 63771	536334	Scott
50	SE	County Road 650, Hwy 51, Broseley, Butler, MO 63932	608573	Butler
51	SL	Wilderness Ln, Old Colony Rd, Hwy Dd, MO 63341	268319	St. Charles
52	SL	Tin House Rd, Hwy Y, Hillsboro, Jefferson, MO 63050	373859	Jefferson
53	SL	Hendricks Rd, Hwy 30, Prairie, Franklin, MO	352615	Franklin
54	SL	Valles Mines School Rd, Valles Mines PO Rd, MO 63020	393922	Jefferson
55	SL	Lake Virginia Dr, Zion Rd, Hwy P, Festus, MO	368471	Jefferson
56	SL	4 Mile Rd, Hwy A, St. Johns, Franklin, MO 63090	316496	Franklin
57	SL	Yeates Rd, Boeuf Creek Rd, Hwy 100, Franklin, MO 63068	296187	Franklin
58	SL	Segelhorst Rd, Hwy 50, Lyon, Franklin, MO 63056	336257	Franklin
59	SL	Hwy H, Hwy J, Hwy 94, St. Charles, MO 63301	195523	St. Charles
60	SL	Iron Hill Rd, Hwy Tt, St. Clair, Franklin, MO 63077	344139	Franklin
61	SW	Main Street, Hwy 160, Greenfield, Dade, MO 65661	485991	Dade
62	SW	NE 9003 Rd, Hwy D, Bates, MO	352932	Bates
63	SW	East 460th Road, Hwy Vv, Hwy 123, MO 65649	466699	Polk
64	SW	Lady Rd, Hwy C, Washington, Vernon, MO 64772	422047	Vernon
65	SW	Gum Rd, Hwy 43, Five Mile, Newton, MO	569360	Newton
66	SW	NE 100th Ln, Hwy C, Milford, Barton, MO 64759	466633	Barton
67	SW	Lamar St, Sarcoxie St, Hwy 37, Avilla, Jasper, MO 64859	519300	Jasper
68	SW	SW 150th Ln, Hwy 126, South West, Barton, MO 64832	487311	Barton
69	SW	Linden Ave, Hwy 14, Hwy 125,Christian, MO 65753	562392	Christian
70	SW	1st St, Hwy P, St. Clair, MO 64724	375649	St. Clair

Table 9.9 is the list of rural multilane three-leg unsignalized intersections. Seventy-one rural multilane three-leg intersections were initially selected. However, one intersection was misclassified because it had a fourth leg and was dropped.

Table 9.9 List of sites for rural multilane three-leg unsignalized intersections

Site No.	District	Description	Intersection No.	County
1	NW	Iris Trail, Hwy 71, White Cloud, Nodaway, MO	34899	Nodaway
2	NW	County Road 54, Hwy 71, Rosendale, Andrew, MO 64483	40661	Andrew
3	NE	Rte J, Hwy 63, Macon, MO	53678	Macon
4	NW	County Road 364, Hwy 59 (71), Savannah, Andrew, MO 64485	54991	Andrew
5	NW	Ava Dr, Hwy 36, Wheeling, Livingston, MO 64688	67148	Livingston
6	NW	State Hwy Ab, Hwy 31, Hwy 36, Easton, Buchanan, MO 64443	70321	Buchanan
7	NE	Kensington Pl, Hwy 63, Macon, MO 63552	77998	Macon
8	NE	State Hwy Hh, Hwy 61, Clay, Ralls, MO	80248	Ralls
9	NE	State Hwy J, Hwy 24, Ralls, MO	80408	Ralls
10	NE	Hwy Ww, Hwy 61, Cuivre, Pike, MO	122588	Pike
11	NE	Hwy F, Hwy 61, Eolia, Lincoln, MO 63344	136430	Lincoln
12	NE	Timber Ridge Dr and Hwy 61	169476	Lincoln
13	CD	County Rd 158, Hwy 54, Jackson, Callaway, MO 65231	181777	Callaway
14	SL	Cinder Rd, Hwy 67, West Alton, St. Charles, MO 63386	207828	St. Charles
15	KC	NW 375th Rd, Hwy 50, Johnson, MO	222211	Johnson
16	KC	Elm Hills Blvd, Hwy 65, Sedalia, Pettis, MO 65301	273240	Pettis
17	KC	Missouri TT, Hwy 7, Harrisonville, Cass, Missouri 64701	292231	Cass
18	SL	Elizabeth Anne Ln, Hwy 100, Franklin, MO	317163	Franklin
19	CD	State Hwy D, Hwy 54, Lohman, Cole, MO	328837	Cole
20	SW	NW Hwy DD, Hwy 7, Honey Creek, Henry, MO	334896	Henry
21	SW	Frisch Avenue, Hwy 65, Lincoln, Benton, MO 65338	340675	Benton
22	SW	Jenny Ln, Hwy 65, Lincoln, Benton, MO 65338	341135	Benton
23	SW	Airport Rd, Hwy 65, Lincoln, Benton, MO 65338	341182	Benton
24	SW	Northwest 311 Road, Hwy 7, Fields Creek, Henry, MO 64735	342130	Henry
25	SW	Locust St, Hwy 65, Lincoln, Benton, MO 65338	342235	Benton
26	SW	State Hwy Ac, Hwy 65, Benton, MO	346252	Benton
27	SW	Cedargate Dr, Hwy 65, Benton, MO	357162	Benton
28	SE	Valles Mines Rd, Hwy 67, Valles Mines, MO 63087	395973	Jefferson
29	CD	5th St, Hwy 54, Camdenton, Camden, MO 65020	400983	Camden
30	CD	4th Street, Hwy 54, Camdenton, Camden, MO 65020	401,000	Camden
31	CD	3rd St, Hwy 54, Camdenton, Camden, MO 65020	401063	Camden
32	CD	Grant Ave, Hwy 54, Camdenton, Camden, MO 65020	401324	Camden
33	CD	Iowa St (Lake Ave), Hwy 54, Camdenton, Camden, MO 65020	402187	Camden
34	SW	Hwy UU, Hwy 13, St. Clair, MO	426433	St. Clair
35	SE	County Road 220, Hwy 67, Mine La Motte, Madison, MO 63645	461488	Madison
36	SE	State Hwy H and Hwy 67	462363	Madison
37	SW	Rocks Dale Rd, Hwy 65, Dallas, MO	470050	Dallas
38	SE	County Road 417, Hwy 67, Central, Madison, MO 63645	478605	Madison
39	SE	County Road 303, Hwy 67, Madison, MO	486267	Madison
40	SE	Hwy EE, Hwy 67, Cedar Creek, Wayne, MO	499137	Wayne
41	SW	State Hwy O, Diggins, Webster, MO 65746	526207	Webster
42	SW	Northwest 351 Road, Hwy 7, Fields Creek, Henry, MO 64735	651611	Henry
43	KC	OR 50 (Old Highway 50), Hwy 50, Pettis, Missouri 65301	652956	Pettis
44	NW	400th Street, Hwy 71, White Cloud, Nodaway, MO	654173	Nodaway
45	NW	County Road 140, Hwy 71, Bolckow, Andrew, MO 64427	654183	Andrew
46	NW	County Road 139, Hwy 71, Rosendale, Andrew, MO 64483	654186	Andrew
47	NE	State Hwy Dd, Hwy 24 (Hwy 36), Marion, MO	919584	Marion
48	NW	112 SE, Hwy 36, Easton, Buchanan, Missouri 64443	954216	Buchanan
49	NE	County Road 494, Hwy 61, Canton, Lewis, MO 63448	954295	Lewis
50	NE	County Road 263, Hwy 24, South River, Marion, MO	982897	Marion

Site No.	District	Description	Intersection No.	County
51	CD	County Road 348, Hwy 54, New Bloomfield, Callaway, MO 65063	984961	Callaway
52	SL	S Buck Creek Rd and Hwy 67	996785	Jefferson
53	SE	County Road 547, Hwy 67, Black River, Wayne, MO 63967	1014034	Wayne
54	SW	Crossroads Dr, Hwy 65, South Benton, Dallas, MO 65622	1022960	Dallas
55	SE	County Road 454, 450, Hwy 67, Twelvemile, Madison, MO 63964	1023614	Madison
56	SE	County Road 452, Hwy 67, Twelvemile, Madison, MO 63964	1024242	Madison
57	SW	Lamine St, Hwy 65, Benton, MO 65338	1039950	Benton
58	SE	County Road 302, Hwy 67, Cedar Creek, Wayne, MO 63636	1042119	Wayne
59	SW	Meyer Rd, Hwy 65, North Lindsey, Benton, MO	1054123	Benton
60	CD	State Hwy K, Hwy 50, Walker, Moniteau, MO 65018	1021606/ 1021605	Moniteau
61	NE	Thompson St, Hwy 24, Hwy 61, Palmyra, Marion, MO 63461	1024454/1024455	Marion
62	KC	Hwy H, Hwy 65, Saline, MO	170127/930296	Saline
63	SL	Wise Rd, Hwy 67, West Alton, St. Charles, MO 63386	203232/203079	St. Charles
64	CD	Missouri A, Hwy 54, Camden, MO	396153/396155	Camden
65	SE	Tower Rd, Hwy 67, Big River, St. Francois, MO 63628	398410/976253	St. Francois
66	SE	Pike Run Rd, Hwy 67, Big River, St. Francois, MO	399038/976296	St. Francois
67	SW	NW 1401 Rd, Hwy 7, Bogard, Henry, MO 64788	651600/327958	Henry
68	NW	Hwy 33, Hwy 36, DeKalb, MO	68202/68162	DeKalb
69	NE	State Hwy H, Hwy 24, South River, Marion, MO	78472/982900	Marion
70	SW	Branson Creek Boulevard, Hwy 65, Hollister, Taney, MO 65672	978785/978785	Taney

Table 9.10 is the list of rural multilane four-leg unsignalized intersections.

Table 9.10 List of sites for rural multilane four-leg unsignalized intersections

Site No.	District	Description	Intersection No.	County
1	NE	County Road 312, 338, Marion, MO 63471	55861	Marion
2	NE	County Road 1330 (A102)(1420), Hwy 63,Randolph,MO 65270	97866	Randolph
3	KC	County Road 339 (318), Hwy UU, Saline, MO 65340	176331	Saline
4	CD	County Road 14, Hwy 54, Callaway, MO 65262	187945	Callaway
5	KC	Buckeye Rd, Hwy 50, Pettis, MO 65337	246176	Pettis
6	CD	County Road 394, Hwy 63, Callaway, MO 65039	279662	Callaway
7	KC	E 315th St, Hwy 7, Cass, MO 64747	312342	Cass
8	KC	O'Bannon Rd, Hwy 7, Cass, MO 64747	313066	Cass
9	SL	Jones Ln, Hwy 100, Franklin, MO 63090	313754	Franklin
10	SW	Northwest 900 Road, Hwy 7, Henry, MO 64739	323701	Henry
11	SW	Northwest 800 Road, Hwy 7, Henry, MO 64788	326085	Henry
12	SW	State Hwy HH, N W 500 Bc, Benton, MO 65338	337086	Benton
13	SW	Zion Church Rd, Hwy 65,Benton, MO 65338	343348	Benton
14	SW	State Hwy H , N W 351 Bc, Benton, MO 65338	344457	Benton
15	SW	SW 400 Rd, Hwy 52, Henry, MO 64735	355004	Henry
16	SW	Southwest 450th Road, Hwy 52, Henry, MO 64735	355980	Henry
17	SW	SE 900 Rd, Hwy 13, Henry, MO 64740	367926	Henry
18	SW	NE 1270 Rd (SE 1100 Rd), Hwy 13, Henry, MO 64740	372958	Henry
19	SE	Canterberry Rd, Hwy 67, St. Francois, MO 63640	451074	St. Francois
20	SW	Woodstock Rd, Hwy 65, Dallas, MO 65644	480168	Dallas
21	SE	County Road 303, 211, Wayne, MO 63956	503562	Wayne
22	SE	County Road 213, Hwy 67, Wayne, MO 63964	512804	Wayne
23	SW	NE 800 Rd, 7th St, St. Clair, MO 64763	653589	St. Clair
24	NW	395th St, Hwy 71, Nodaway, MO 64423	654171	Nodaway
25	NW	County Road 137 ,41, Andrew, MO 64483	654174	Andrew
26	NW	County Road 80, 36, Andrew, MO 64427	654182	Andrew
27	CD	Forest Rd, Hwy 50, Moniteau, MO 65018	655027	Moniteau
28	SW	SE 1150, Hwy 13, St. Clair. MO 64738	941779	St. Clair
29	SW	East 310th Road, Hwy 13, Polk, MO 65674	941785	Polk
30	CD	County Line Rd , Hwy 50, Moniteau, MO 65023	975965	Moniteau
31	CD	Shooters Club Rd, Hwy 50, Moniteau. MO 65018	976005	Moniteau
32	NE	State Hwy U, Hwy 24, Marion, MO 63456	982890	Marion
33	SE	State Hwy O, Monday Ln, Butler MO 63967	1014049	Butler
34	SE	County Road 501, 401, Butler MO 63967	1014051	Butler
35	SW	Foose Rd, Hwy 65, Jackson, Dallas, MO 65622	1019957	Dallas
36	SE	County Road 216, 305, Wayne, MO 63964	1042125	Wayne
37	SE	Hwy 49, Hwy 172, Wayne, MO 63967	1014045	Wayne
38	CD	Jacket Factory Road, Hwy 50, Moniteau, MO 65018	1021590	Moniteau
39	SE	State Highway C, Hwy 67, Madison, MO 63645	1024002	Madison
40	SE	County Road 209, 303, Oregon, MO 63645	1042121	Oregon
41	SE	County Road 211, 303, Wayne, MO 63956	1042123	Wayne
42	NE	Creech Ln, Hwy 61, Lincoln, MO 63379	158982/158986	Lincoln
43	CD	Missouri T, Hwy 54, Callaway, MO 65231	177959/177956	Callaway
44	KC	State Hwy CC, Hwy 65, Pettis, MO 65351	199292/210624	Pettis
45	KC	NW 821st Rd, Hwy 50, Johnson, MO 64019	226286/226104	Johnson
46	CD	County Road 338, Hwy 54, Callaway, MO 65063	244134/984721	Callaway
47	KC	State Hwy T, Hwy 50, Pettis, MO 65301	249999/250088	Pettis
48	KC	Missouri T, Hwy 7, Cass, MO 64747	296848/296743	Cass

Site No.	District	Description	Intersection No.	County
49	NW	370th St, Hwy 71, Nodaway, MO 64423	30947/654167	Nodaway
50	SL	St Johns Rd, Hwy 100, Franklin, MO 63090	312682/1024463	Franklin
51	SL	Hwy 100, Hwy V, Franklin, MO 63055	318872/1024465	Franklin
52	CD	Abbott Rd, Hwy 54, Miller, MO 65032	344653/344604	Miller
53	SW	SE 700 Rd, Hwy 52, Henry, MO 64740	362072/653616	Henry
54	CD	State Hwy V, Hwy 54, Miller, MO 65026	367877/367923	Miller
55	SL	Timbercreek Dr, Baisch Dr, Jefferson, MO 63020	388534/997231	Jefferson
56	NE	County Road 567, Hwy 61, Lewis, MO 63448	48315/48292	Lewis
57	NE	State Hwy V, Hwy 61, Lewis, MO 63471	49594/49602	Lewis
58	NE	County Road 349, 308, Marion, MO 63471	51604/51603	Marion
59	NW	Hwy 36, Hwy 5, Linn, MO 64651	66977/67046	Linn
60	NW	State Highway C, Hwy Z, Buchanan, MO 64443	69991/70053	Buchanan
61	NE	County Road 441, 409, Marion, MO 63401	70986/70950	Marion
62	NE	County Rd 1745 (B56), 1640 (A40), Randolph, MO 65239	935184/92565	Randolph
63	SW	SE 750 Rd, Hwy 13, St. Clair, MO 64738	970861/417848	St. Clair
64	CD	Murphy Ford Rd, Hwy 50, Cole, MO 65023	975964/975956	Cole
65	CD	9 Hills Rd, Hwy 50, Cole, MO 65109	975966/975958/975962	Cole
66	CD	Route U, Hwy 50, Cole, MO 65023	975983/975990	Cole

Sixty-seven rural multilane four-leg intersections were identified initially. However, one intersection was a J-turn and was dropped. The rural multilane lists, for three- and four-leg intersections, contain almost all such intersections in Missouri due to the scarcity of such intersections in the state.

Table 9.11 lists the urban three-leg unsignalized intersections.

Table 9.11 List of sites for urban three-leg unsignalized intersections

Site No.	District	Description	Intersection No.	County
1	CD	Swifts Highway, Southwest Blvd, Jefferson City, Cole, MO 65109	305939	Cole
2	CD	Court St, Hwy 5, New Franklin, Howard, MO 65274	175046	Howard
3	CD	Young St, E 10th St, Dent Ford Rd, Salem, Dent, MO 65560	456083	Dent
4	CD	Hwy W, US54W TO RTW, Callaway, MO	297854	Callaway
5	CD	Holloway Street, Rolla, 11th St, Phelps County, MO 65401	409794	Phelps
6	CD	Maywood Dr, W Edgewood Dr, Jefferson City, Cole, MO 65109	305756	Cole
7	CD	Grace Ln, Sombart Rd, Boonville, Cooper, MO 65233	959247	Cooper
8	CD	North Park Avenue, W 4th St, Salem, Dent, MO 65560	456871	Dent
9	CD	Fuqua Drive, Hwy 5, US 40, Boonville, Cooper, MO 65233	196263	Cooper
10	CD	County Road 3060, Rd 44, Old St James Rd, Hy Point Ind. Dr, Rolla, Phelps, Missouri 65401	405755	Phelps
11	KC	Victor St, Prospect Ave, Kansas City, Jackson, MO 64128	159600	Jackson
12	KC	Hillcrest Road, E 107th Rd, Kansas City, Jackson, MO	195531	Jackson
13	KC	Swope Ln, N Fairview Dr, Independence, Jackson, MO 64056	148666	Jackson
14	KC	Rhodus Rd, NE 1040th St, Excelsior Springs, Clay, MO 64024	115223	Clay
15	KC	Northwest Robinhood Lane, NW 108th St, Kansas City, Platte, MO	121303	Platte
16	KC	Oak Terrace, 64113, Kansas City, Jackson, MO 64113	176297	Jackson
17	KC	Lauren St, Birmingham Rd, Liberty, Clay, MO 64068	939962	Clay
18	KC	Killion Dr, E 24th St, Sedalia, Pettis, MO 65301	267677	Pettis
19	KC	Ella St, Hwy 58, Belton, Cass, MO 64012	223036	Cass
20	KC	Cole Rd, E Kentucky Rd, Jackson, Missouri 64050	147308	Jackson
21	NE	Sparks Avenue, Buchanan St, Moberly, Randolph, MO 65270	1031957	Randolph
22	NE	Daugherty St, Rollins St, Macon, MO 63552	73300	Macon
23	NE	W Normal St, S Osteopathy, Kirksville, Adair, MO 63501	32041	Adair
24	NE	East Anderson Street, Agricultural St, Hwy J, Mexico, Audrain, MO 65265	141064	Audrain
25	NE	Hwy Ee, E Burkhart St, Moberly, Randolph, MO 65270	106291	Randolph
26	NE	E Goggin St, S Rutherford, Macon, MO 63552	73953	Macon
27	NE	Perkins Blvd, W Perry St, Troy, Lincoln, MO 63379	181671	Lincoln
28	NE	N Abat St, W Liberty St, Hwy Ff, Mexico, Audrain, Missouri 65265	141791	Audrain
29	NE	W Bourke Street, Sunset Hills Dr, Macon, MO 63552	73408	Macon
30	NE	S Spoede Ln, E Veterans Memorial Pkwy, OR 70, Truesdale, Warren, MO	219459	Warren
31	NW	Parker Rd, Washington St, St. Joseph, Buchanan, MO 64504	77417	Buchanan
32	NW	South Market Street, Lincoln Ter, Maryville, Nodaway, MO 64468	19167	Nodaway
33	NW	South East Street, E 2nd St, Cameron, Clinton, MO 64429	72581	Clinton
34	NW	Helena St, St Joseph Ave, Hwy 59, Buchanan, MO 64505	62916	Buchanan
35	NW	Wilton Dr, Elizabeth St, St. Joseph, Buchanan, MO 64504	76153	Buchanan
36	NW	W 8th St, Cherry St, Cameron, DeKalb, Missouri 64429	71210	DeKalb
37	NW	Prindle St, S 4th St, St. Joseph, Buchanan, MO 64504	74533	Buchanan
38	NW	West Meadow Lane, Messanie St, St. Joseph, Buchanan, MO 64501	67330	Buchanan
39	NW	Mary St, S 22md St, St. Joseph, Buchanan, MO	67534	Buchanan
40	NW	County Line Rd, 28th Terrace, St. Joseph, Andrew County, MO	59571	Andrew
41	SE	South Pacific Street, Merriwether St, Cape Girardeau, MO 63703	496314	Cape Girardeau

Site No.	District	Description	Intersection No.	County
42	SE	Hwy K, Loraine St, Bonne Terre, St. Francois, MO 63628	412211	St. Francois
43	SE	East Elk Street, N Nelson Ave, Dexter, Stoddard, MO 63841	589794	Stoddard
44	SE	East Elk Street, Gibson Ave, State Route CC, Dexter, Stoddard, MO 63841	602197	Howell
45	SE	Glenn Drive, County Line Rd, Sikeston, Scott, MO 63801	577242	Scott
46	SE	Hovis Farm Rd, W Main St. Hwy Z, Park Hills, MO 63601	421875	St. Francois
47	SE	Highland Avenue, W 3rd St, Caruthersville, Pemiscot, MO 63830	645579	Pemiscot
48	SE	Burgoyne Drive, Hwy 63, West Plains, Howell, MO 65775	601287	Howell
49	SE	Clay Street, Hwy K, Perry, St. Francois, MO 63628	412269	St. Francois
50	SE	Vine St, N Front St, Hwy 32, Park Hills, St. Francois, MO 63601	424183	St. Francois
51	SL	Patricia Ridge Drive, Old Halls Ferry Rd, Black Jack, St. Louis, MO 63033	226548	St. Louis
52	SL	Kossuth Ave, Gano Ave, St. Louis, MO	264601	St. Louis city
53	SL	Cabanne Ave, Union Blvd, St. Louis, MO	267897	St. Louis city
54	SL	Midland Blvd, Bryant Ave, St. Louis, MO	1019326	St. Louis
55	SL	Sapphire Ave, College Ave, St. Louis, MO 63136	250551	St. Louis
56	SL	Ringer Rd, Kinswood Ln, OR 255, St. Louis, MO	316451	St. Louis
57	SL	South Duchesne Drive, Walter PI, St. Charles, MO 63301	225902	St. Charles
58	SL	Wall Street, E Maple Ave, Wentzville, St. Charles, MO 63385	219068	St. Charles
59	SL	Glaser Rd, N Service Rd E, OR 44, Sullivan, Franklin, MO 63080	361456	Franklin
60	SL	Sadonia Ave, Moran Dr, St. Louis, MO 63135	233589	St. Louis
61	SW	Glenwood Ave, W Farm Rd 178, E Hines St, Republic, Greene, MO 65738	937218	Greene
62	SW	State Hwy Mm, Nevada St, Oronogo, Jasper, MO	519949	Jasper
63	SW	South Grant Street, Hwy 96, E Grant Ave, Carthage, Jasper, MO 64836	522684	Jasper
64	SW	South Peyton Street, E Ohio St, Hwy 18, Clinton, Henry, MO 64735	345735	Henry
65	SW	E Portland St, S Fairway St, Springfield, Greene, MO	522711	Greene
66	SW	Mill St, N Main St, Willard, Greene, MO 65781	539712	Greene
67	SW	West Cherokee Street, S Weaver Ave, Springfield, Greene, MO 65807	524371	Greene
68	SW	South Cavalier Avenue, E Cherry St, Springfield, Greene, MO 65802	518931	Greene
69	SW	Michigan Avenue, E 7th St, Hwy 66, Joplin, Jasper, MO	545140	Jasper
70	SW	Adams St, W Hadley St, Aurora, Lawrence, MO 65605	569431	Lawrence

Table 9.12 is the list of urban four-leg unsignalized intersections.

Table 9.12 List of sites for urban four-leg unsignalized intersections

Site No.	District	Description	Intersec. No.	County
1	CD	Marshall St, E High St, Jefferson City, Cole, MO 65101	304938	Cole
2	CD	Vintage Ln, Vintage Ct, Rte C, Jefferson City, MO 65109	312195	Cole
3	CD	North Aurora Street, W 1st St, Eldon, Miller, MO 65026	349377	Miller
4	CD	Vine St, Hwy 5, Hwy 40, Main St, Boonville, Cooper, MO 65233	187208	Cooper
5	CD	Clark Ave, Atchison St, Moreau Dr, Jefferson City, MO 65101	308178	Cole
6	CD	Fulkerson St, High St, Jefferson City, Cole, MO 65109	301453	Cole
7	CD	Hough St, McKinley St, Jefferson City, Cole, MO 65101	306250	Cole
8	CD	North Dilworth, Missouri J, County Rd 322, Salem, Dent, MO 65560	456497	Dent
9	CD	Atkinson Rd, William Woods Ave, Fulton, Callaway, MO 65251	209569	Callaway
10	CD	North Grand Avenue, W 9th St, Eldon, Miller, MO 65026	350342	Miller
11	KC	Northwest Old Pike Road, NW 53rd St, Gladstone, Clay, MO 64118	136897	Clay
12	KC	Charlotte St, E 43rd St, Kansas City, MO 64131	165415	Jackson
13	KC	Main St, 38th St, Kansas City, Jackson, MO	163188	Jackson
14	KC	North Huntsman Boulevard, N Campbell Blvd, Hwy 58, Raymore, Cass, MO 64083	224016	Cass
15	KC	North 81st Terrace, NE Antioch Rd, Kansas City, Clay, MO 64119	1014604	Clay
16	KC	North Holmes Street, NE 45th St, Kansas City, Clay, MO	139797	Clay
17	KC	Crysler St, E 42nd St, Kansas City, Jackson, MO 64133	166696	Jackson
18	KC	W Black Diamond St, College St, Richmond, Ray, MO 64085	122705	Ray
19	KC	Ararat Dr, S Park Dr, Sni A Bar Rd, Kansas City, Jackson, MO	168731	Jackson
20	KC	Northeast 39th Street, N Prather Rd, Hwy 1, Kansas City, Clay, MO	141967	Clay
21	NE	Center St, N 7th St, Hannibal, Marion, MO 63401	76414	Marion
22	NE	State Hwy Mm, W Main St, Warrenton, MO 63383	222282	Warren
23	NE	South Sturgeon Street, E Rollings St, Moberly, Randolph, MO 65270	106143	Randolph
24	NE	W Brewington Ave, Hwy 63, Kirksville, Adair, MO 63501	28087	Adair
25	NE	S Cuivre St, W Main St, Bowling Green, Pike, MO 63334	1026956	Pike
26	NE	Wightman St, S 4th St, Moberly, Randolph, MO 65270	106235	Randolph
27	NE	Magnolia Ave, Bird St, Hannibal, Marion, MO 63401	76551	Marion
28	NE	W Pearson St, N Washington St, Mexico, Audrain, MO 65265	1038144	Audrain
29	NE	County Road 418, Hwy Mm, Hannibal, Marion, MO 63401	77182	Marion
30	NE	Holman Rd, Fisk Ave, Moberly, Randolph, MO 65270	106542	Randolph
31	NW	Jules St, N 7th St, St. Joseph, Buchanan, MO	66244	Buchanan
32	NW	South Harris Street, N Harris St, 2nd St, State Hwy A, Cameron, Clinton, MO 64429	72360	Clinton
33	NW	West 24th Street, Princeton Rd, Route AA, Trenton, Grundy, MO 64683	40344	Grundy
34	NW	Jules St, Main St, St. Joseph, Buchanan, MO	66236	Buchanan
35	NW	Lulu St, 22nd St, Trenton, Grundy, MO 64683	40463	Grundy
36	NW	N Mulberry Street, W 11th St, Maryville, Nodaway, MO 64468	17320	Nodaway
37	NW	E Franklin Street, N 4th St, St. Joseph, Buchanan, MO 64501	65213	Buchanan
38	NW	Cook Rd, Riverside Rd, St. Joseph, Buchanan, MO	60813	Buchanan
39	NW	Market St, W Main St, Rushville, Buchanan, MO 64484	63827	Buchanan
40	NW	N Dewey Street, Hwy 46, Maryville, Nodaway, MO 64468	18163	Nodaway
41	SE	Mary Street, Hwy 61, Jackson, Cape Girardeau, MO 63755	484881	Cape Girardeau

Site No.	District	Description	Intersec. No.	County
42	SE	Hwy 25, Broadwater Rd, CRD 524, Como, New Madrid, MO 63863	625178	New Madrid
43	SE	Walker Avenue, 9th St, Caruthersville, Pemiscot, MO 63830	645764	Pemiscot
44	SE	South Henderson Avenue, Independence St, Cape Girardeau, MO 63703	496062	Cape Girardeau
45	SE	Alice St, Neat St, Poplar Bluff, Butler, MO 63901	596476	Butler
46	SE	Sikes Ave, Hwy 61, Sikeston, Scott, MO 63801	573513	Scott
47	SE	Locust Avenue, Hwy 84, Caruthersville, Pemiscot, MO 63830	645659	Pemiscot
48	SE	Carleton Ave, 4th St, Caruthersville, Pemiscot, MO 63830	645616	Pemiscot
49	SE	Daisy Ave, Adams St, Jackson, Cape Girardeau, MO 63755	645616	Cape Girardeau
50	SE	Carzon Rd, Hwy K, Perry, St. Francois, MO 63628	412139	St. Francois
51	SL	Ohio Avenue, Arsenal Ave, St. Louis, MO	286596	St. Louis city
52	SL	Russell Blvd, 13th St, St. Louis, MO	283857	St. Louis city
53	SL	Chariot Dr, Gladiator Dr, Fenton, St. Louis, MO 63026	309450	St. Louis
54	SL	Leonard Ave, Washington Blvd, St. Louis, MO	273816	St. Louis city
55	SL	Creekside Ln, Chambray Ct, St. Louis, MO 63141	266616	St. Louis
56	SL	North Mosley Road, Terra Mar Ln, Hunters Pond Rd, St. Louis, MO 63141	268375	St. Louis
57	SL	Monique Ct, Boca Raton Dr, Willott Rd, St. Peters, St. Charles, MO 63376	232797	St. Charles
58	SL	Parnell St, Warren St, St. Louis, MO	269334	St. Louis city
59	SL	Hampton Avenue, Hartford St, St. Louis, MO	285072	St. Louis city
60	SL	Baxter Rd, Summer Ridge Dr, Manchester, St. Louis, MO	277546	St. Louis
61	SW	Kickapoo Ave, E Grant St, Springfield, Greene, MO	520141	Greene
62	SW	W Atlantic St, N Main St, Springfield, Greene, MO	513439	Greene
63	SW	East 33rd Street, Finley Ave, Joplin, Newton, MO 64804	551867	Newton
64	SW	South Lillian Avenue, W Madison St, Bolivar, Polk, MO 65613	463380	Polk
65	SW	Morgan Avenue, W Cofield St, Aurora, Lawrence, MO 65605	566266	Lawrence
66	SW	South Fountain Street, W Main St, Carterville, Jasper, MO 64835	529689	Jasper
67	SW	Daniels St, S Carnation Rd, Aurora, Lawrence, MO 65605	569938	Lawrence
68	SW	Highland Ave, Hwy 66, Joplin, Jasper, MO 64801	545220	Jasper
69	SW	North Pine Street, E Hubble Dr, Hwy CC, Marshfield, Webster, MO 65706	497046	Webster
70	SW	East Hickory Street, RU 71, N Osage Blvd, Nevada, Vernon, MO 64772	428046	Vernon

Several sites were changed from the previous calibration for various reasons, including geometric changes and erroneous intersection numbers.

9.5 Data Collection

The data required for urban unsignalized intersections consisted of AADTs for major and minor approaches, number of approaches with left/right-turn lanes, skew angle, and the presence of lighting. A list of the data types collected and their sources is shown in Table 9.13.

Table 9.13 List of data sources for unsignalized intersections

Data Description	Source
AADT	TMS
No. of Approaches with Left-Turn Lanes	Aerials
No. of Approaches with Right-Turn Lanes	Aerials
Presence of Lighting	ARAN and Street View
No. of Crashes	TMS

Aerial photographs were used to determine the presence of either left- or right-turn lanes, the number of legs, and the skew angle. ARAN video, along with aerial and street view photographs, were used to determine the presence of lighting at the intersections. The AADTs from 2012 to 2014 and total crashes were collected from the TMS.

Several challenges were encountered during the collection of data for urban unsignalized intersections. One issue was the total number of crashes for the three-year period, which was considerably lower than the HSM recommendation of at least 100 crashes for a facility type. Even with oversampling (i.e., 70 sites), the total number of crashes observed for unsignalized facility types was still below the HSM recommendation. Another difficulty occurred when the crash query was initiated. The program that was utilized had to be handled in a particular way or the crash query might produce incorrect results. For example, after searching for the desired intersection number, careful consideration was required when selecting the intersecting travelways. The minor leg direction, especially, was sometimes problematic. If a direction other than the minor approach leg was selected, the query would show that no crashes were observed on that site. However, if the approach direction was chosen as the selected travelway, the query would produce crashes if there were actual crashes observed at the intersection within the specified time frame.

9.5.1 Summary Statistics for Unsignalized Intersections

Descriptive statistics for all unsignalized intersections are shown in Table 9.14.

Table 9.14 Sample descriptive statistics for unsignalized intersections

Intersection Type	Description	Ave.	Min.	Max.	Std. Dev.
R2L 3ST[1]	Major AADT (2014)	1365.5	34.0	7264.0	1671.8
	Minor AADT (2014)	73.3	1.0	768.0	111.4
	No. of App. W/ Left-Turn Lanes	0.0	0.0	1.0	0.1
	No. of App.W/ Right-Turn Lanes	0.0	0.0	0.0	0.0
	Skew Angle	14.4	0.0	70.0	21.1
	Crashes/Site/3 Years	0.3	0.0	3.0	0.7
	Number of Crashes in 3 Years	22			
	No. of Intersections W/ Lighting	7			
R2L 4ST[2]	Major AADT (2014)	1711.7	42.0	8464.0	2185.3
	Minor AADT (2014)	238.7	4.0	3170.0	455.1
	No. of App. W/ Left-Turn Lanes	0.0	0.0	0.0	0.0
	No. of App. W/ Right-Turn Lanes	0.0	0.0	0.0	0.0
	Skew Angle	8.9	0.0	70.0	14.6
	Crashes/Site/3 Years	0.6	0.0	6.0	1.3
	Number of Crashes in 3 Years	44			
	No. of Intersections W/ Lighting	26			
U 3ST[3]	Major AADT (2014)	4318.5	26.0	19752.0	4447.7
	Minor AADT (2014)	301.6	12.0	3887.0	548.6
	No. of App. W/ Left-Turn Lanes	0.2	0.0	1.0	0.4
	No. of App. W/ Right-Turn Lanes	0.0	0.0	0.0	0.0
	Skew Angle	N/A	N/A	N/A	N/A
	Crashes/Site/3 Years	0.8	0.0	6.0	1.4
	Number of Crashes in 3 Years	57			
	No. of Intersections W/ Lighting	53			
U 4ST[4]	Major AADT (2014)	4510.7	30.0	23975.0	4881.8
	Minor AADT (2014)	616.2	14.0	4984.0	821.3
	No. of App. W/ Left-Turn Lanes	0.2	0.0	2.0	0.6
	No. of App. W/ Right-Turn Lanes	0.0	0.0	0.0	0.0
	Skew Angle	N/A	N/A	N/A	N/A
	Crashes/Site/3 Years	2.5	0.0	27.0	4.0
	Number of Crashes in 3 Years	172			
	No. of Intersections W/ Lighting	66			
RML 3ST[5]	Major AADT (2014)	12069.7	2754.0	35500.0	7837.3
	Minor AADT (2014)	372.1	5.0	1329.0	325.2
	No. of App. W/ Left-Turn Lanes	0.8	0.0	2.0	0.5
	No. of App. W/ Right-Turn Lanes	0.2	0.0	1.0	0.4
	Skew Angle	5.2	0.0	40.0	9.8
	Crashes/Site/3 Years	2.4	0.0	46.0	5.9
	Number of Crashes in 3 Years	169			
	No. of Intersections W/ Lighting	11			

Intersection Type	Description	Ave.	Min.	Max.	Std. Dev.
RML 4ST[6]	Major AADT (2014)	9608.5	3352.0	21740.0	4008.2
	Minor AADT (2014)	474.9	134.0	1834.0	314.6
	No. of App. W/ Left-Turn Lanes	1.6	0.0	2.0	0.8
	No. of App. W/ Right-Turn Lanes	0.2	0.0	2.0	0.5
	Skew Angle	4.7	0.0	30.0	8.5
	Crashes/Site/3 Years	2.2	0.0	23.0	3.3
	Number of Crashes in 3 Years	144			
	No. of Intersections W/ Lighting	5			

Notes:

[1]R2L 3ST Rural Two-Lane Three-Leg Unsignalized Intersections
[2]R2L 4ST Rural Two-Lane Four-Leg Unsignalized Intersections
[3]U 3ST Urban Three-Leg Unsignalized Intersections
[4]U 4ST Urban Four-Leg Unsignalized Intersections
[5]RML 3ST Rural Multilane Three-Leg Unsignalized Intersections
[6]RML 4ST Rural Multilane Four-Leg Unsignalized Intersections

The average AADTs were much higher for rural multilane (i.e., 12,070 and 9,609) compared to rural two-lane intersections (i.e., 1,366 and 1,712). The average AADTs for urban intersections were 4,319 and 4,511, respectively, for three- and four-leg intersections.

The highest average skew angle observed was 14.4 degrees for rural two-lane three-leg intersections. Approaches with left-turn lanes were most common for rural multilane intersections, with averages of 0.8 (three-leg) and 1.6 (four-leg). The row entitled “Number of Crashes in 3 Years” is the total number of crashes for all the sites for a particular facility type. As can be seen in Table 9.14, the three types of intersections that experienced the recommended 100 crashes were urban four-leg intersections (172 crashes), rural multilane three-leg intersections (169 crashes), and rural multilane four-leg intersections (144 crashes).

9.6 Results and Discussion

9.6.1 Rural Two-Lane Three- and Four-Leg Stop-Sign Intersections

The base HSM SPF models developed for rural two-lane unsignalized stop-controlled intersections considered crashes within 250 ft (76 m) of a particular intersection using negative binomial regression analysis. The data used for the regression analysis were obtained from 382 three-leg stop-controlled intersections in Minnesota, which included five years of crash data (1985 to 1989), and 324 four-leg stop-controlled intersections, also from Minnesota, which included five years of crash data (1985 to 1989) for each intersection (Harwood et al. 2007).

The calibration factor for rural two-lane unsignalized intersections in Missouri yielded the calibration factor values of 0.69 for three-leg intersections and 0.41 for four-leg intersections. Figure 9.11 shows the IHSDM output for the three-leg intersection calibration, and Figure 9.12 shows the output for the four-leg intersection calibration.

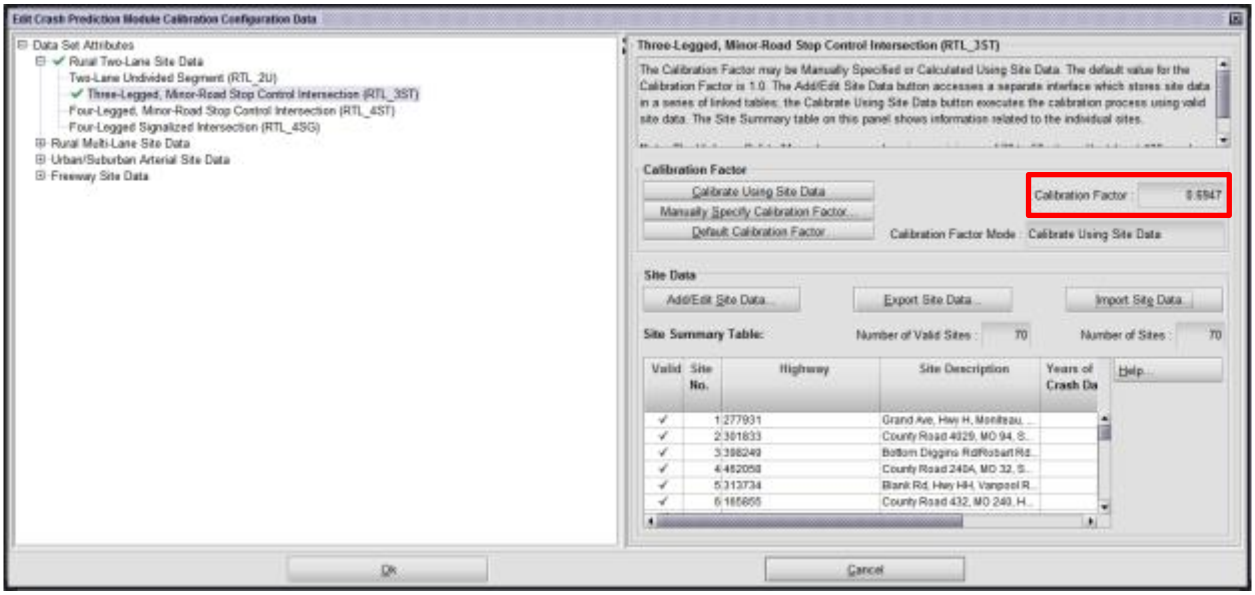

Figure 9.11 Calibration output for rural two-lane three-leg unsignalized intersections

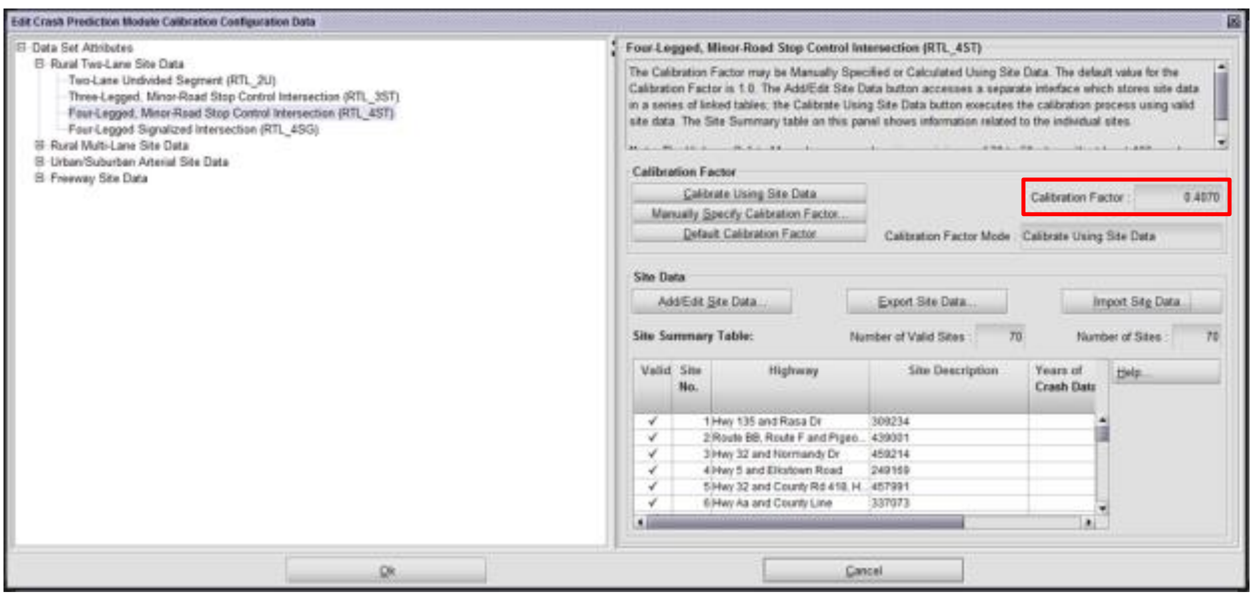

Figure 9.12 Calibration output for rural two-lane four-leg unsignalized intersections

Table 9.15 shows the calibration results for the individual sites. These results indicate that the numbers of crashes observed at rural two-lane three-leg and four-leg unsignalized intersections in Missouri were lower than the numbers of crashes predicted by the HSM for the same intersection types.

Table 9.15 Rural two-lane three- and four-leg unsignalized intersection results

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Observed	Predicted	No.	Int. No.	Observed	Predicted
1	277931	0	0.2222	1	309234	0	0.3465
2	301833	0	0.5181	2	439001	1	1.185
3	398249	0	0.1771	3	459214	6	1.5552
4	462058	0	0.3604	4	249169	1	0.8395
5	313734	0	0.0188	5	457991	3	3.9527
6	165855	0	0.7175	6	337073	0	0.2433
7	395691	3	1.7822	7	185659	0	0.208
8	358162	1	0.3312	8	150348	0	0.1743
9	437012	0	0.0244	9	941340	0	0.5666
10	341235	1	2.476	10	376560	1	0.1095
11	1024754	0	0.3335	11	257488	0	1.2743
12	148501	1	1.5098	12	247971	0	0.3627
13	183496	0	1.8426	13	144057	3	3.1319
14	194504	0	0.0501	14	94741	0	0.3375
15	128338	1	2.1804	15	131307	1	1.4396
16	257933	0	0.2433	16	179272	0	1.4468
17	182234	0	0.3335	17	266798	3	14.943
18	101512	0	0.0855	18	139264	3	0.9872
19	199141	0	0.0829	19	265534	0	6.6787
20	259956	0	0.0511	20	314183	0	1.7611
21	117	0	0.0129	21	31011	0	0.0724
22	119371	0	0.1997	22	498	0	0.02
23	5567	0	0.021	23	1029271	0	0.3368
24	73147	0	0.0263	24	122384	0	0.4329
25	81668	0	0.0194	25	1037510	0	1.0193
26	111199	0	0.0216	26	72647	0	0.0958
27	56428	0	0.0409	27	43610	0	0.8797
28	66821	0	0.059	28	114079	0	0.1016
29	200260	0	0.1389	29	1026494	0	0.0182
30	98338	0	0.0034	30	35796	0	0.1379
31	49142	0	0.0306	31	8607	0	0.0155
32	49076	0	0.0306	32	87502	1	0.669
33	51127	0	0.0849	33	8111	0	0.8551
34	30409	0	0.0396	34	4139	0	0.1008
35	89124	0	0.1261	35	76413	0	0.0804
36	59129	0	0.6982	36	22531	0	0.0397
37	30013	0	0.0088	37	26276	0	0.6971
38	2101	0	0.0559	38	41297	0	0.0131
39	31927	0	0.0106	39	27746	0	0.065
40	56702	0	0.2425	40	14176	1	0.3458
41	516183	0	0.9281	41	626406	0	0.0655
42	616858	1	0.1933	42	453325	0	0.4245
43	569355	0	0.05	43	513096	0	0.0305
44	592827	0	0.0442	44	587463	0	0.3528

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Observed	Predicted	No.	Int. No.	Observed	Predicted
45	925236	0	0.0723	45	478407	0	0.2061
46	563643	0	0.2156	46	637405	1	0.9892
47	659340	3	0.6481	47	447271	0	0.1295
48	564661	0	0.1805	48	640131	0	1.2359
49	564170	0	0.2114	49	536334	0	0.4963
50	563127	0	0.4225	50	608573	3	0.2778
51	373777	0	0.314	51	268319	0	0.5353
52	334130	0	0.175	52	373859	0	1.6047
53	197233	1	0.5288	53	352615	0	2.566
54	199154	1	1.9143	54	393922	0	1.8128
55	333345	0	0.1915	55	368471	0	2.7782
56	377213	2	0.4809	56	316496	5	8.2053
57	360531	0	0.2189	57	296187	1	7.6337
58	199192	0	0.4244	58	336257	1	4.755
59	354737	2	1.975	59	195523	2	4.2138
60	338859	0	0.0515	60	344139	0	1.0168
61	1010106	1	0.8574	61	485991	0	1.6488
62	602021	0	0.3099	62	352932	0	0.2977
63	423141	0	0.0106	63	466699	1	0.4945
64	547167	1	0.0611	64	422047	0	0.4381
65	555567	2	0.8011	65	569360	5	9.8368
66	455897	0	0.0377	66	466633	0	0.0954
67	498873	0	0.9577	67	519300	0	2.1379
68	636407	1	2.7442	68	487311	0	0.5318
69	452012	0	1.1088	69	562392	0	5.3213
70	548004	0	0.3293	70	375649	1	0.4247
Sum		22	31.6696	Sum		44	108.0962
Calibration Factor		0.694672493		Calibration Factor		0.407044836	

9.6.2 Rural Multilane Three- and Four-Leg Stop-Sign Intersections

The base HSM SPF models developed for rural multilane unsignalized intersections with stop control on the minor road included accidents within 250 ft (76 m) of a particular intersection. The selected model for the regression analysis was a negative binomial because it took into account the overdispersion commonly found in crash data. The data used for the regression analysis were obtained from 403 three-leg stop-controlled intersections and 403 four-leg stop-controlled intersections in California. Depending upon the particular site, between 3 to 10 years of data were used (Lord et al. 2008).

The calibration factor for rural multilane unsignalized intersections in Missouri produced the calibration factor values of 0.95 for three-leg intersections and 0.65 for four-leg intersections. Figures 9.13 and 9.14 show the IHSDM output for the calibration of three-leg and four-leg intersections, respectively.

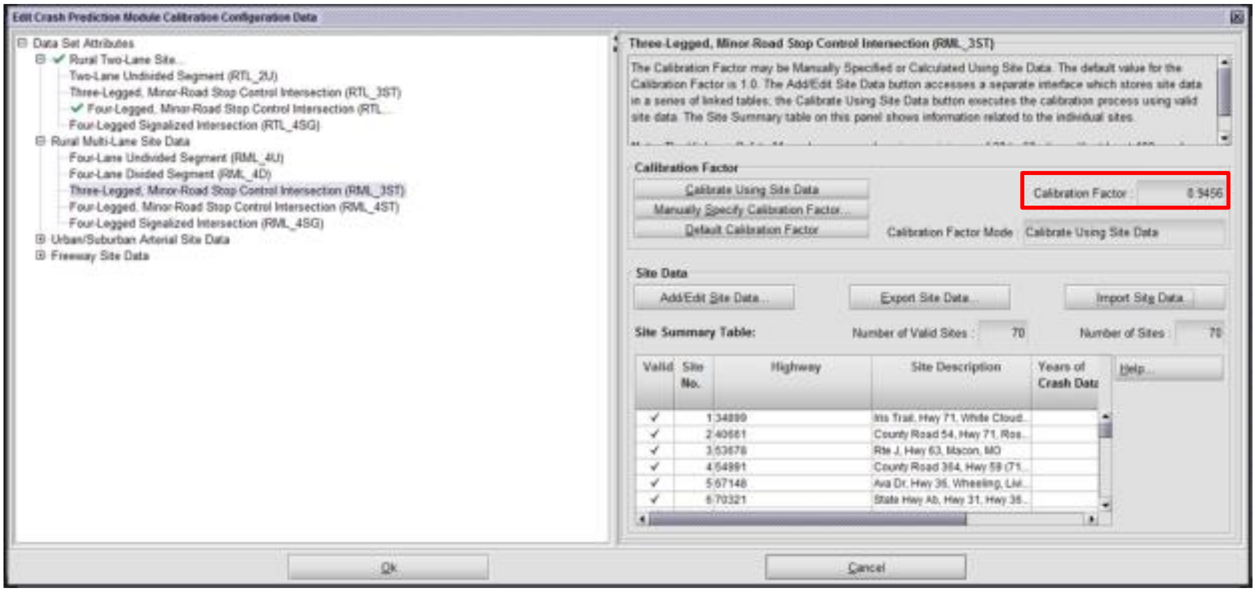

Figure 9.13 Calibration output for rural multilane three-leg unsignalized intersections

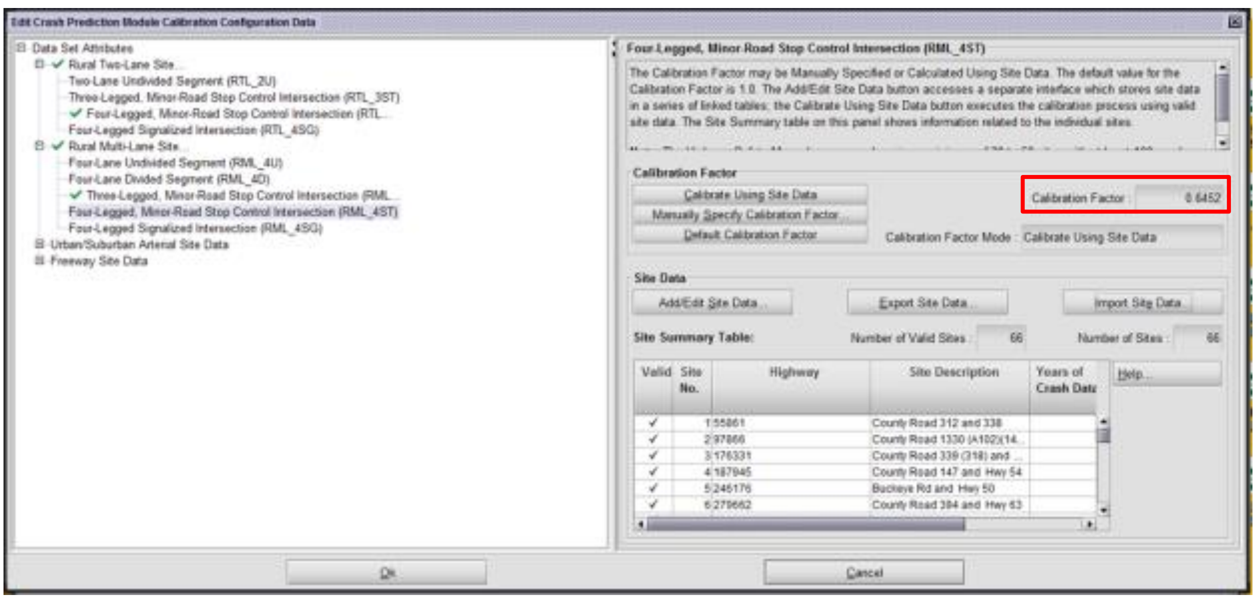

Figure 9.14 Calibration output for rural multilane four-leg unsignalized intersection

Table 9.16 shows the calibration results for individual sites. These results indicate that the number of crashes observed at rural multilane three-leg unsignalized intersections in Missouri was similar to the value predicted by the HSM for this site type. For four-leg intersections, the number of crashes observed was much lower than the number of crashes predicted by the HSM for this site type.

Table 9.16 Rural multilane three- and four-leg unsignalized intersection results

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Obs.	Pred.	No.	Int. No.	Obs.	Pred.
1	34899	0	0.943	1	55861	0	2.9941
2	40661	0	0.9747	2	97866	2	2.7163
3	53678	1	0.6598	3	176331	3	1.9851
4	54991	4	2.5371	4	187945	5	2.4138
5	67148	0	1.5404	5	246176	0	5.78
6	70321	2	1.1834	6	279662	4	6.4279
7	77998	0	2.5614	7	312342	0	2.9345
8	80248	4	3.392	8	313066	0	7.1691
9	80408	6	1.786	9	313754	1	3.5438
10	122588	4	2.1338	10	323701	0	7.2391
11	136430	2	1.522	11	326085	0	6.9691
12	169476	1	6.2813	12	337086	0	1.4552
13	181777	0	2.2964	13	343348	1	3.3975
14	207828	4	8.7491	14	344457	3	3.8688
15	222211	3	3.9346	15	355004	0	3.8992
16	273240	7	3.3363	16	355980	0	3.3545
17	292231	1	2.0437	17	367926	1	2.9783
18	317163	2	2.2482	18	372958	1	2.6104
19	328837	0	2.3535	19	451074	0	2.9314
20	334896	0	0.9784	20	480168	0	3.3467
21	340675	0	0.9726	21	503562	0	0.6748
22	341135	2	0.9736	22	512804	1	0.8567
23	341182	1	0.9736	23	653589	1	3.4569
24	342130	1	1.7668	24	654171	2	2.4283
25	342235	0	0.9736	25	654174	0	1.331
26	346252	1	0.8091	26	654182	0	3.3727
27	357162	0	1.3635	27	655027	0	2.5269
28	395973	0	4.3504	28	941779	1	2.0516
29	400983	2	9.5136	29	941785	2	2.0516
30	401,000	2	7.3757	30	975965	1	1.5502
31	401063	3	9.8006	31	976005	1	1.4854
32	401324	8	7.3757	32	982890	2	1.3503
33	402187	3	5.2651	33	1014049	1	1.0399
34	426433	0	0.877	34	1014051	0	1.4842
35	461488	2	0.9962	35	1019957	0	2.1307
36	462363	0	1.2616	36	1042125	0	0.6736
37	470050	0	1.4295	37	1014045/568338	2	1.4346
38	478605	0	0.3023	38	1021590/1021587	5	3.077
39	486267	0	0.4498	39	1024002/474565	4	2.0971
40	499137	0	0.3641	40	1042121/501937	0	0.6748
41	526207	3	3.0201	41	1042123/503562	0	0.7601
42	651611	0	2.7827	42	158982/158986	5	4.8275
43	652956	1	2.665	43	177959/177956	4	2.8051
44	654173	0	1.6304	44	199292/210624	2	2.8311
45	654183	0	1.2009	45	226286/226104	2	10.4716
46	654186	0	1.2009	46	244134/984721	5	5.8356
47	919584	0	1.038	47	249999/250088	3	6.8382
48	954216	1	3.3195	48	296848/296743	4	2.5172
49	954295	0	1.1896	49	30947/654167	2	1.5481

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Obs.	Pred.	No.	Int. No.	Obs.	Pred.
50	982897	1	1.0174	50	312682/1024463	5	4.5021
51	984961	2	3.7041	51	318872/1024465	23	9.1166
52	996785	11	12.3544	52	344653/344604	3	3.4836
53	1014034	0	0.4366	53	362072/653616	2	2.6373
54	1022960	0	0.8065	54	367877/367923	6	5.9549
55	1023614	0	0.3731	55	388534/997231	5	8.8413
56	1024242	0	0.3731	56	48315/48292	1	1.9537
57	1039950	0	0.9736	57	49594/49602	0	3.9099
58	1042119	1	0.3783	58	51604/51603	0	5.7083
59	1054123	0	0.8075	59	66977/67046	5	2.5587
60	1021606/1021605	0	0.8297	60	69991/70053	4	2.5922
61	1024454/1024455	7	1.5377	61	70986/70950	1	9.6786
62	170127/930296	1	2.5213	62	935184/92565	1	2.0952
63	203232/203079	46	6.6039	63	970861/417848	2	2.6399
64	396153/396155	12	6.3786	64	975964/975956	1	1.5646
65	398410/976253	1	2.9512	65	975966/975958/ 975962	5	2.2889
66	399038/976296	2	2.9512	66	975983/975990	9	1.4688
67	651600/327958	1	1.8086	Sum		144	223.1922
68	68202/68162	6	1.2219	Calibration Factor		0.645183837	
69	78472/982900	3	1.7397				
70	978785/978785	4	2.2662				
Sum		169	178.7312				
Calibration Factor		0.945553994					

9.6.3 Urban Arterial Three- and Four-Leg Stop-Controlled Intersections

The base HSM SPF models developed for urban unsignalized intersections with stop control on the minor road included accidents within 250 ft (76 m) of a particular intersection, but only those that the officer determined were intersection related. Different SPFs were developed using regression analysis with a negative binomial distribution. The different SPFs included multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The data used for the regression analysis were obtained from 83 (36 in Minnesota and 47 in North Carolina) three-leg stop-controlled intersections and 96 (48 in Minnesota and 48 in North Carolina) four-leg stop-controlled intersections. The accident data obtained for the study consisted of four years (1988 to 2002) of Minnesota intersection data and four years (1997 to 2003) of North Carolina intersection data (Harwood et al. 2007).

As shown in Figures 9.15 and 9.16, the calibration factor for urban arterial unsignalized intersections in Missouri produced the calibration factor values of 1.28 for three-leg intersections and 1.27 for four-leg intersections.

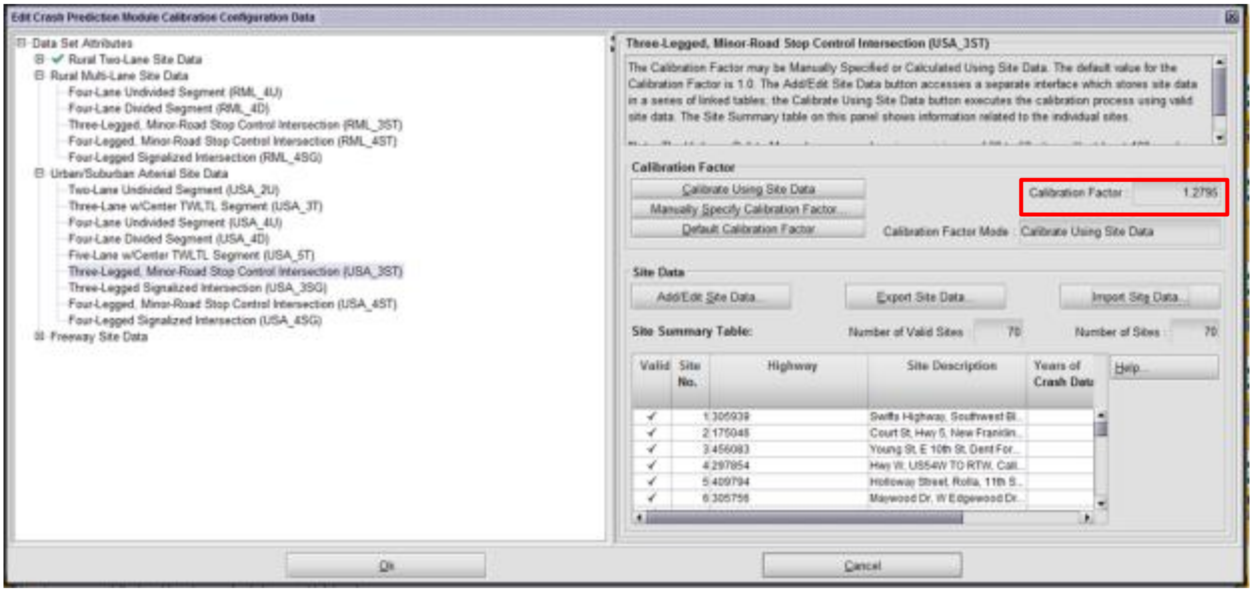

Figure 9.15 Calibration output for urban three-leg unsignalized intersections

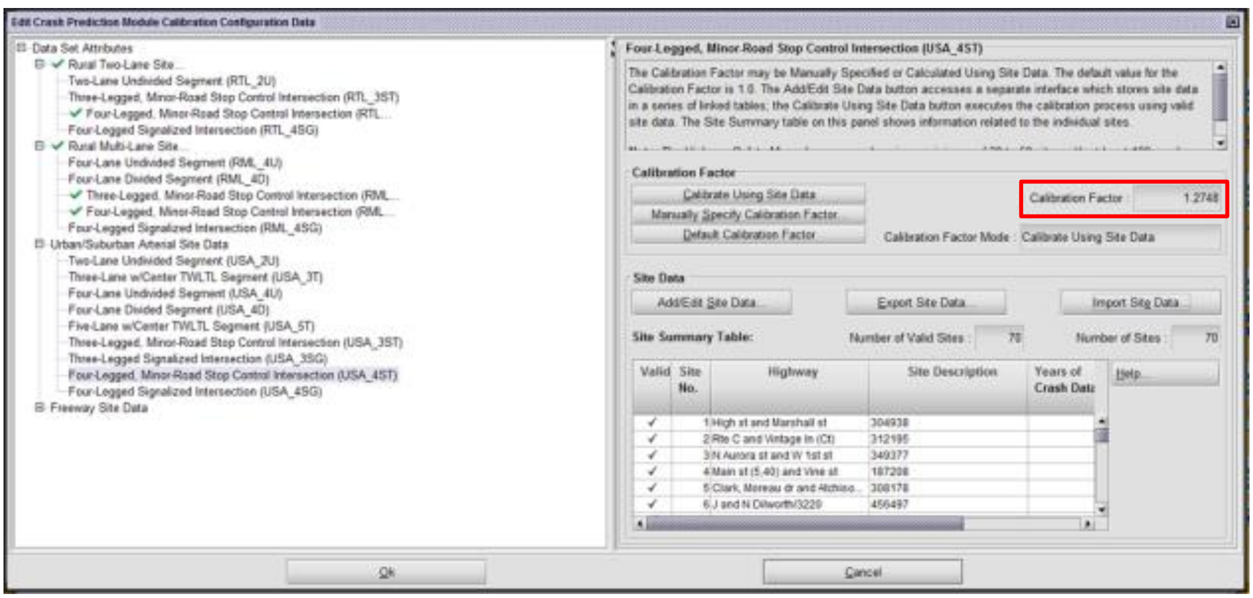

Figure 9.16 Calibration output for urban four-leg unsignalized intersections

Table 9.17 shows the calibration results for individual sites. These results indicate that the numbers of crashes observed at urban arterial three-leg and four-leg unsignalized intersections in Missouri were greater than the numbers of crashes predicted by the HSM for these site types.

Table 9.17 Urban three- and four-leg unsignalized intersection results

Three-Leg				Four-Leg			
		Crashes				Crashes	
No.	Int. No.	Observed	Predicted	No.	Int. No.	Observed	Predicted
1	305939	1	1.3569	1	304938	2	1.5651
2	175046	0	0.2124	2	312195	0	2.1724
3	456083	0	0.0482	3	349377	2	0.5576
4	297854	0	0.3626	4	187208	3	4.8639
5	409794	1	0.384	5	308178	4	2.8623
6	305756	0	0.3061	6	456497	1	1.1398
7	959247	0	0.2429	7	209569	2	1.4923
8	456871	0	0.044	8	350342	1	0.7692
9	196263	0	1.0225	9	645895	3	3.2437
10	405755	1	0.5968	10	310182	0	0.5858
11	159600	1	0.8677	11	136897	0	2.7267
12	195531	0	0.4291	12	165415	0	0.3736
13	148666	0	0.3232	13	163188	27	4.5707
14	115223	0	0.0381	14	224016	4	4.6689
15	121303	0	0.1421	15	139797	0	0.752
16	176297	1	1.5222	16	166696	2	1.7632
17	939962	0	0.0924	17	122705	2	0.4366
18	267677	0	0.2399	18	168731	0	0.8411
19	223036	5	1.8955	19	141967	0	2.7657
20	147308	0	0.5364	20	156640	3	1.7429
21	1031957	0	0.2498	21	76414	2	0.8567
22	73300	1	0.0923	22	222282	3	3.8284
23	32041	0	1.2296	23	106143	0	2.5855
24	141064	0	0.3728	24	28087	1	3.6513
25	106291	1	0.6967	25	1026956	0	0.6593
26	73953	0	0.0537	26	106235	2	0.2206
27	181671	0	0.0676	27	76551	0	0.4096
28	141791	1	0.4342	28	1038144	0	0.4286
29	73408	1	0.2057	29	77182	5	2.1846
30	219459	5	0.8922	30	106542	3	1.1339
31	77417	0	0.0394	31	66244	0	1.3415
32	19167	0	0.7981	32	72360	2	0.8241
33	72581	0	0.0496	33	40344	2	0.9969
34	62916	3	2.0155	34	66236	0	0.4215
35	76153	0	0.0763	35	40463	0	0.2464
36	71210	0	0.0785	36	17320	3	0.9704
37	74533	0	0.0568	37	65213	0	0.4952
38	67330	0	0.9022	38	60813	0	1.6315
39	67534	6	1.4762	39	63827	0	0.1514
40	59571	0	0.358	40	18163	1	1.1513
41	496314	1	0.1121	41	484881	15	4.7638
42	412211	3	0.7851	42	625178	3	2.3698
43	589794	0	0.0538	43	645764	0	0.1176
44	602197	0	0.3511	44	496062	4	1.7974

Three-Leg				Four-Leg			
		Crashes				**Crashes**	
No.	**Int. No.**	**Observed**	**Predicted**	**No.**	**Int. No.**	**Observed**	**Predicted**
45	577242	0	0.0813	45	596476	2	0.2477
46	421875	2	0.5137	46	573513	6	2.0934
47	645579	2	0.4949	47	645659	2	3.5169
48	601287	4	1.1713	48	645616	1	1.0037
49	412269	0	0.8632	49	485469	1	0.8663
50	424183	0	0.5577	50	412139	6	2.5887
51	226548	0	1.176	51	286596	1	2.8729
52	264601	1	0.0482	52	283857	10	1.8503
53	267897	0	2.8798	53	309450	0	2.2299
54	1019326	4	0.9285	54	273816	2	2.743
55	250551	0	0.1267	55	266616	0	0.782
56	316451	0	1.4699	56	268375	1	1.2452
57	225902	1	1.8974	57	232797	3	3.1885
58	219068	0	0.2175	58	269334	0	5.0751
59	361456	0	0.138	59	285072	5	8.5303
60	233589	0	0.2312	60	277546	4	3.5811
61	937218	1	0.2641	61	520141	4	2.3897
62	519949	0	0.0551	62	513439	2	1.4219
63	522684	0	2.6202	63	551867	0	0.4196
64	345735	2	1.0154	64	463380	0	0.9044
65	522711	1	0.3224	65	566266	1	0.5355
66	539712	1	0.469	66	529689	3	1.3601
67	524371	1	0.7469	67	569938	0	1.2819
68	518931	2	1.0252	68	545220	3	4.748
69	545140	3	2.9328	69	497046	3	2.6
70	569431	0	0.193	70	428046	10	3.7197
Sum		57	44.5497	Sum		172	134.9266
Calibration Factor		1.279469895		Calibration Factor		1.27476717	

9.6.4 Severity Distribution Factors

Utilizing the data employed for calibration, severity distribution factors were computed according to the classification used in Missouri. Crash severity factors were obtained for fatal, disabling injury, minor injury, and property damage only crashes. Table 9.18 shows the severity distribution factors for stop-controlled intersections. Fatal and disabling injury crashes showed higher proportions for rural multilane facilities.

Table 9.18 Severity distribution factors

Percentage of Total Crashes by Collision Type						
Crash Severity Level	**U 3ST[1]**	**U 4ST[2]**	**R2L 3ST[3]**	**R2L 4ST[4]**	**RML 3ST[5]**	**RML 4ST[6]**
Fatal	0.0	0.0	0.0	0.0	0.6	1.4
Disabling Injury	3.5	2.9	4.5	2.3	6.5	7.6
Minor Injury	22.8	23.3	22.7	20.5	24.9	26.4
Property Damage Only	73.7	73.8	72.7	77.3	68.0	64.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Notes:

[1]U 3ST = Urban Three-Leg Unsignalized Intersections
[2]U 4ST = Urban Four-Leg Unsignalized Intersections
[3]R2L 3ST = Rural Two-Lane Three-Leg Unsignalized Intersections
[4]R2L 4ST = Rural Two-Lane Four-Leg Unsignalized Intersections
[5]RML 3ST = Rural Multilane Three-Leg Unsignalized Intersections
[6]RML 4ST = Rural Multilane Four-Leg Unsignalized Intersections

9.6.5 Crash Type Distribution Factors

The CDFs represent the proportion of predicted crashes by crash type. The data available from the calibration were used to estimate these factors. Some data processing was required because Missouri crash type categories differed from the HSM types. Therefore, different categories were aggregated to provide classifications similar to those recommended by the HSM. The crash types were also divided by multiple- and single-vehicle crashes. Tables 9.19 to 9.21 show crash type distributions for stop-controlled intersections.

Table 9.19 Rural two-lane three-leg and four-leg stop-controlled intersection crash types

Percentage of Total Crashes by Collision Type						
	Three-Leg			**Four-Leg**		
Collision Type	**Fatal and Injury**	**Property Damage Only**	**Total**	**Fatal and Injury**	**Property Damage Only**	**Total**
Single-vehicle						
Collision with animal	0	6.3	4.5	0	5.9	4.5
Collision pedestrian and bicycle	16.7	0	4.5	0	0	0
Out of control	16.7	50	40.9	30	17.6	20.5
Other single-vehicle crashes	0	0	0	0	5.9	4.5
Total single-vehicle crashes	33.3	56.3	50	30	29.4	29.5
Multiple-Vehicle						
Sideswipe	0	0	0	20	5.9	9.1
Angle collision	50	18.8	27.3	20	23.5	22.7
Rear end and head on collision	16.7	12.5	13.6	30	32.4	31.8
Other multiple-vehicle collision	0	12.5	9.1	0	8.8	6.8
Total multiple-vehicle collision	66.7	43.8	50	70	70.6	70.5
Total crashes	100	100	100	100	100	100

Table 9.20 Rural multilane three-leg and four-leg stop-controlled intersection crash types

Percentage of Total Crashes by Collision Type						
	Three-Leg			Four-Leg		
Collision Type	**Fatal and Injury**	**Property Damage Only**	**Total**	**Fatal and Injury**	**Property Damage Only**	**Total**
Single-vehicle						
Collision with animal	1.9	5.2	4.1	2	3.2	2.8
Collision pedestrian and bicycle	1.9	0	0.6	0	0	0
Out of control	11.1	20	17.2	25.5	29	27.8
Other single-vehicle crashes	3.7	4.3	4.1	7.8	19.4	15.3
Total single-vehicle crashes	18.5	29.6	26	35.3	51.6	45.8
Multiple-Vehicle						
Sideswipe	13	4.3	7.1	2	1.1	1.4
Angle collision	42.6	24.3	30.2	52.9	26.9	36.1
Rear end and head on collision	18.5	31.3	27.2	9.8	10.8	10.4
Other multiple-vehicle collision	7.4	10.4	9.5	0	9.7	6.3
Total multiple-vehicle collision	81.5	70.4	74	64.7	48.4	54.2
Total crashes	100	100	100	100	100	100

Table 9.21 Crash type distribution for urban three-leg and four-leg stop-controlled intersections

Percentage of Total Crashes by Collision Type						
	Three-Leg			Four-Leg		
Collision Type	**Fatal and Injury**	**Property Damage Only**	**Total**	**Fatal and Injury**	**Property Damage Only**	**Total**
Single-vehicle						
Collision with animal	0	0	0	0	0	0
Collision pedestrian and bicycle	6.7	0	1.8	11.1	0.8	3.5
Out of control	13.3	11.9	12.3	15.6	5.5	8.1
Other single-vehicle crashes	13.3	9.5	10.5	4.4	6.3	5.8
Total single-vehicle crashes	33.3	21.4	24.6	31.1	12.6	17.4
Multiple-Vehicle						
Sideswipe	6.7	16.7	14	2.2	7.9	6.4
Angle collision	13.3	14.3	14	44.4	31.5	34.9
Rear end and head on collision	46.7	33.3	36.8	22.2	28.3	26.7
Other multiple-vehicle collision	0	14.3	10.5	0	19.7	14.5
Total multiple-vehicle collision	66.7	78.6	75.4	68.9	87.4	82.6
Total crashes	100	100	100	100	100	100

9.7 Comparison to Previous Calibration

9.7.1 Rural Two-Lane Three- and Four-Leg Stop Sign Intersections

The calibration results for rural two-lane three-leg intersection facilities closely resembled prior calibration results using data from 2009 to 2011. The previous calibration efforts found a calibration factor of 0.77, which was only slightly higher than the recent results of 0.69. This similarity is likely due to the fact that the input variables also showed little variation. The average AADTs for major roads decreased slightly from 1,421 to 1,365.5 while those of the minor roads remained nearly unchanged (from 72 to 73.3).

The calibration results for rural two-lane four-leg intersection facilities also closely resembled prior calibration results using data from 2009 to 2011. The previous calibration efforts found a calibration factor of 0.49, which was only slightly higher than the recent result of 0.41. This similarity is likely due the fact that the input variables also showed very little variation. The average AADTs for major roads decreased slightly from 1,746.5 to 1,711.7 while those of the minor roads remained nearly unchanged (from 243.9 to 238.7). Note that the source of the AADT could affect its accuracy, depending on whether the AADT was a measured value or a value estimated from growth factors.

9.7.2 Rural Multilane Three- and Four-Leg Stop-Sign Intersections

The calibration results for rural multilane three-leg intersections were fairly close to prior calibration results using data from 2009 to 2011. The previous calibration found a calibration factor of 1.12, which was slightly higher than the recent result of 0.95. This similarity is likely reflected in the fact that the input variables also showed little variation. The average AADT for the major road was 11,972 for 2009 to 2011 and 12,070 for 2012 to 2014. The minor road AADT was 350 for 2009 to 2011 and 372 for 2012 to 2014.

The calibration results for rural multilane four-leg intersection facilities also closely resembled prior calibration results using data from 2009 to 2011. The previous calibration efforts found a calibration factor of 0.71, which was only slightly higher than the recent result of 0.65. This similarity is likely due to the fact that the input variables also showed little variation. The average AADT for the major road was 9,561 for 2009 to 2011 and 9,609 for 2012 to 2014. The minor road AADT was 470 for 2009 to 2011 and 475 for 2012 to 2014.

9.7.3 Urban Arterial Three- and Four-Leg Stop-Sign Intersections

The calibration results for urban arterial three-leg intersection facilities were fairly close to prior calibration results that used data from 2009 to 2011. The previous calibration efforts found a calibration factor of 1.06, which was slightly lower than the recent result of 1.28. The AADT values were similar for the major road, 4,312 to 4,319, and for the minor road, 304 to 302. Therefore, the slight increase was likely due to other factors.

The calibration results for urban arterial four-leg intersection facilities closely resembled prior calibration results using data from 2009 to 2011. The previous calibration efforts found a calibration factor of 1.30, which was slightly higher than the recent results of 1.27. This similarity is likely due to the fact that the input variables also showed little variation. The average AADT for the major road increased from 4,488.8 to 4,511, while that of the minor road increased from 608 to 616.

9.7.4 Summary

Table 9.22 shows that the new calibration factors for stop-controlled intersections are similar to the previous calibration factors. The total observed crashes are almost the same between the two periods of 2009 to 2011 and 2012 to2014.

Table 9.22 Summary of HSM intersection calibration results for Missouri

	Previous (2009-2011)			New (2012-2014)		
Facility Type	**All Sites**	**Total Observed Crashes**	**Calibration Factor**	**All Sites**	**Total Observed Crashes**	**Calibration Factor**
U 3ST[1]	70	52	1.06	70	57	1.28
U 4ST[2]	70	179	1.30	70	172	1.27
R2L 3ST[3]	70	25	0.77	70	22	0.69
R2L 4ST[4]	70	49	0.49	70	44	0.41
RML 3ST[5]	71	191	1.12	70	169	0.95
RML 4ST[6]	67	159	0.71	66	144	0.65

Notes:

[1]U 3ST = Urban Three-Leg Unsignalized Intersections
[2]U 4ST = Urban Four-Leg Unsignalized Intersections
[3]R2L 3ST = Rural Two-Lane Three-Leg Unsignalized Intersections
[4]R2L 4ST = Rural Two-Lane Four-Leg Unsignalized Intersections
[5]RML 3ST = Rural Multilane Three-Leg Unsignalized Intersections
[6]RML 4ST = Rural Multilane Four-Leg Unsignalized Intersections

CHAPTER 10. DISTRIBUTION OF CRASH SEVERITY

10.1 Introduction and Scope

Both crash severity and crash frequency data are important because the impact of crashes differs greatly depending on severity. The impact of crashes, in turn, affects how agencies prioritize and implement their safety plans. In Chapters 4 through 9, the calibration results of 16 facility types were presented. The Missouri calibration factors allow the use of HSM SPFs for modeling and analyzing crash frequency on Missouri roadways. In order to obtain the number of crashes by severity in Missouri, SDFs are needed. This chapter presents the results from an analysis of crashes throughout Missouri. The results include a comparison of the distribution of crash severities between the samples used for calibration and comprehensive statewide data. When the results of this chapter are coupled with the results from Chapters 4 through 9, the number of crashes on Missouri facilities can then be estimated for the specific severity categories of fatal, disabling injury, minor injury, and property damage only.

10.2 Rural Two-Lane Undivided Segment Crash Severity

Table 10.1 shows the query criteria used for identifying all crashes that occurred on Missouri's rural two-lane undivided roadways.

Table 10.1 Rural two-lane undivided segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"RURAL"	"TWO-LANE/SUPER TWO-LANE "	"LOCAL/MAJOR COLLECTOR/MINOR ARTERIAL/MINOR COLLECTOR/PRINCIPAL ARTERIAL"	"0"

Table 10.2 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.2 Rural two-lane undivided segment severity distribution

	R two-lane U Samples		All Population Data	
Severity	**Crashes**	**SDF**	**Crashes**	**SDF**
Fatal	9	0.032	624	0.020
Disabling Injury	23	0.081	2,609	0.084
Minor Injury	68	0.240	8,225	0.266
Property Damage Only	183	0.647	19,482	0.630
Total Crashes	283	1.000	30,940	1.000

The total number of crashes on two-lane undivided segments in Missouri was 30,940, and the total number of crashes from the calibration sample was 283. The comparison between the sample and the population SDFs showed that they were very similar.

10.3 Rural Multilane Divided Segment Crash Severity

Table 10.3 shows the query criteria used for identifying all crashes that occurred on Missouri's rural multilane divided roadways.

Table 10.3 Rural multilane divided segment criteria

URBAN_RURAL_CLASS	ROADWAY_TYPE_NAME	FUNC_CLASS_NAME	INTERSECTION_NO
"RURAL"	"EXPRESSWAY"	"MAJOR COLLECTOR/MINOR ARTERIAL/PRINCIPAL ARTERIAL"	"0"

Table 10.4 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.4 Rural multilane divided segment severity distribution

Severity	R ML D Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	6	0.012	11	0.014
Disabling Injury	20	0.039	35	0.043
Minor Injury	118	0.228	198	0.245
Property Damage Only	373	0.721	565	0.699
Total Crashes	517	1.000	808	1.000

The total number of crashes on multilane divided segments in Missouri was 808, and the total number of crashes from the calibration sample was 517. The comparison between the sample and the population SDFs showed that they were also very similar.

10.4 Urban Two-Lane Undivided Segment Crash Severity

Table 10.5 shows the query criteria used for identifying all crashes that occurred on Missouri's urban two-lane undivided roadways.

Table 10.5 Urban two-lane undivided segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"URBAN/URBANIZED"	"TWO-LANE/SUPER TWO-LANE "	"LOCAL/MAJOR COLLECTOR/MINOR ARTERIAL/MINOR COLLECTOR/PRINCIPAL ARTERIAL"	"0"

Table 10.6 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.6 Urban two-lane undivided severity distribution

Severity	U two-lane U Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	4	0.011	106	0.008
Disabling Injury	5	0.014	528	0.039
Minor Injury	87	0.238	3,188	0.235
Property Damage Only	270	0.738	9,733	0.718
Total Crashes	366	1.000	13,554	1.000

The total number of crashes on two-lane undivided segments in Missouri was 13,554, and the total number of crashes from the calibration sample was 366. The comparison between the sample and the population SDFs showed that they were similar, except for disabling injury.

10.5 Urban Four-Lane Divided Segment Crash Severity

Table 10.7 shows the query criteria used for identifying all crashes that occurred on Missouri's urban four-lane divided roadways.

Table 10.7 Urban four-lane divided segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"URBAN/URBANIZED"	"EXPRESSWAY"	"LOCAL/MAJOR COLLECTOR/MINOR ARTERIAL/MINOR COLLECTOR/PRINCIPAL ARTERIAL"	"0"

Table 10.8 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.8 Urban four-lane divided severity distribution

Severity	U 4 L D Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	7	0.017	48	0.003
Disabling Injury	15	0.037	421	0.024
Minor Injury	101	0.251	3,994	0.228
Property Damage Only	280	0.695	13,020	0.745
Total Crashes	403	1.000	17,483	1.000

The total number of crashes on four-lane divided segments in Missouri was 17,483, and the total number of crashes from the calibration sample was 403. The comparison between the sample and the population SDFs showed that there were minor differences throughout the various severity levels.

10.6 Urban Five-Lane Undivided Segment Crash Severity

Table 10.9 shows the query criteria used for identifying all crashes that occurred on Missouri's urban five-lane undivided roadways.

Table 10.9 Urban five-lane undivided segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"URBAN/URBANIZED"	"5 LANE SECTION"	"LOCAL/MAJOR COLLECTOR/MINOR ARTERIAL/ PRINCIPAL ARTERIAL"	"0"

Table 10.10 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.10 Urban five-lane undivided severity distribution

Severity	U 5L Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	2	0.003	30	0.003
Disabling Injury	11	0.015	193	0.021
Minor Injury	197	0.273	2,292	0.250
Property Damage Only	511	0.709	6,657	0.726
Total Crashes	721	1.000	9,172	1.000

The total number of crashes on five-lane undivided segments in Missouri was 9,172, and the total number of crashes from the calibration sample was 721. The comparison between the sample and the population SDFs showed that they were similar.

10.7 Rural Four-Lane Freeway Segment Crash Severity

Table 10.11 shows the query criteria used for identifying all crashes that occurred on Missouri's rural four-lane freeway segments.

Table 10.11 Rural four-lane freeway segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"RURAL"	"FREEWAY"	"INTERSTATE/FREEWAY"	"0"

Table 10.12 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.12 Rural four-lane freeway severity distribution

	R FW Samples		All Population Data	
Severity	Crashes	SDF	Crashes	SDF
Fatal	6	0.005	108	0.009
Disabling Injury	30	0.027	413	0.035
Minor Injury	144	0.129	1,738	0.148
Property Damage Only	933	0.838	9,499	0.808
Total Crashes	1,113	1.000	11,758	1.000

The total number of crashes on rural four-lane freeway segments in Missouri was 11,758, and the total number of crashes from the calibration sample was 1,113. The comparison between the sample and the population SDFs showed that they were slightly different.

10.8 Urban Four-Lane and Six-Lane Freeway Segment Crash Severity

Table 10.13 shows the query criteria used for identifying all crashes that occurred on Missouri's urban four- and six-lane freeway segments.

Table 10.13 Urban four-lane and six-lane freeway segment criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	FUNC_CLASS_NAME	INTERSECTION_ NO
"URBAN/URBANIZED"	"FREEWAY"	"INTERSTATE/FREEWAY"	"0"

Table 10.14 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.14 Urban four-lane and six-lane freeway severity distribution

Severity	U FW Samples Crashes	U FW Samples SDF	All Population Data Crashes	All Population Data SDF
Fatal	23	0.007	170	0.004
Disabling Injury	85	0.026	886	0.022
Minor Injury	687	0.207	8,757	0.216
Property Damage Only	2,521	0.760	30,822	0.759
Total Crashes	3,316	1.000	40,635	1.000

The total number of crashes on urban four- and six-lane freeway segments in Missouri was 40,635, and the total number of crashes from the calibration sample was 3,316. The comparison between the sample and the population SDFs showed that they were similar.

10.9 Urban Three-Leg Signalized Intersection Crash Severity

Table 10.15 shows the query criteria used for identifying all crashes that occurred on Missouri's urban three-leg signalized intersections.

Table 10.15 Urban three-leg signalized intersection criteria

URBAN_RURAL_CLASS	ROADWAY_TYPE_NAME	NO_OF_APPRCH_LEGS	INTERSECTION_NO	SIGNALIZED_FLAG
"URBAN/URBANIZED"	Exclude "Ramp"	3	Excluded "0"	Y

Table 10.16 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.16 Urban three-leg signalized intersection severity distribution

Severity	U 3SG Samples Crashes	U 3SG Samples SDF	All Population Data Crashes	All Population Data SDF
Fatal	1	0.002	4	0.002
Disabling Injury	10	0.019	33	0.020
Minor Injury	107	0.202	430	0.264
Property Damage Only	411	0.777	1,164	0.714
Total Crashes	529	1.000	1,631	1.000

The total number of crashes on urban three-leg signalized intersections in Missouri was 1,631, and the total number of crashes from the calibration sample was 529. The comparison between the sample and the population SDFs showed that fatal and disabling injury SDFs were similar, but minor injury and PDO SDFs were slightly different.

10.10 Urban Four-Leg Signalized Intersection Crash Severity

Table 10.17 shows the query criteria used for identifying all crashes that occurred on Missouri's urban four-leg signalized intersections.

Table 10.17 Urban four-leg signalized intersection criteria

URBAN_RURAL_CLASS	ROADWAY_TYPE_NAME	NO_OF_APPRCH_LEGS	INTERSECTION_NO	SIGNALIZED_FLAG
"URBAN/URBANIZED"	Excluded "Ramp"	4	Excluded "0"	Y

Table 10.18 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.18 Urban four-leg signalized intersection severity distribution

	U 4SG		All	
	Samples		Population Data	
Severity	Crashes	SDF	Crashes	SDF
Fatal	3	0.002	26	0.002
Disabling Injury	34	0.025	233	0.021
Minor Injury	300	0.219	2577	0.228
Property Damage Only	1035	0.754	8478	0.749
Total Crashes	1372	1.000	11314	1.000

The total number of crashes on urban four-leg signalized intersections in Missouri was 11,314, and the total number of crashes from the calibration sample was 1,372. The comparison between the sample and the population SDFs showed that they were similar.

10.11 Rural Two-Lane Three-Leg Unsignalized Intersection Crash Severity

Table 10.19 shows the query criteria used for identifying all crashes that occurred on Missouri's rural two-lane three-leg unsignalized intersections.

Table 10.19 Rural two-lane three-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	NO_OF_APPRCH_LEGS	INTERSECTION_ NO	SIGNALIZED_FLAG
"RURAL"	"TWO-LANE/SUPER TWO-LANE "	3	Excluded "0"	N

Table 10.20 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.20 Rural two-lane three-leg unsignalized intersection severity distribution

	R 3ST Samples		All Population Data	
Severity	**Crashes**	**SDF**	**Crashes**	**SDF**
Fatal	0	0.000	2	0.005
Disabling Injury	1	0.045	17	0.039
Minor Injury	5	0.227	85	0.197
Property Damage Only	16	0.727	327	0.759
Total Crashes	22	1.000	431	1.000

The total number of crashes on rural two-lane three-leg unsignalized intersections in Missouri was 431, and the total number of crashes from the calibration sample was 22. The comparison between the sample and the population SDFs showed that they were somewhat different. The difference was not surprising because there were few crashes on rural two-lane three-leg unsignalized intersections.

10.12 Rural Two-Lane Four-Leg Unsignalized Intersection Crash Severity

Table 10.21 shows the query criteria used for identifying all crashes that occurred on Missouri's rural two-lane four-leg unsignalized intersections.

Table 10.21 Rural two-lane four-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	NO_OF_APPRCH_LEGS	INTERSECTION_ NO	SIGNALIZED_FLAG
"RURAL"	"TWO-LANE/SUPER TWO-LANE "	4	Excluded "0"	N

Table 10.22 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.22 Rural two-lane four-leg unsignalized intersection severity distribution

Severity	R 4ST Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	0	0.000	122	0.014
Disabling Injury	1	0.023	546	0.063
Minor Injury	9	0.205	2,269	0.262
Property Damage Only	34	0.773	5,715	0.661
Total Crashes	44	1.000	8,652	1.000

The total number of crashes on rural two-lane four-leg unsignalized intersections in Missouri was 8,652, and the total number of crashes from the calibration sample was 44. The comparison between the sample and the population SDFs showed that they were somewhat different. The difference is not surprising because the calibration sample only contained 44 crashes.

10.13 Rural Multilane Three-Leg Unsignalized Intersection Crash Severity

Table 10.23 shows the query criteria used for identifying all crashes that occurred on Missouri's rural multilane three-leg unsignalized intersections.

Table 10.23 Rural multilane three-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	NO_OF_APPRCH_ LEGS	INTERSECTION_ NO	SIGNALIZED_ FLAG
"RURAL"	"three lane/5 LANE /EXPRESSWAY/ MULTILANE LANE/SHARED FOUR LANE "	3	Excluded "0"	"N"

Table 10.24 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.24 Rural multilane three-leg unsignalized intersection severity distribution

Severity	R ML 3ST Samples		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	1	0.006	8	0.013
Disabling Injury	11	0.065	43	0.070
Minor Injury	42	0.249	177	0.289
PDO	115	0.680	384	0.627
Total	169	1.000	612	1.000

The total number of crashes on rural multilane three-leg unsignalized intersections in Missouri was 612, and the total number of crashes from the calibration sample was 169. The comparison between the sample and the population SDFs showed that they were somewhat different.

10.14 Rural Multilane Four-Leg Unsignalized Intersection Crash Severity

Table 10.25 shows the query criteria used for identifying all crashes that occurred on Missouri's rural multilane four-leg unsignalized intersections.

Table 10.25 Rural multilane four-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	NO_OF_APPRCH_LEGS	INTERSECTION_ NO	SIGNALIZED_FLAG
"RURAL"	"three lane/5 LANE /EXPRESSWAY/ MULTILANE LANE/SHARED FOUR LANE "	4	Excluded "0"	N

Table 10.26 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.26 Rural multilane four-leg unsignalized intersection severity distribution

	R ML 4ST		All	
	Samples		Population Data	
Severity	Crashes	SDF	Crashes	SDF
Fatal	2	0.014	4	0.007
Disabling Injury	11	0.076	37	0.066
Minor Injury	38	0.264	142	0.253
Property Damage Only	93	0.646	379	0.674
Total Crashes	144	1.000	562	1.000

The total number of crashes on rural multilane four-leg unsignalized intersections in Missouri was 562, and the total number of crashes from the calibration sample was 144. The comparison between the sample and the population SDFs showed that they were somewhat different.

10.15 Urban Three-Leg Unsignalized Intersection Crash Severity

Table 10.27 shows the query criteria used for identifying all crashes that occurred on Missouri's urban three-leg unsignalized intersections.

Table 10.27 Urban three-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE_ NAME	NO_OF_APPRCH_LEGS	FUNC_CLASS_NAME	SIGNALIZED_FLAG
“URBAN/URBANIZED”	Exclude “FREEWAY /RAMP ”	3	“PRINCIPAL ARTERIAL/MINOR ARTERIAL”	“N”

Table 10.28 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.28 Urban three-leg unsignalized intersection severity distribution

	U 3ST		All	
	Samples		Population Data	
Severity	Crashes	SDF	Crashes	SDF
Fatal	0	0.000	5	0.003
Disabling Injury	2	0.035	44	0.028
Minor Injury	13	0.228	394	0.250
Property Damage Only	42	0.737	1,132	0.719
Total Crashes	57	1.000	1,575	1.000

The total number of crashes on urban three-leg unsignalized intersections in Missouri was 1,575, and the total number of crashes from the calibration sample was 57. The comparison between the sample and the population SDFs showed that they were somewhat different.

10.16 Urban Four-Leg Unsignalized Intersection Crash Severity

Table 10.29 shows the query criteria used for identifying all crashes that occurred on Missouri’s urban four-leg unsignalized intersections.

Table 10.29 Urban four-leg unsignalized intersection criteria

URBAN_RURAL_ CLASS	ROADWAY_TYPE _ NAME	NO_OF_APPRCH _ LEGS	FUNC_CLASS_NAME	SIGNALIZED _ FLAG
“URBAN/URBANIZED”	Excluded “FREEWAY/RAMP ”	4	“PRINCIPAL ARTERIAL/MINOR ARTERIAL”	“N”

Table 10.30 shows the severity distribution factor for both the calibration sample and the entire Missouri population of data.

Table 10.30 Urban four-leg unsignalized intersection severity distribution

Severity	U 4ST Sample		All Population Data	
	Crashes	SDF	Crashes	SDF
Fatal	0	0	48	0.004
Disabling Injury	5	0.029	341	0.026
Minor Injury	40	0.233	3388	0.255
Property Damage Only	127	0.738	9513	0.716
Total Crashes	172	1.000	13290	1.000

The total number of crashes on urban four-leg unsignalized intersections in Missouri was 13,290, and the total number of crashes from the calibration sample was 172. The comparison between the sample and the population SDFs showed that they were similar.

CHAPTER 11. CONCLUSIONS

This calibration project addressed all of the most common Missouri transportation facilities with the exception of freeway interchanges, which were calibrated recently as part of another project. Small sample sizes would not provide adequate data for useful calibration of the less common transportation facilities. By applying the calibration values produced in this project, the safety analyst can be confident that the results are applicable to Missouri roadways.

The HSM has revolutionized how safety data are analyzed. In the past, the observed number of crashes was the oft-used measure; now, the expected crash frequency has become the measure for making data-driven safety decisions. This new approach addresses the regression-to-the-mean problem and takes into consideration both the observed number of crashes and the predicted number of crashes based on the wealth of national research. By calibrating the HSM, the safety analyst takes advantage of the national safety experience while simultaneously accounting for Missouri's local characteristics.

Several notable items resulted from the comparison of the previous calibration factors to the current calibration factors. For most facilities, there were some slight changes in the calibration factor values. These were expected; otherwise, continued calibration would not be needed. However, it is beneficial to consider a few specific facility types. For urban four-lane freeway segments, the multi-vehicle PDO factor has decreased from 3.59 to 1.46. The primary reason for the decrease in value is due to the avoidance of the vicinity of interchanges. The sites from the previous calibration were reused, but they were moved away from the vicinity of the interchange. Queuing and turbulence near speed change lanes could result in crashes occurring on the mainline. Such crashes should not be classified as segment crashes because they are primarily a function of interchange operation. For urban signalized intersections, the three-leg and four-leg calibration values continue to be high (i.e., 2.95 and 5.21). These high calibration values do not mean that Missouri intersections are unsafe when compared to the rest of the US. The various possible reasons for these values were part of a detailed discussion in Section 8.5.1. A good alternate approach to calibration is to develop Missouri-specific SPFs for these two facility types, which eliminates the need to use these high calibration values.

The HSM recommends that recalibration be performed continuously every two to three years. The recalibration ensures that changes in driver behavior, vehicular technology, land use, climate, and crash reporting are taken into account when modeling with the HSM. For example, the Missouri Uniform Crash Report was updated in 2012. With the experience gained from each calibration, future calibrations become more efficient and more accurate. One example of a lesson learned from the previous calibration is that the vicinity of interchange facilities should be avoided in the sampling for freeway segments in order to avoid including interchange-related crashes. HSM calibration helps to promote the use of the HSM as it keeps the HSM models current and applicable to local conditions. Therefore, the recalibration of the HSM on an ongoing basis is recommended.

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