Calibration of the Highway Safety Manual for Missouri

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The new Highway Safety Manual (HSM) contains predictive models that need to be calibrated to local conditions. This calibration process requires detailed data types, such as crash frequencies, traffic volumes, geometrics, and land-use. The HSM does not document in detail techniques for gathering such data, since data systems vary significantly across states. The calibration process also requires certain decisions, such as the correct sampling approach, determination of the minimum segment length, the treatment of left-turn phasing, and the inclusion or exclusion of speed-change lane crashes. This report describes the challenges, practical solutions, and results from a statewide HSM calibration in Missouri, including lessons learned from other states such as Kansas, Illinois, and New Hampshire. The models calibrated included five segment and eight intersection site types, as well as three freeway segment types that will be part of the next edition of the HSM. The applied random sampling technique ensured geographic representativeness across the state. A variety of data processing techniques were utilized, including CAD, which was used to obtain geometric data. Some of the challenges encountered during calibration included data availability, obtaining a sufficient sample size for certain site types, maintaining a balance between segment homogeneity and minimum segment length, and excluding inconsistent crash data. 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 SPFs.</td></tr>
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Disclaimer

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Executive Summary

The new Highway Safety Manual (HSM) contains safety prediction models and modification factors that need to be calibrated to local conditions. This calibration process requires detailed data collection, such as crash frequency, traffic volume, geometrics, and land use. The HSM does not document in detail techniques for gathering such data, since data systems vary significantly across states. The calibration process also requires certain decisions, such as the selection of the correct sampling approach, the determination of minimum segment length, the treatment of left-turn phasing, and the inclusion or exclusion of speed-change lane adjacent crashes. This report describes the challenges, practical solutions, and results from statewide HSM calibration in Missouri, including lessons learned from other states such as Kansas, Illinois, and New Hampshire.

The calibrated models include five segment and eight intersection site types, and also include three freeway segment types that will be part of the next edition of the HSM. Three years of traffic and crash data from 2009-2011 were used in this calibration. The applied random sampling technique ensured geographic representativeness across the state. Data processing techniques included examining videologs for roadside features, estimating horizontal curve parameters using CAD, reviewing street view photographs to verify inventories and configuration, and measuring median widths using aerial photographs. Some of the challenges encountered during calibration included data availability, finding a sufficient sample size for certain site types, maintaining a balance between segment homogeneity and minimum segment length, and excluding inconsistent crash data.

A summary of the calibration results is shown in Table ES.1. In the table, PDO means Property Damage Only, FI means fatal and injury, SV means single vehicle and MV means

multiple vehicles. The results indicate that the number of crashes predicted by the HSM was generally consistent with the number of crashes observed in Missouri, with a few exceptions. The calibration factors for urban signalized intersections were high, indicating that the number of crashes at signalized intersections in Missouri was greater than the number of crashes predicted by the HSM. There could be several reasons for this disparity, such as differences between the Missouri and HSM definitions of intersection crashes, differences in the data between Missouri and the sites used to develop the HSM predictive models, and changes in recent driver behavior, such as the increase in mobile device use. The calibration factors were also high for PDO multiple vehicle crashes on freeway segments. The calibration factors for rural stop controlled intersections were low.

The results of this research demonstrate many vital aspects of HSM calibration, such as the importance of having a thorough understanding of both the HSM itself and of the available data; the need to compile data from a variety of sources; the need to evaluate tradeoffs; and the benefits of shared knowledge between agencies that are working with the HSM.

The outcomes of this project suggest that many possible areas for future research exist, both in terms of statewide HSM calibration and the general application of the HSM. One potential area of research for the general application of the HSM is sensitivity analysis to investigate the effects of different levels of data and modeling detail on HSM calibration. In addition, it may be desirable for Missouri to develop its own statewide SPFs for some site types, such as signalized intersections.

Table ES.1 Summary of HSM calibration results for Missouri

Site type	Number of Sites	Number of Observed Crashes (3 Years)	Calibration Factor
Rural Two-Lane Undivided Highway Segments	196	302	0.82
Rural Multilane Divided Highway Segments	37	715	0.98
Urban Two-Lane Undivided Arterial Segments	73	259	0.84
Urban Four-Lane Divided Arterial Segments	66	567	0.98
Urban Five-Lane Undivided Arterial Segments	59	752	0.73
Rural Four-Lane Freeway Segments (PDO SV)	47	1229	1.51
Rural Four-Lane Freeway Segments (PDO MV)	47	645	1.98
Rural Four-Lane Freeway Segments (FI SV)	47	268	0.77
Rural Four-Lane Freeway Segments (FI MV)	47	150	0.91
Urban Four-Lane Freeway Segments (PDO SV)	39	583	1.62
Urban Four-Lane Freeway Segments (PDO MV)	39	669	3.59
Urban Four-Lane Freeway Segments (FI SV)	39	142	0.70
Urban Four-Lane Freeway Segments (FI MV)	39	153	1.40
Urban Six-Lane Freeway Segments (PDO SV)	54	477	0.88
Urban Six-Lane Freeway Segments (PDO MV)	54	1482	1.63
Urban Six-Lane Freeway Segments(FI SV)	54	206	1.01
Urban Six-Lane Freeway Segments (FI MV)	54	424	1.20
Urban Three-Leg Signalized Intersections	35	531	3.03
Urban Four-Leg Signalized Intersections	35	1347	4.91
Urban Three-Leg Stop-Controlled Intersections	70	52	1.06
Urban Four-Leg Stop-Controlled Intersections	70	179	1.30
Rural Two-Lane Three-Leg Stop-Controlled Intersections	70	25	0.77
Rural Two-Lane Four-Leg Stop-Controlled Intersections	70	49	0.49
Rural Multilane Three-Leg Stop-Controlled Intersections	70	46	0.28
Rural Multilane Four-Leg Stop-Controlled Intersections	70	94	0.39

Chapter 1 Introduction

The new Highway Safety Manual (HSM) provides methods and tools to assist in the quantitative evaluation of safety. The HSM includes a large knowledge base of historical crash and countermeasure performance data collected from across the United States. This knowledge base was used to produce predictive models and modification factors that relate to a wide range of geometric and operational conditions. However, in order to apply these models effectively, they need to be calibrated to local conditions and to the relevant time period.

A research project was undertaken to calibrate the HSM for Missouri for eight segment site types (including three freeway segment types) and eight intersection site types. Though freeways were not included in the first edition of the HSM, crash prediction models for freeways have been developed, and some states have already started to calibrate freeway models. Therefore, the calibration of freeway segments was undertaken in the current research report.

This report documents the statewide HSM calibration in Missouri, and includes details on the challenges encountered, pragmatic solutions devised, and the finalized calibration values. Since the HSM is still relatively new, there is a need for additional guidance regarding the calibration process. Such additional guidance could be on the topic of the sampling approach, the determination of minimum segment length, the treatment of left-turn phasing and the inclusion or exclusion of speed-change lane adjacent crashes. The application of the HSM is both an art and a science, and in many cases requires the use of engineering judgment. Agencies can benefit by sharing their initial experiences surrounding HSM calibration. The objectives of this report are to share experiences with HSM calibration, to promote the use of HSM as a tool, to improve safety, and to present the HSM calibration results for Missouri, along with possible explanations for select results.

This research report is organized as follows. Chapter 2 describes some of the HSM calibration experiences of other states, including results from a literature search and from discussions with other states. Chapter 3 provides an overview of the methodology used for the HSM calibration. Chapters 4-7 describe the HSM calibration for segment site types. Chapters 8 and 9 describe the HSM calibration for intersection site types. Finally, chapter 10 includes a summary of the results and recommendations for possible future research.

Chapter 2 Literature Review

2.1 Introduction

This chapter provides an overview of the HSM calibration efforts of other agencies through a review of existing literature. In addition, discussions were held with colleagues in other states to learn about their calibration experiences.

2.2 HSM Calibration in North Carolina

Srinivasan and Carter (2011) calibrated several site types in North Carolina using data compiled from several sources.

2.2.1 Methods for Collecting Data

The North Carolina researchers used the Highway Safety Information System (HSIS) to collect roadway inventory, traffic volumes, and crash data. Crash data were collected from the Traffic Engineering Accident Analysis System (TEAAS) of the North Carolina Department of Transportation (NCDOT). NCDOT GIS files and Google Maps were used for aerial and street views. To accommodate the characteristics of North Carolina, the researchers classified segments by geographic characteristics (coast, piedmont, and mountain) for each type of road.

2.2.2 Scope of Calibration

Several site types were calibrated, as shown in Tables 2.1 and 2.2. Two types of segments (rural two-lane, rural four-lane) and two types of intersections (three-leg and four-leg rural four-lane stop controlled) were not calibrated due to a lack of sufficient samples.

Table 2.1 Segment site types for North Carolina HSM calibration

Segments Site Type	Coast (mi.)	Mountain (mi.)	Piedmont (mi.)	Total (mi.)
Rural Four-Lane Divided	18.59	21.31	9.87	49.77
Urban Two-Lane Undivided (2U)	11.47	18.33	29.59	59.39
Urban Two-Lane with TWLTL (3T)	3.15	0.72	3.7	7.57
Urban Four-Lane Divided (4D)	2.94	2.73	9.83	15.5
Urban Four-Lane Undivided (4U)	3.52	4.3	7.47	15.29
Urban Four-Lane with TWLTL (5T)	4.16	3.88	4.42	12.46

Table 2.2 Intersection site types for North Carolina HSM calibration

Intersection Facility Type	Coast	Mountain	Piedmont	Total
Rural Two-Lane, Minor Road Stop Controlled Three-Leg (3ST)	75	32	26	133
Rural Two-Lane, Signalized Four-Leg (4SG)	4	3	12	19
Rural Two-Lane, Minor Road Stop Controlled Four-Leg (4ST)	40	4	15	59
Rural Four-Lane, Signalized Four-Leg (4SG)	10	4	9	23
Urban Arterial, Signalized Three-Leg (3SG)	12	9	10	31
Urban Arterial, Minor Road Stop Controlled Three-Leg (3ST)	26	32	15	73
Urban Arterial, Signalized Four-Leg (4SG)	47	35	40	122
Urban Arterial, Minor Road Stop Controlled Four-Leg (4ST)	6	5	9	20

2.2.3 Methods of Sampling

North Carolina attempted to develop its own models, but was unable to do so due to a lack of available data. The researchers recognized that the random selection of segments is suggested by the HSM manual; however, for reasons related to efficiency, the researchers selected entire routes and used all segments from a route. To minimize bias introduced by using the same routes, all routes were used in a single county or adjacent counties. This step allowed the samples to contain a reasonable mix of road classes.

Intersection data collection was conducted by collecting segments of roads, taking into consideration the HSM facility type. Intersection areas were extended by 250 feet in each direction from the center of the intersection point. For the number of samples, roughly the same number of groups was selected from three geographic areas.

The sample size varied for different types of segments and intersections. For example, urban two-lane with TWLTL had a sample size of 7.57 miles, the lowest size. The longest sample was urban two-lane undivided (2U), with 59.39 miles. For intersections, the smallest sample size was rural two-lane signalized four-leg (4SG), with 19 samples, and the largest sample size was rural two-lane minor road stop controlled three-leg (3ST), with 133 samples. All segment types met the HSM recommended minimum of 100 crashes per year. However, half of the intersection types exhibited fewer than 100 crashes per year.

2.2.4 Results and Calibration Factors

The HSM calibration results for segments in North Carolina are shown in Table 2.3. Rural four-lane divided (4D), urban two-lane undivided (2U), and urban four-lane with TWLTL (5T) had values of less than 2.0. Urban two-lane with TWLTL (3T), urban four-lane divided (4D), and urban four-lane undivided (4U) had much higher values.

The HSM calibration results for intersections in North Carolina are shown in Table 2.4. Rural two-lane 3ST, rural two-lane 4SG, rural two-lane 4ST, rural four-lane 4SG, urban arterial 3ST, and urban arterial 4ST had values of less than or relatively close to 1.00. Urban arterial 3SG and urban arterial 4SG had relatively higher values.

The results from the three years of data were not significantly different by year. One unique analysis included results by geographic region and year. Although the researchers did not explicitly describe these results, they could be valuable, and could be used by other agencies to model their own regional HSM projects. Three facilities on three-lane and four-lane roads had higher calibration factors than did other types of roads. One of main reasons for this difference was that North Carolina had a 50 percent higher fatal crash rate than did Washington, which was one of the states whose data was used for the HSM model. But this is not a full explanation for the higher values for two types of roads.

Table 2.3 Calibration results for North Carolina segments

Segment Site Type	Calibration Factor
Rural Four-Lane Divided (4D)	0.97
Urban Two-Lane Undivided (2U)	1.54
Urban Two-Lane with TWLTL (3T)	3.62
Urban Four-Lane Divided (4D)	3.87
Urban Four-Lane Undivided (4U)	4.04
Urban Four-Lane with TWLTL (5T)	1.72

Table 2.4 Calibration results for North Carolina intersections

Intersection Site Type	Calibration Factor
Rural Two-Lane, Minor Road Stop Controlled Three-Leg (3ST)	0.57
Rural Two-Lane, Signalized Four-Leg (4SG)	1.04
Rural Two-Lane, Minor Road Stop Controlled Four-Leg (4ST)	0.68
Rural Four-Lane, Signalized Four-Leg (4SG)	0.49
Urban Arterial, Signalized Three-Leg (3SG)	2.47
Urban Arterial, Minor Road Stop Controlled Three-Leg (3ST)	1.72
Urban Arterial, Signalized Four-Leg (4SG)	2.79
Urban Arterial, Minor Road Stop Controlled Four-Leg (4ST)	1.32

2.3 HSM Calibration in Utah

Brimley et al. (2012) calibrated rural, two-lane highways in Utah.

2.3.1 Methods for Collecting Data

To acquire local road information, select segments, and obtain visual data, the Road View Explorer of the Utah Department of Transportation (UDOT) was used. In addition, Google Earth was used for geometric measurements. UDOT provided data regarding crash histories and AADT. Because the availability of curvature data was limited, only tangent segments were adopted as a new variable in the new model.

2.3.2 Scope of Calibration

In the Utah study, 426 crashes were recorded on 157 segments from rural, two-lane, two-way roads, to be used in the Utah SPF. The calibration included three years of data from 2005 to 2007. In addition to the calibration of the HSM model, the researchers were able to develop jurisdiction-specific SPFs due to availability of data, in accordance with the HSM manual.

In particular, a new model was developed through negative binomial regression and an over-dispersion parameter. For jurisdiction-specific SPFs, negative binomial regression is recommended to account for the dispersion present. The researchers showed that the jurisdiction-specific model improved the correlation between local characteristics and crash rates in Utah.

2.3.3 Methods of Sampling

Data was collected as randomly as possible. Some additional characteristics of segments were included, such as speed limit, the presence or absence of a shoulder rumble strip, passing ability, and the percentage of single-unit trucks. It was assumed that these variables were related to total crash frequencies. The scope of the study was limited to segments with AADT counts of less than 10,000 and speed limits higher than 55 mph, in order to represent Utah rural two-lane highways.

2.3.4 Results and Calibration Factors

The Utah model calibration predicted 368 crashes for three years, with a calibration factor of 1.16. There were four SPFs developed with two conventional models and two transformed models that used the natural log of the AADT. The over-dispersion parameters were 1.20 (75% confidence level) and 1.24 (95% confidence level) for the conventional models. The over-dispersion parameters were 1.14 (75% confidence level) and 1.19 (95% confidence level) for the transformed models. To select the preferred model, the Bayesian information criterion (BIC), as shown in Table 2.5, was used. The model that produced the lowest value was preferred. The transformed model at a 95% confidence level had the lowest value, at 583.7.

Table 2.5 BIC values for Utah HSM study

Type of calibration	BIC value
The calibrated HSM SPF	1095.6
Conventional method (75%)	607.4
Conventional method (95%)	601.5
Transformed method (75%)	596.7
Transformed method (95%)	583.7

2.4 HSM Calibration in Oregon

Xie et al. (2011) calibrated several facility types in Oregon with data compiled from several sources.

2.4.1 Methods for Collecting Data

Three years of crash data from 2004-2006 were used for the Oregon study. The researchers acquired crash data from the Statewide Crash Data System of the Oregon Department of Transportation (ODOT). Crashes that were intersection-related or occurred within

250 ft of an intersection were classified as intersection crashes. All other crashes were classified as segment crashes.

The Oregon calibration study did not use any default values. The researchers were concerned that default values could impact the level of precision. Local characteristic were incorporated through various data sources, including digital volume logs and aerial photographs. In addition, drawing tools were used to measure distance for some of the variables.

For intersections, Oregon resources did not provide enough information to accurately estimate the number of pedestrians in a given intersection area. This led the researchers to assume medium pedestrian volumes in all signalized intersection areas. To determine signal phasing, it was assumed that a minor road had the same phasing as a major road if there were dedicated left-turn lanes. Another obstacle for data collection was minor road AADT. For rural areas, minor road AADT was not available. Models were developed to estimate the missing AADT.

2.4.2 Scope of Calibration

Three facility types described in the HSM were calibrated. Both segments and intersections of rural two-lane highways, rural multilane highways, and urban and suburban arterials were studied, as shown in Tables 2.6 and 2.7. A total of 18 factors were calibrated.

Table 2.6 Estimated calibration factors for Oregon segment types

Rural Two-Lane	Rural Multilane		Urban and Suburban Arterials				
R2	MRU	MRD	2U	3T	4D	4U	5T
0.74	0.36	0.78	0.63	0.82	1.43	0.65	0.64

Table 2.7 Estimated calibration factors for Oregon intersection types

Rural Two-lane			Rural Multilane			Urban and Suburban Arterials			
R3ST	R4ST	R4SG	MU3ST	MR4ST	MR4SG	U3ST	U4ST	U3SG	U4ST
0.32	0.31	0.47	0.16	0.4	0.15	0.35	0.44	0.75	1.1

2.4.3 Methods of Sampling

Overall, the Oregon study selected sites following the general guidance suggested by the HSM. Researchers picked sites for each type of road randomly to avoid bias. Each segment was divided into approximately two-mile sections. If there was an intersection, segments were divided at intersections to maintain homogeneity. A review of crash history was also performed following random site selection.

2.4.4 Results and Calibration Factors

The Oregon calibration results are summarized in Tables 2.6 and 2.7. The results obtained in Oregon show that most calibration factors were much less than 1.00 for both segments and intersections. Only one segment type (urban four-lane divided) and one intersection type (urban four-lane signalized intersection) had calibration factors greater than 1.00. The results seemed to imply that Oregon facilities were generally safer than the national average. The researchers found some other possible explanations. First, the threshold level for generating a crash report was higher ($1,500) than in other states such as Washington and California ($700), which had supplied some of the original HSM data. The lower number of crashes reported by individual drivers was verified through comparison with the HSM default value. In HSM, fatal and injury (FI) crashes accounted for 32 percent of all crashes, while property damage only (PDO) crashes were 68 percent of all crashes. Therefore, PDO crashes were approximately twice as frequent as FI crashes. However, in the case of Oregon, PDO crashes were only 46 percent of all crashes, while FI crashes were 54 percent of all crashes. After adjusting this difference into the calibration, the calibration factor increased. The calibration factor for rural two-lane highways increased from 0.74 to 1.15. There was another explanation for U4D segments. U4D segments were not common in Oregon. The sample size for U4D segments was small, at only 5.87 miles.

2.5 HSM Calibration in Louisiana

Sun et al. (2006) calibrated rural two-lane highways in Louisiana.

2.5.1 Methods for Collecting Data

The Louisiana DOT provided basic information, such as ADT. However, some data had to be collected by the researchers. The researchers reviewed the annual pavement condition survey to obtain driveway density information. Hard copies of original design files were reviewed to obtain horizontal curve data.

2.5.2 Scope of Calibration

Rural two-lane highway segments were the only facilities to be tested. This study was performed in the relatively early stages of HSM projects. Three years of data, from 1999 to 2001, were used for calibration.

2.5.3 Methods of Sampling

Based on the attributes of the segments, rural two-lane highways were divided into 4,123 control sections. The average length was 3.25 mi. The length varied from 0.03 mi to 16.96 mi. ADT also varied from 45 vpd to 24,029 vpd. Due to a lack of available data, the suggested HSM calibration was not followed. Instead, the research team created a database that could be utilized for Louisiana rural two-lane highways. Major variables were collected and adopted. However, some variables were set to default values, such as roadside hazard rating and driveway density.

Two groups of segments were selected for analysis. In the first group, 26 samples were randomly selected with average crash rates. In the second group, 16 samples with high crash rates were selected.

2.5.4 Results and Calibration Factor

The result for the first group was 1.1, which was nearly the same as the state average of 1.3. The group was tested with three different scenarios based on the availability of driveway density data and the calibration parameter. Scenario 1, without the data for driveway density or calibration parameter, resulted in the lowest value. Scenario 3, with available data for the calibration parameter but not driveway density, had the highest value. Horizontal curve data were not available in all three of these scenarios. The average crash rate of group 2 was 2.5 times higher than the state average. Overall, the results indicated that the difference between the observed and predicted values was less than five percent.

2.6 HSM Calibration in Illinois

Williamson and Zhou (2012) calibrated rural two-lane Highways in Illinois.

2.6.1 Methods for Collecting Data

The data collection was similar to HSM, or a traditional approach including the extensive inspection of roadways, review of crash reports, and correspondence with local agencies.

2.6.2 Scope of Calibration

Five segments were randomly selected from six counties. Three years (2005-2007) of crash data including 165 total crashes were analyzed. Crashes that occurred within 250 feet of an intersection were classified as intersection crashes in accordance with the HSM. Two SPFs were used in the study: the HSM SPF and the SPF developed specifically for Illinois.

2.6.3 Methods of Sampling

Six counties were randomly selected to ensure that the prediction is representative of the entire state. Five random segments from each county were selected.

2.6.4 Results and Calibration Factor

The HSM SPF predicted 22.1 total crashes, and the localized SPF predicted 19.6 total crashes. Based on these crash numbers, calibration factors were calculated as 1.40 and 1.58, respectively. The study showed that number of crashes on Illinois rural two-lane highway segments was higher than the national average.

The researchers performed a validation process using 10 randomly selected test segments in counties with similar conditions. Both methods were applied, and the results indicated a 53 percent correlation and a 59 percent correlation between the observed and predicted crashes, respectively. This test helped to confirm that the results were reasonable.

In Illinois, the reporting threshold for a crash increased from $500 to $1,500 in 2009. This new threshold reduced the number of crashes significantly, from 422,778 (2007) and 408,258 (2008) to 292,106 (2009). The study suggested adjusting for any bias caused by the new threshold to accurately predict crash numbers.

<u>2.7 HSM Calibration in Italy</u>

Martinelli et al. (2009) calibrated rural two-lane highways in the Italian province of Arezzo.

2.7.1 Methods for Collecting Data

Since the Arezzo province was located in a mountainous area, it was important to take curvature data into account when developing the model. Extensive GIS data collection was performed throughout the province of Arezzo. After several steps of review, the sample size was reduced from 1,300 km to 938 km. AADT was not available for parts of some segments. The network was divided into two groups, with and without AADT data. Three years of crash data collected from 2002 to 2004 exhibited a total of 3,783 crashes. After data cleaning procedures, such as excluding intersection areas, 402 crashes remained. Driveway data from 1996 were provided by the province of Arezzo.

2.7.2 Scope of Calibration

In this study, 938 km of rural two-lane highway from the mountainous province of Arezzo were studied. The calibration followed HSM procedure and divided the entire system into segments and intersections.

2.7.3 Methods of Sampling

The road network used for the study was divided into 8,379 sections with an average length of 112 m. Each section had homogeneous characteristics with respect to geometric data and AADT.

2.7.4 Results and Calibration Factor

A significant number of sections did not have crash records, as there were only 402 total crashes and 0.05 average crashes per section. This led to a low calibration factor value of 0.17 for the calibration factor proposed by the HSM. The researchers developed three comparisons to evaluate the calibration. The first comparison was between the base model and the full model. Because of the high rate of curvature, the base model was a better estimation than the full model. The second comparison used average and section-by-section parameters. Average parameters exhibited better prediction than did section-by-section parameters due to weighted averaging, since average parameters were not biased by length. The third comparison utilized different coefficient calculation methods, such as number of accidents, densities, or weighted average. The weighted average ratio provided better crash prediction than did the number of accidents ratio and the densities ratio.

2.8 Discussions with Other States

Discussions were held with colleagues from several states to learn about their experiences calibrating the HSM. The lessons learned from other states were of great benefit during the calibration process. These conversations also helped to demonstrate how states apply the HSM differently based on data availability and the geographic characteristics of their state. These conversations are discussed in relevant sections of the current report.

Chapter 3 Methodology

3.1 Introduction

This chapter provides an overview of the methodology used for HSM calibration, including site type selection, sampling, data collection, and calibration. The sampling and data collection procedures for specific site types are discussed in greater detail in subsequent chapters of this report.

3.2 Selection of Site Types for Calibration

The HSM includes a wide range of site types on rural two-lane undivided highways (HSM chapter 10), rural multilane highways (HSM chapter 11), and urban and suburban arterials (HSM chapter 12). In addition, appendix C of the HSM contains the proposed HSM chapter 18 for the predictive methodology for freeways. A preliminary step in the calibration process for this project was to meet with MoDOT technical advisors to determine which facilities would be calibrated for Missouri. The MoDOT technical advisors included Michael Curtit, John Miller, and Ashley Reinkemeyer—experts in highway safety, and representatives of the state of Missouri at NCHRP 17-50 (Lead State Initiative for Implementing the Highway Safety Manual) and TRB ANB25 (Highway Safety Performance committee). The site types for calibration (Table 3.1) were selected based upon state priorities as well as the availability of sufficient samples. Some facilities, such as rural four-lane undivided segments and rural eight-lane segments, were not calibrated in Missouri because they were not common or were non-existent. In Kansas, urban facilities were not calibrated due to a lack of sufficient samples for urban two-lane and urban multilane arterials. Illinois calibrated most HSM models, with the exception of some of the severity distribution functions and freeways.

Table 3.1 HSM site types calibrated for Missouri

<table>
<tr><th>HSM Chapter</th><th>Segment Type</th><th>Intersection Type</th></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Rural Two-Lane, Two-Way Highways</td><td>Rural Two-Lane Stop Controlled, Three-Leg</td></tr>
<tr><td>Rural Two-Lane Stop Controlled, Four-Leg</td></tr>
<tr><td rowspan="2">11</td><td rowspan="2">Rural Multilane Divided Highways</td><td>Rural Multilane Stop Controlled, Three-Leg</td></tr>
<tr><td>Rural Multilane Stop Controlled, Four-Leg</td></tr>
<tr><td rowspan="4">12</td><td>Urban Two-Lane Undivided Arterials</td><td>Urban Signalized, Three-Leg</td></tr>
<tr><td>Urban Multilane Divided Arterials</td><td>Urban Signalized, Four-Leg</td></tr>
<tr><td>Urban Five-Lane Undivided Arterials w/ TWLTL</td><td>Urban Stop Controlled, Three-Leg</td></tr>
<tr><td>-</td><td>Urban Stop Controlled, Four-Leg</td></tr>
<tr><td rowspan="3">Appendix C*</td><td>Rural Four-Lane Freeways</td><td rowspan="3">-</td></tr>
<tr><td>Urban Four-Lane Freeways</td></tr>
<tr><td>Urban Six-Lane Freeways</td></tr>
</table>

*Freeway interchange and ramp terminals will be calibrated in the subsequent project.

3.3 General Sampling Procedure

An important consideration for HSM calibration is sampling. Since it is labor- and cost-prohibitive to use all facilities, the HSM recommends that a representative sample of the specific site type be used. 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**. The sampling procedures for this project were based upon these guidelines, while also attempting to ensure geographic diversity across the state. The minimum number of sites was met for all site types. However, a few of the site types did not generate at least 100 crashes per year due to low volumes and rural settings. For example, rural two-lane three-leg stop-controlled intersections had a major approach AADT of only 1,421 vpd and a minor approach AADT of only 72 vpd. It should be noted that the HSM recommendation is not a hard threshold, since the accuracy of calibration is a function of the variability in the data

The state of Missouri is divided into seven MoDOT districts. Sampling was performed based upon intersections and segments in the MoDOT Transportation Management System (TMS) database. For most site types, five random samples were selected from each MoDOT district, resulting in at least 35 samples per site type. In comparison, Illinois performed separate calibrations for the Chicago metropolitan area and the rest of the state. For each calibration in Illinois, 100 random samples (50 samples from the state system and 50 samples from the local system) were generated. For both states, a master list of facilities for each site type was generated in a spreadsheet, and a spreadsheet random number generator was used to generate the samples from the list.

For some site types in Missouri, it was not possible to generate five samples for each district. For example, most of the urban six-lane freeway segments in Missouri were located in the Kansas City and St. Louis districts. For this site type, sampling was performed from all districts simultaneously to generate a minimum sample size of 35 sites. The urban six-lane freeway samples included only one segment that was not located in either the Kansas City or St. Louis districts. The sampling process for three-leg signalized intersections also required some at-large sampling because some districts, such as the northeast district, did not contain five samples for this site type.

Another sampling challenge involved the need to exclude some samples due to geographic location or lack of adequate data. In particular, samples from the city of Columbia, Missouri were excluded due to concerns regarding the accuracy of the crash data. The Columbia Police Department does not record PDO crashes, in contrast to the rest of the state. Other states also face challenges in terms of the quality of their crash data. For example, New Hampshire was waiting to improve the quality of their crash data prior to calibration, since only approximately 70 percent of crashes were located geographically.

3.3.1 Sampling of Segments

The sampling of segments was based on database queries of the TMS table TMS_TRF_INFO_SEGMENT_VW, which divided a road facility into segments based on AADT. Additional information for the database queries, such as number of lanes, was obtained from the TMS table TMS_SS_PAVEMENT. Ensuring that the segments were homogeneous with respect to AADT was important, since AADT was required input for the HSM SPFs for segments. Database queries were performed for different segment site types based on criteria such as the number of lanes, median type, and urban/rural designation. The output from the database queries was imported into a spreadsheet, and the spreadsheet random number generator function was used to create the samples. The sampled segments were verified visually to ensure that they met the criteria for a given site type.

Special considerations for the sampling of segments included minimum segment length and balancing between segment homogeneity and minimum segment length. A minimum segment length of 0.5 miles (0.8 km) was initially used before the segments were subdivided to ensure homogeneity. However, after the initial sampling of urban arterial segments, it was noted that most of the segments were located outside of highly developed urban areas. Since urban built-up areas contain frequent intersections, the segment lengths in these areas are shorter than in typical suburban areas. The use of a minimum length of 0.5 miles (0.8 km) for urban arterial segments created the concern that bias toward segments at the outer limits of urban areas could be introduced. Therefore, the decision was made to use a minimum segment length of 0.25 miles

(0.4 km) for urban arterial segments. Due to the shorter length of urban arterial segments, a minimum sample size of 70, based on 10 samples per district, was used for these facilities.

Another consideration for the calibration of segments involved balancing the need for homogeneous segments with data requirements and a minimum segment length. The HSM recommends that segments be homogeneous with respect to geometric characteristics and AADT. Various state experiences illustrate different segment length approaches. Kansas used a segment length of 10 miles (16 km) that was subdivided to ensure homogeneity. Illinois used a shorter minimum length of 1 to 2 miles (1.6 to 3.2 km). AADT is an important input for the HSM crash prediction models, and the segments used in Missouri were homogeneous with respect to AADT since they were based on the segments in the TMS Table TMS_TRF_INFO_SEGMENT_VW before any subdivisions were performed. These segments were not aggregated since the resulting segments would not be homogeneous with respect to AADT. The segments were further subdivided based on major changes in geometric characteristics. Minor changes were not dispositive due to concerns that too many short segments could create bias and increase data requirements. Examples of characteristics that were used to subdivide segments include speed category for urban arterials, median type, effective median width for freeways and rural multilane highways, and horizontal curve radius for rural two-lane highways. Freeway segments were subdivided to ensure that each segment contained at most one entrance ramp and one exit ramp to meet the requirements of the HSM freeway methodology. After subdivision, some of the segments were shorter than the desired minima of 0.5 miles (0.8 km) for rural segments and 0.25 miles (0.4 km) for urban segments. These segments were not excluded because they were part of a larger segment before they were subdivided. Excluding these segments could potentially bias the results towards segments with less frequent cross section changes or interchanges. In Illinois, minor changes in the cross section, such as changes in shoulder width, were not used to subdivide segments. But a major change in cross section or curvature required the application of a separate CMF to the sub-segment.

Another challenge encountered during the sampling process was the need to verify samples visually. The MoDOT TMS database contained a field that indicated the site type, such as a two-lane or five-lane facility. However, it was necessary to confirm the site type visually because the coded site type frequently did not match the actual site type. For example, some segments were coded in the database as five-lane segments with a two-way left-turn lane, but were actually a different site type, such as a four-lane divided segment for all or part of the segment. In these cases, the segments were either discarded or the endpoints of the segment were adjusted to reflect only the portion of the segment that met the criteria for a five-lane section. For the sampling of freeways, some segments contained at-grade intersections and were therefore excluded, since freeways should not contain any at-grade intersections.

Some of the summary statistics for the segment site types that were calibrated are shown in Table 3.2. The variation in the number of samples, the number of crashes, the segment length, and AADT reflects the diverse characteristics and settings of the different site types. As previously discussed, rural segment lengths were much longer than urban segments. Additional summary statistics are provided in subsequent chapters of this report.

Table 3.2 Selected summary statistics for segment samples

Segment Site type	Number of Samples	Number of Crashes (3 Years)	Average Segment Length (mi)	Average AADT (vpd)
Rural Two-Lane Undivided	196	302	0.55	2910
Rural Multilane Divided	37	715	2.60	12719
Urban Two-Lane Undivided Arterial	73	259	0.81	5585
Urban Four-Lane Divided Arterial	66	567	1.06	13979
Urban Five-Lane Undivided Arterial w/ TWLTL	59	752	0.64	15899
Rural Four-Lane Freeway	47	2292	3.02	24730
Urban Four-Lane Freeway	39	1547	1.46	29027
Urban Six-Lane Freeway	54	2589	0.75	86757

3.3.2 Sampling of Intersections

The sampling of intersections was based on database queries of the TMS table TMS_TRF_INFO_SEGMENT_VW. Each row of this table corresponded to a leg of an intersection. Database queries were performed for different intersection types based on criteria such signalization, number of legs, and urban/rural designation. The output from the database queries was imported into a spreadsheet. Because the database contained a separate record for each leg of the intersection, the intersections in the spreadsheet were filtered to ensure that each intersection was listed only once in the spreadsheet. The spreadsheet random number generator function was used to create the intersection samples. The sampled intersections were verified visually to ensure that they met the criteria for a given site type.

Some of the summary statistics for the intersection site types that were calibrated are shown in Table 3.3. The table illustrates the relatively low number of crashes at rural facilities. Additional summary statistics are provided in subsequent chapters of this report.

Table 3.3 Selected summary statistics for intersection samples

Intersection Site type	Number of Samples	Number of Crashes (3 Years)	Average Major AADT (vpd)	Average Minor AADT (vpd)
Urban Three-Leg Signalized	35	531	17551	2795
Urban Four-Leg Signalized	35	1347	16399	7801
Urban Three-Leg Stop-Controlled	70	52	4381	303
Urban Four-Leg Stop-Controlled	70	179	4547	636
Rural Two-Lane Three-Leg Stop-Controlled	70	25	1421	72
Rural Two-Lane Four-Leg Stop-Controlled	70	49	1785	182
Rural Multilane Three-Leg Stop-Controlled	70	46	11069	342
Rural Multilane Four-Leg Stop-Controlled	70	94	9831	483

3.4 General Data Sources

The data for the HSM calibration were collected from a variety of sources, including the MoDOT Transportation Management System (TMS) database, aerial and street view photographs, and other ad-hoc sources. Since a geometric database was not available, a method to estimate horizontal curve data from CAD and aerial photographs was developed. In some cases where data were not available, default values were assumed. The data sources are described in greater detail in the following sections.

3.4.1 MoDOT Transportation Management (TMS) Database

In Missouri, a source for much of the data was the MoDOT TMS database. TMS centralizes different types of data such as crashes, geometric characteristics, and traffic for both roadway segments and intersections. Examples of the TMS data used for calibration include lane width, shoulder width, and AADT. TMS contains many different applications. One of the TMS applications frequently utilized in this project was State of the System (SOS). SOS contains a variety of data for road segments such as functional class, AADT, lane width, shoulder width, and shoulder type. The segments in SOS are divided so that they are homogeneous with respect to AADT.

TMS also contains statewide Automated Road Analyzer (ARAN) video, which was used to derive data visually. The ARAN van travels around the state of Missouri to collect various types of relevant data such as pavement smoothness, pavement rutting, grade, and cross fall. The ARAN van also collects images every 21.12 feet. As shown in Figure 3.1, the field of view from ARAN included the median, if any; the travelway; the shoulder or sidewalk; and the roadside. ARAN images were used to obtain data such as roadside hazard rating, number of driveways, offset to fixed objects, number of fixed objects, area type, type of on-street parking, proportion of segment with on-street parking, median type, barrier offset, median shoulder width, proportion of segment with outside or median rumble strips, proportion of segment with barrier, and presence of lighting. Some of the data collected, such as offset to fixed objects and median shoulder width, required the visual estimation of lateral distances. These data were not available from other sources. The ARAN video included location data in the form of continuous log miles, which represent the distance from the beginning of the segment to a point on the segment. ARAN log mile data were used to determine the locations of critical points, such as the beginning and end of horizontal curves and the beginning and end of freeway speed-change lanes.

Figure 3.1 ARAN photo showing driveway, shoulder, and roadside

Similar to other states, a Statewide Traffic Accident Records System (STARS) program exists in Missouri that computerizes uniform crash reports. MoDOT works closely with the Missouri State Highway Patrol to compile and maintain the crash database. The MoDOT Accident Browser interface in TMS was used to query crash data for all site types except freeway segments. The data provided by the Accident Browser included the location of the accident, date and time of the accident, type of accident, accident severity, weather, and whether the accident occurred at an intersection or interchange. HSM segment calibration requires that intersection crashes be excluded, and freeway calibration requires that crashes on speed-change lanes be excluded. The continuous log mile of the crash in the Accident Browser was used to determine whether a crash occurred within the limits of a speed-change lane. For freeway segments, an SQL (structured query language) database query was used to obtain crash data, because the number of vehicles involved in a crash was required for this site type but was not available in the Accident Browser. To issue the SQL query, ODBC (open database connectivity) was used to access the MoDOT TMSProd database. Three years of traffic and crash data from 2009-2011 were used in calibration. This approach was consistent with the HSM, which recommends that at least three years of crash data be used for calibration.

3.4.2 Aerial and Street View Photographs

In addition to ARAN, aerial maps and street view photographs were also used to derive data visually. One popular interface and free source for such data was provided by Google. Aerial maps, such as the one shown in Figure 3.2, were especially helpful in determining the driveway type for urban arterials. Aerial maps were also used to collect intersection data, such as the number of turn lanes, skew angle, maximum number of lanes crossed by pedestrians, and the number of schools, bus stops, and alcohol sales establishments within 1,000 feet of a signalized intersection. Street view photographs were utilized, along with ARAN video, to verify the number of legs at a signalized intersection and to verify that the intersection was signalized. The street view photograph had a wider view than the ARAN video, and could be rotated and viewed simultaneously with the aerial map. But unlike ARAN video, the street view photograph did not allow for the use of the continuous log mile to locate a segment or intersection or to locate specific features on a segment.

Figure 3.2 Aerial photograph of two-lane suburban road (Google 2013)

Another source of aerial maps was the Center for Applied Research and Environmental Systems (CARES). CARES provides a map room where the user can make an interactive map for a part of Missouri, such as a county. The user can select which layers to include on the map, such as aerial photographs, MoDOT highways, and county boundaries. The map viewer includes tools such as a distance measurement tool and a map export tool. The CARES map viewer was used to locate some segments, to identify ramp names for some freeway segments, and to measure the effective median width for rural multilane divided highways.

3.4.3 Use of CAD for Estimating Horizontal Curve Data

The HSM calibration of rural two-lane undivided highway segments and freeway segments required data for the length and radius of horizontal curves. Ideally, a geometric database containing this information would be available. Some states, such as Kansas, maintain a good inventory of design plans and are able to obtain geometric data from plans. In Missouri, neither a geometric database nor a centralized design plan database existed. Instead, data from ARAN and aerial photographs were used for estimating the horizontal curve data. ARAN was used to visually estimate the continuous log miles for the beginning and end of each horizontal curve. The curve length could then be calculated as the difference between the continuous log miles for the beginning and end of the curve. It is important to note that curve length, as defined by the HSM, includes portions of the curve located *outside* the segment limits for rural two-lane highways, but includes only the portion located *within* the segment limits for freeways. To estimate the curve radius, an aerial image file of the segment was generated from an aerial photograph and attached to an AutoCAD drawing as a raster reference file at the proper scale. An arc was drawn on top of the aerial image, and the radius of the curve was measured in AutoCAD, as shown in Figure 3.3. Although this method did not provide the same level of accuracy as a geometric database or design plans, it was an effective way of estimating the as-built horizontal curve data. This method could also be useful for a state like New Hampshire, which has concerns regarding the quality of its existing geometric data.

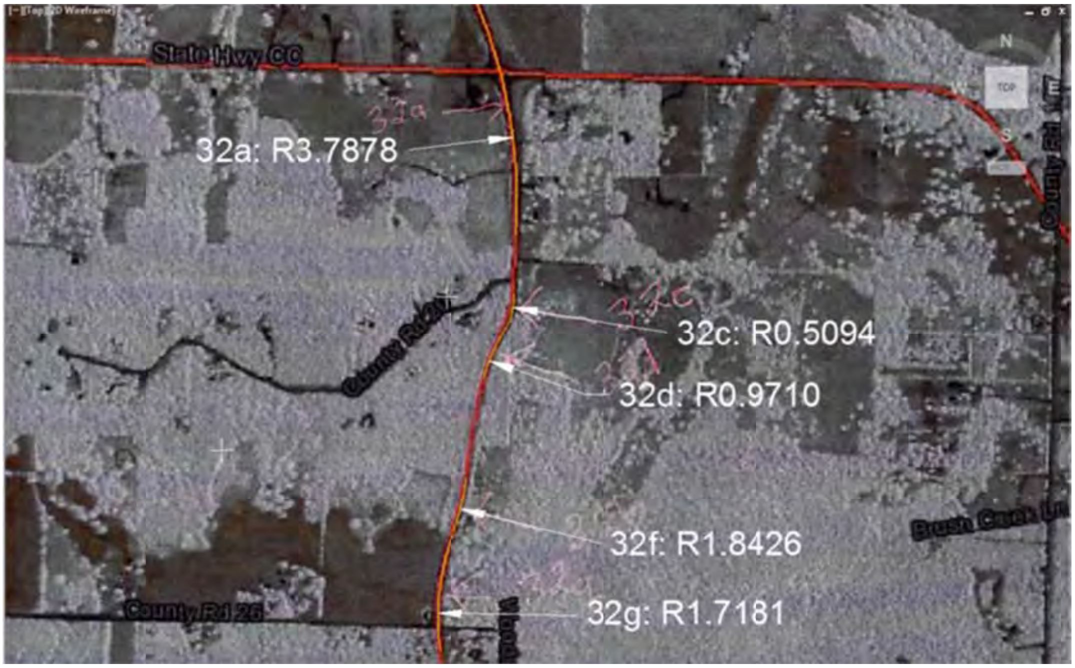


Figure 3.3 Example of horizontal curve estimation using aerial photograph

3.4.4 Other Data Sources

In some cases, ad-hoc data were obtained from other sources, such as MoDOT. For example, MoDOT provided a list of signalized intersections with red-light-running cameras and automated speed enforcement. The type of left turning phasing and right-turn-on-red restrictions had to be gathered from individual MoDOT districts. MoDOT also provided ramp AADT data for ramps that were missing AADT data in TMS.

3.4.5 Use of Default Values

In some cases, the data needed for HSM calibration were not available, so default values were assumed. Although the ARAN van collects some data regarding cross slope and vertical grades, MoDOT indicated that these data were not always accurate, and were not available for every route. Therefore, base condition values of zero percent were assumed for both the vertical grade and superelevation variance. It was assumed that all of the horizontal curves did not have spirals, because MoDOT indicated that most existing horizontal curves did not have spirals. Due to the lack of available data, the HSM base condition values were also used for the following variables: clear zone width, pedestrian volumes, and proportion of high volumes for freeways. This approach was also utilized by other states based on data availability. For example, Louisiana (Sun et al. 2006) assumed the base condition values for roadside hazard rating, driveway density, and horizontal and vertical curvature due to a lack of available data. Utah (Brimley et al. 2012) only included tangent segments in their calibration of rural two-lane highways because horizontal curvature data were not available at the time of the study.

3.5 Calibration

The calibration factor for each site type was determined by dividing the observed crash frequency by the predicted crash frequency. Crash prediction could be implemented through the use of spreadsheets. Spreadsheets for select site types were available from AASHTO. Alternately, equations for HSM SPFs and CMFs could be coded into spreadsheets to compute the calibration factor. Another method for computing calibration factors, employed in the HSM calibrations in Missouri and Kansas, was the use of the Interactive Highway Safety Design Model (IHSDM). IHSDM is a software suite developed by FHWA for evaluating safety and operations in geometric design. IHSDM has separate modules for calibrating different site types, including the recently added freeway module. Currently, the IHSDM software does not include the capability to import freeway curve data using a text file. However, the freeway curve data can be added to IHSDM by copying the data from a spreadsheet and pasting it directly into IHSDM.

A summary of the calibration factors obtained in this project is shown in Table 3.4. In the table, PDO means Property Damage Only, FI means fatal and injury, SV means single vehicle and MV means multiple vehicles. The calibration results for each site type are further discussed in subsequent chapters pertaining to the specific site type. Missouri factors were generally lower than 1.0, meaning Missouri facilities experienced fewer crashes than the national average. Some major exceptions were urban three-leg and four-leg signalized intersections, unsignalized intersections, and PDO MV crashes on urban four-lane freeways. Possible explanations for these exceptions are addressed in detail in subsequent chapters.

Table 3.4 Summary of calibration results

Site type	Calibration Factor
Rural Two-Lane Undivided Highway Segments	0.82
Rural Multilane Divided Highway Segments	0.98
Urban Two-Lane Undivided Arterial Segments	0.84
Urban Four-Lane Divided Arterial Segments	0.98
Urban Five-Lane Undivided Arterial Segments	0.73
Rural Four-Lane Freeway Segments (PDO SV)	1.51
Rural Four-Lane Freeway Segments (PDO MV)	1.98
Rural Four-Lane Freeway Segments (FI SV)	0.77
Rural Four-Lane Freeway Segments (FI MV)	0.91
Urban Four-Lane Freeway Segments (PDO SV)	1.62
Urban Four-Lane Freeway Segments (PDO MV)	3.59
Urban Four-Lane Freeway Segments (FI SV)	0.70
Urban Four-Lane Freeway Segments (FI MV)	1.40
Urban Six-Lane Freeway Segments (PDO SV)	0.88
Urban Six-Lane Freeway Segments (PDO MV)	1.63
Urban Six-Lane Freeway Segments (FI SV)	1.01
Urban Six-Lane Freeway Segments (FI MV)	1.20
Urban Three-Leg Signalized Intersections	3.03
Urban Four-Leg Signalized Intersections	4.91
Urban Three-Leg Stop-Controlled Intersections	1.06
Urban Four-Leg Stop-Controlled Intersections	1.30
Rural Two-Lane Three-Leg Stop-Controlled Intersections	0.77
Rural Two-Lane Four-Leg Stop-Controlled Intersections	0.49
Rural Multilane Three-Leg Stop-Controlled Intersections	0.28
Rural Multilane Four-Leg Stop-Controlled Intersections	0.39

Chapter 4 Rural Two-Lane Undivided Segments

4.1 Introduction and Scope

Chapter 10 of the HSM describes the methodology for crash prediction on rural two-lane undivided roadway segments, which were calibrated as part of this project.

4.2 HSM Methodology

As described in chapter 10 of the HSM, the SPF for rural two-lane undivided roadway segments predicts the number of total crashes on the segment per year for base conditions. The SPF is based on the AADT and length of the segment.

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \qquad (4.1)$$

where,

$N_{spf\ rs}$ = predicted total crash frequency for roadway segment base conditions;

AADT = annual average daily traffic volume (vehicles per day); and

L = length of roadway segment (miles).

The base conditions for the SPF are shown in Table 4.1.

Table 4.1 Base conditions for roadway segments on rural two-lane roads

Description	Base Condition
Lane width	12 feet
Shoulder width	6 feet
Shoulder type	Paved
Roadside Hazard Rating	3
Driveway density	5 driveways per 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%

4.3 Sampling Considerations

For rural two-lane roadway segments, a random sample of five sites from each MoDOT district was generated based on a minimum length of 0.5 miles per site. TMS was used to generate database queries with a list of candidate rural two-lane sites for each district. The criteria used to generate the queries are shown in Table 4.1. The field DRVD_TRFRNGINFO_YEAR was used to limit the query to 2011 data since TMS contained AADT data for each year. The AADT data for other years were later obtained 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 provide AADT for 2011 in the query output. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes which 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 two-lane segments through the use of the NUMBER_OF_LANES field.

Table 4.2 Query criteria for rural two-lane sites

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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

The sampled sites were reviewed to ensure that ARAN data were available for the sites, and to verify that the sites were of the proper site type and were homogeneous with respect to cross section. Some sampled sites were discarded and replaced with another sampled site because they did not contain adequate ARAN data. The END_URBAN_RURAL_CLASS field was also checked in TMS to confirm that the value of the field was urban. If the value of this field was not urban, the sample site was also checked in ARAN to determine whether the site was rural or urban based upon surrounding land use characteristics. One site from the Southwest District was subdivided because a portion of the site contained a two-way left turn lane.

The list of sampled sites is shown in Table 4.2. Most of the sites were Missouri state highways, although there were a few sites that 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	220.73	223.31	Camden	2.58
3	CD	MO 17	N	156.57	160.31	Miller	3.74
4	CD	MO 5	N	222.80	226.89	Howard	4.10
5	CD	MO 124	W	23.24	25.06	Howard	1.82
6	KC	MO 13	S	127.13	130.91	Johnson	3.79
7	KC	MO 45	N	9.29	15.98	Platte	6.69
8	KC	MO 210	E	26.63	27.71	Ray	1.08
9	KC	MO 273	S	19.05	23.01	Platte	3.96
10	KC	MO 58	E	47.62	49.59	Johnson	1.97
11	NE	MO 47	S	53.33	55.89	Warren	2.56
12	NE	MO 19	S	21.55	22.05	Ralls	0.50
13	NE	MO 6	E	168.84	176.65	Knox	7.82
14	NE	MO 94	W	60.97	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	2.83
24	SE	MO 91	S	17.92	18.87	Stoddard	0.95

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	County	Length (mi)
25	SE	MO 34	E	71.46	73.68	Bollinger	2.22
26	SL	MO 100	E	56.23	57.20	Franklin	0.97
27	SL	MO 110	W	0.75	4.18	Jefferson	3.43
28	SL	RT H	E	4.22	10.77	Jefferson	6.55
29	SL	RT C	S	13.16	14.39	Franklin	1.24
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	15.80	20.57	Greene	4.77
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	18.44	20.94	Greene	2.51
36	SW	MO 125	S	20.94	21.51	Greene	0.57

Since 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 estimated visually from ARAN. A separate segment was created for each horizontal curve. All of the tangent sections from a given site were combined into one segment since they were homogeneous with respect to cross section and horizontal curvature. The calibration data set consisted of 196 segments, of which 160 segments were horizontal curves.

4.4 Data Collection

A list of the data types collected for rural two-lane undivided highways and their sources is shown in Table 4.3. All data, except for horizontal curve data, were collected before the sites in Table 4.2 were subdivided based on horizontal curvature. This method of data collection was used to help ensure that bias created by short segments was not introduced. Lane width and outside paved shoulder width were assumed to be the same in each direction. This assumption was reasonable since most rural two-lane highways were symmetric with respect to cross section. The relationship between the TMS shoulder type and the HSM shoulder type is shown in Table 4.4. 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.

Table 4.4 List of 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	ARAN , Aerials
Horizontal Curve Length	ARAN
Superelevation Variance	Assume 0 percent
Presence of spirals	Assume spirals not present
Vertical Grade	Assume 0 percent
Driveway Density	ARAN
Presence of Centerline Rumble Strips	ARAN
Presence of Passing Lanes	ARAN
Presence of Two-Way Left Turn Lane	ARAN
Roadside Hazard Rating	ARAN
Presence of Lighting	ARAN
Presence of Automated Speed Enforcement	MoDOT
Number of Crashes	TMS

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	Bituminuous 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

The horizontal curve data were estimated using computer-aided design (CAD) using the procedure outlined in chapter 3. One concern relating 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, since they were homogeneous with respect to horizontal curvature, AADT, and cross section.

The following data were not readily available: superelevation variance, presence of spirals, and grade. Based on discussions with MoDOT, it seemed reasonable to assume that all horizontal curves were designed to the correct superelevation rate. Therefore, a superelevation variance value of zero was assumed. 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 greater than 50 mph, and a curve radius less than 2,865 feet. However, MoDOT indicated that most existing horizontal curves on Missouri highways did not have spirals. Therefore, it was assumed for calibration purposes that all horizontal curves did not have spirals. A grade value of zero percent was also assumed. This value correlated to the level terrain category in the HSM that includes grades between -3 percent and 3 percent. 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 in the HSM for these factors.

Descriptive statistics for the segments are shown in Table 4.6. The average length of the sampled segments was 0.55 miles. The segments ranged in length between 0.04 miles and 7.52 miles, with a median of 0.16 miles. The length standard deviation was 1.12 miles. Many of the segment lengths were less than the 0.5 mile minimum because they were horizontal curves. The minimum length for segments that did not contain horizontal curves was 0.505 miles. 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. Most of the segments had turf shoulders. Two of the segments had centerline rumble strips, and one of the segments had a two-way left turn lane. None of the segments had lighting or automated speed enforcement. The segments with horizontal curves had an average curve radius of 1,706 feet and an average curve length of 0.17 miles. The radii of the curve segments varied between 216 feet and 8,484 feet, with a standard deviation of 1,388 feet. The average number of crashes was 1.5, and ranged between zero and 45 crashes. The standard deviation of crashes was 4.4, which was larger than the average. The total number of crashes for the segments was 302 (100.7 per year), which was greater than the HSM recommended minimum of 100 per year.

Table 4.6 Descriptive statistics for rural two-lane undivided samples (Sample size = 196)

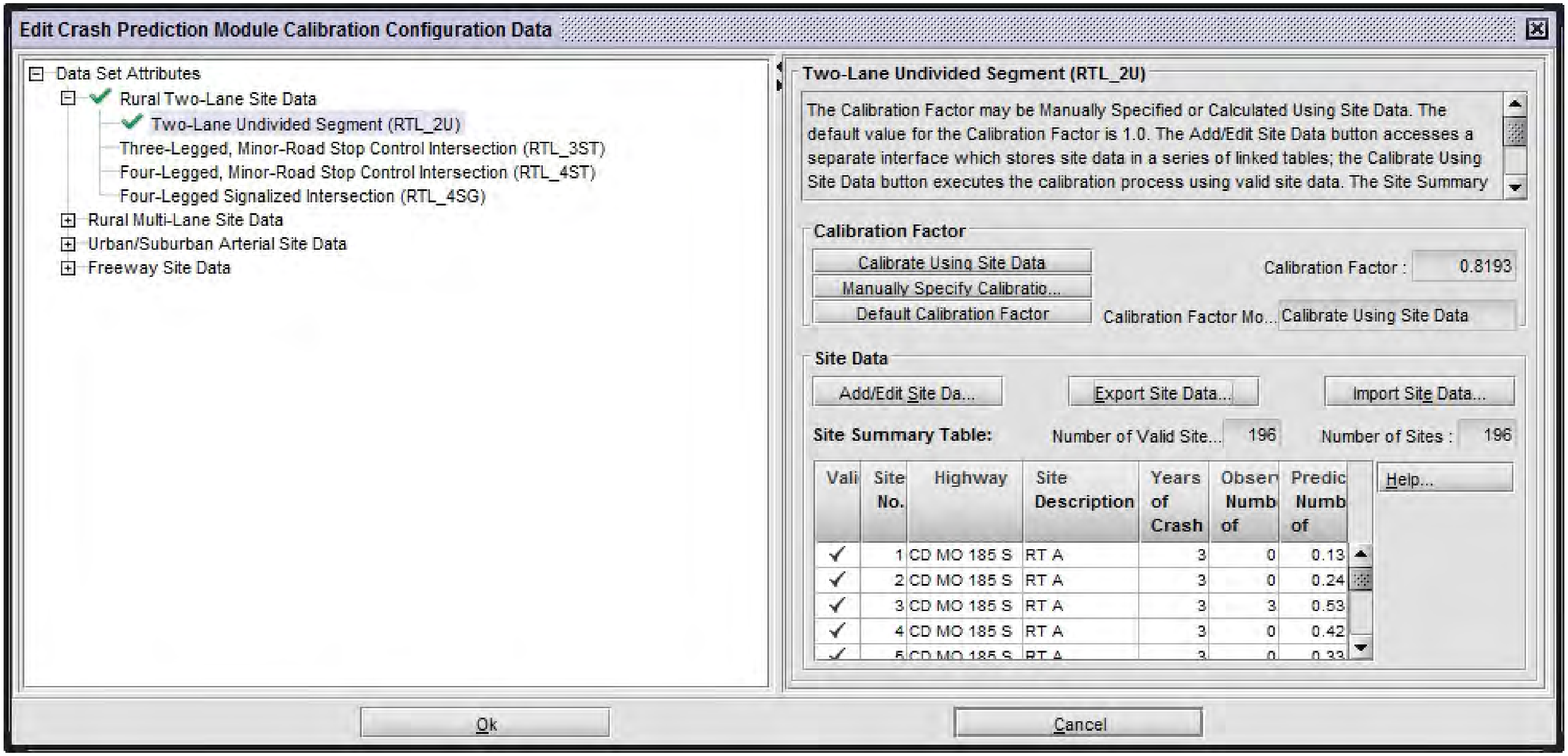
Description	Average	Min.	Max.	Std. Dev.
Length (mi)	0.55	0.04	7.52	1.12
AADT (2011)	2910	271	11360	2187
Lane Width (ft)	11.0	10.0	12.5	0.8
Shoulder Width (ft)	3.8	1.0	10.0	2.4
Driveway Density (per mi)	7.9	1.2	19.4	4.4
Roadside Hazard Rating	4.3	1.0	6.0	1.0
Horizontal Curve Radius (ft)*	1706	216	8483	1388
Horizontal Curve Length (mi)*	0.17	0.04	0.64	0.11
Presence of Spirals	0.0	0.0	0.0	0.0
Superelevation Variance	0.0	0.0	0.0	0.0
Grade	0.0	0.0	0.0	0.0
Number of Crashes (3 Years)	1.5	0.0	45.0	4.4
Description				**No. of Segments**
Shoulder Type = Paved				75
Shoulder Type = Gravel				19
Shoulder Type = Turf				102
Tangent Segments				36
Curve Segments				160
Centerline Rumble Strips				2
Passing Lanes				0
Two-Way Left Turn Lane				1
Lighting				0
Automated Speed Enforcement				0

* Horizontal curve segments only

4.5 Results and Discussion

The original models were obtained using data from two states: Minnesota and Washington. The base models were developed in separate studies by Vogt and Bared et al. (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 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 accident data (1985-1989) for each roadway segment in Minnesota and three years of accident data (1993-1995) for each roadway segment in Washington.

The calibration factor for rural two-lane undivided roadway segments in Missouri yielded a calibration factor value of 0.82. The IHSDM output is shown in Figure 4.1. These results indicated that the number of crashes observed in Missouri was slightly less than the number of crashes predicted by the HSM for this site type.



Vali	Site No.	Highway	Site Description	Years of Crash	Obser Numb of	Predic Numb of
✓	1	CD MO 185 S	RT A	3	0	0.13
✓	2	CD MO 185 S	RT A	3	0	0.24
✓	3	CD MO 185 S	RT A	3	3	0.53
✓	4	CD MO 185 S	RT A	3	0	0.42

Figure 4.1 Calibration output for rural two-lane undivided segments

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 were not common in Missouri. The HSM crash prediction models for this site type applied only to segments with four through lanes. In addition, the models did not include sections of multilane highways that were located within the limits of an interchange.

5.2 HSM Methodology

As described in chapter 11 of the HSM, the SPF for rural multilane divided highway segments predicts the number of total 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 equation:

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

where,

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

$AADT$ = annual average daily traffic (vehicles/day) on roadway segment;

L = length of roadway segment (miles); and

a, b = 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 condition.

Table 5.1 Base conditions for SPF 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

5.3 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. The field DRVD_TRFRNGINFO_YEAR was used to limit the query to 2011 data, since TMS contained AADT data for each year. The AADT data for other years were later obtained 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 provide AADT for 2011 in the query output. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes which 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 through the use of the BEG_DIVIDED_UNDIVIDED and NUMBER_OF_LANES fields.

Table 5.2 Query criteria for rural multilane segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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

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 or interstate, since the HSM predictive method for rural multilane highways did not apply to these facilities. The sample segments were also reviewed in 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 urban. If the value of this field was not urban, 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 for each direction in ARAN, since 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.

A segment was classified as heterogeneous if it contained two types of medians: a traversable median and a median barrier. These segments were subdivided based on median type to ensure that each segment had a homogeneous cross section. Therefore, the final sample for the calibration of rural multilane divided highways consisted of 37 segments. The list of the sample segments is shown in Table 5.3. Kansas City and St. Louis districts each had one more segment than did other districts, because they each contained one segment that was subdivided into two segments due to a change in median type. Thirty segments were US numbered highways, and seven were Missouri numbered highways. No highway contributed more than four segments. The highways with four segments in the sample were MO-13, US-50, and US-61. Segment lengths will be discussed in greater 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. There were 28 counties represented in the samples out of a total of 114 Missouri counties, or, 25%.

Table 5.3 List of samples for rural multilane divided segments

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
1	CD	US 50	W	134.72	136.03	1.31	Cole
2	CD	US 50	E	148.89	151.06	1.85	Cole
3	CD	US 54	W	155.79	157.86	1.74	Camden
4	CD	US 63	S	99.20	100.67	1.02	Boone
5	CD	MO 5	S	226.15	228.38	1.78	Camden
6	KC	US 50	E	29.97	31.51	1.55	Johnson
7	KC	MO 13	N	209.20	212.88	1.57	Ray
8	KC	MO 13	N	210.75	211.89	1.14	Ray
9	KC	MO 7	N	137.51	140.83	2.96	Cass
10	KC	US 65	N	154.46	157.73	3.27	Pettis
11	KC	US 50	W	208.26	209.33	0.63	Johnson
12	NE	US 61	S	34.11	37.69	3.29	Lewis
13	NE	US 61	S	9.06	11.32	2.11	Clark
14	NE	US 24	E	186.59	188.17	1.59	Marion
15	NE	US 61	N	291.25	294.25	3.00	Pike
16	NE	US 63	S	35.71	39.43	3.72	Adair
17	NW	US 59	S	68.72	71.24	2.04	Andrew
18	NW	US 71	N	281.10	283.09	1.99	Nodaway
19	NW	US 59	N	33.37	35.79	2.06	Andrew
20	NW	US 36	W	107.63	109.88	2.24	Linn
21	NW	US 36	E	31.34	32.89	1.55	Dekalb
22	SE	US 67	S	76.92	84.79	7.58	St. Francois
23	SE	US 67	N	27.14	31.90	4.27	Butler
24	SE	US 60	W	197.73	204.42	6.09	Wright

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	SE	US 63	S	291.58	294.84	2.81	Howell
26	SE	US 60	W	185.87	191.35	4.70	Texas
27	SL	MO 21	N	172.60	177.76	4.16	Jefferson
28	SL	US 61	S	130.19	132.90	2.71	St. Charles
29	SL	MO 100	W	44.53	48.28	2.87	Franklin
30	SL	MO 100	W	45.36	46.24	0.88	Franklin
31	SL	US 67	N	129.80	135.12	4.94	Jefferson
32	SL	MO 21	S	21.58	26.30	2.88	Jefferson
33	SW	US 65	S	310.30	313.11	2.81	Taney
34	SW	MO 7	N	119.64	124.34	4.26	Henry
35	SW	MO 13	S	170.86	171.87	1.00	St. Clair
36	SW	US 60	W	230.27	230.83	0.56	Webster
37	SW	MO 13	N	120.89	121.81	0.93	St. Clair

Note: Limits of Segment 8 Excluded from Segment 7.

Limits of Segment 30 Excluded from Segment 29.

5.4 Data Collection

A list of the data types collected for rural multilane divided highways and their sources is shown in Table 5.4. Lane width and outside paved shoulder width were determined separately for each direction. The ARAN viewer was 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 photographs created on the CARES (2013) website or in Google Maps (2013). To be consistent with the HSM methodology, 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. A median width of 30 ft was used for segments with a median barrier, as recommended by the HSM. Segment length was calculated as the average of the segment length in both directions, with interchange limits excluded. A list of automated enforced locations was provided by MoDOT.

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)

Descriptive statistics for the segments are shown in Table 5.5. The average length of the sampled segments was well above the minimum length of 0.5 miles. The segments ranged in length between 0.56 and 7.59 miles, with the average length being 2.60 miles and the median being 2.1 miles. The length standard deviation was 1.57 miles. The volumes averaged 12,719 AADT, with a maximum of 33,571. The segments were relatively uniform with respect to lane and shoulder width, but showed some variation with respect to effective median width. The average number of crashes was 19.3, and ranged between 3.0 and 119.0 crashes. The standard deviation of crashes was 24.6, which was larger than the average. The total number of crashes was 715.0, which easily exceeded the HSM recommended of 100 crashes per year. Most of the segments had traversable medians. None of the segments had lighting or automated speed enforcement.

Table 5.5 Descriptive statistics for rural multilane divided samples (Sample size = 37)

Description	Average	Min.	Max.	Std. Dev.
Length (mi)	2.60	0.56	7.59	1.57
AADT (2011)	12719	5249	33571	6571
Left lane width (ft)	11.9	10.0	12.0	0.5
Right lane width (ft)	12.0	12.0	12.0	0.0
Left outside pvd. shldr. width (ft)	9.6	4.0	10.0	1.2
Right outside pvd. shldr. width (ft)	9.7	6.0	12.0	1.0
Effective median width (ft)	62.7	30.0	250.0	41.0
Number of crashes (3 years)	19.3	3.0	119.0	24.6
Description				**No. of Segments**
Non-traversable median				5
Lighting				0
Automated speed enforcement				0

5.5 Results and Discussion

The original models were developed using data from Texas, California, New York, and Washington. The details of the model development are described in 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. 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 miles in four different states. Even though none of the states were in the Midwest, the dataset was a large national dataset that should reflect national design and behavior.

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

State	Number of Segments	Total Length (mi)	Minimum AADT (vpd)	Maximum AADT (vpd)
Texas	1733	1750	160	90000
California	1087	519	1300	61000
New York	197	139	1082	46717
Washington	35	196	3187	61947

The calibration factor for rural multilane divided highways in Missouri yielded a value of 0.98. The IHSDM output is shown in Figure 5.1. These results indicated close agreement between the number of crashes predicted by the HSM and the number of crashes observed in Missouri for this site type.

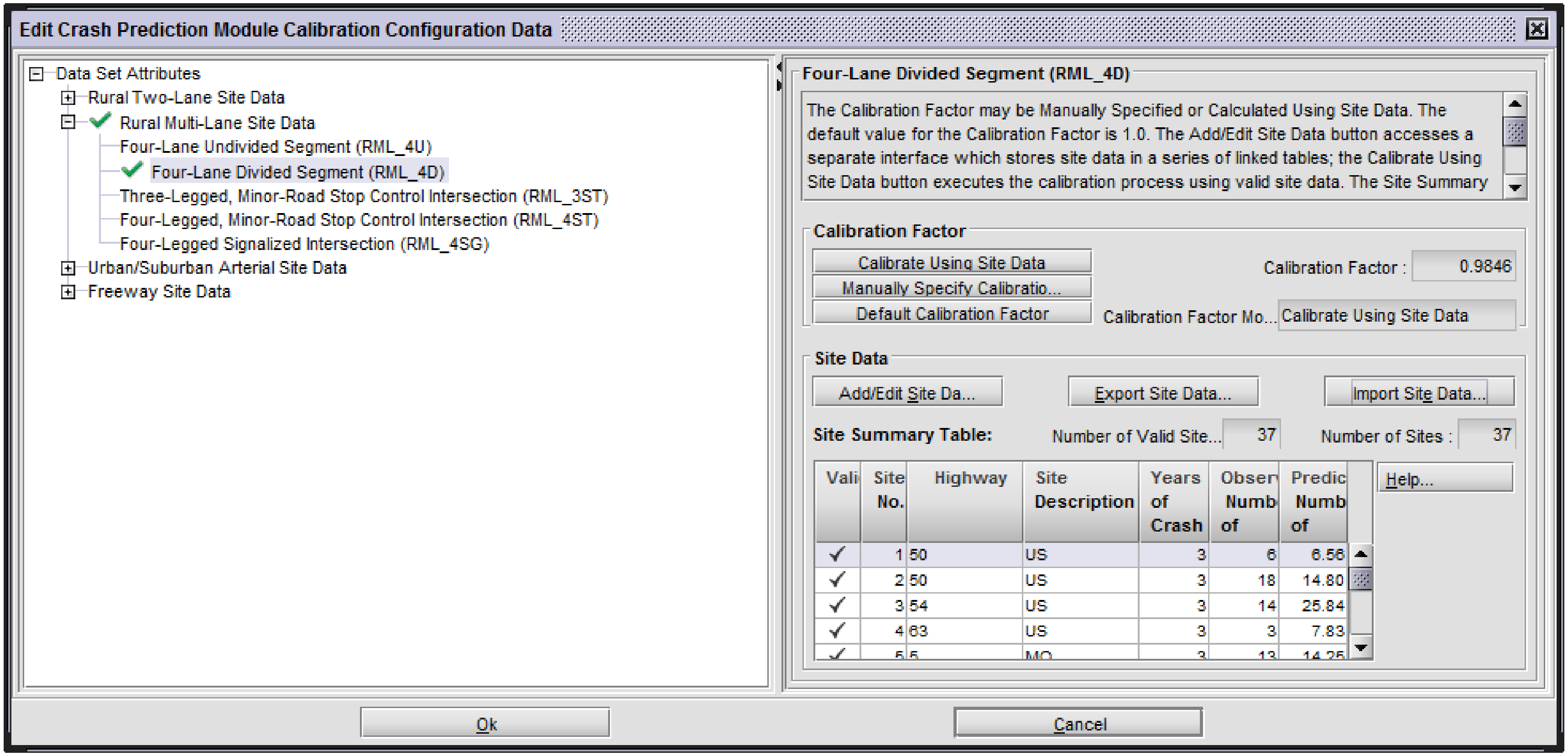


Figure 5.1 Calibration output for rural multilane divided segments

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 only performed for two-lane undivided segments, four-lane divided segments, and five-lane undivided segments with a two-way left turn lane.

6.2 HSM Methodology

As described in chapter 12 of the HSM, the SPFs for urban arterial segments predict the number of total crashes on the segment per year for the base conditions. The SPF is based on the AADT and length of the segment, and is obtained through equations 6.1-6.7 below, with the base conditions listed in Table 6.1:

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

where,

$N_{predicted\ rs}$ = predicted average crash frequency of an individual roadway segment for the selected year;

C_r = calibration factor for roadway segments of a specific type developed for use for a particular geographical area;

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

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

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

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

where,

$N_{spf\ rs}$ = predicted total average crash frequency of an individual roadway segment for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions);

$CMF_{lr} \times \ldots \times CMF_{nr}$ = crash modification factors for roadway segments.

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

where,

N_{brmv} = predicted average crash frequency of multiple-vehicle non-driveway collisions for base conditions;

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

N_{brdwy} = predicted average crash frequency of multiple-vehicle driveway-related collisions.

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

$$N_{brdwy} = \sum_{\substack{all\\driveway\\types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)} \tag{6.5}$$

where,

$a + b$ = regression coefficients;

$AADT$ = annual average daily traffic volume (vehicles/day) on roadway segment;

L = length of roadway segment (mi);

n_j = number of driveways within roadway segment of driveway type j including all driveways on both sides of the road;

N_j = Number of driveway-related collisions per driveway per year for driveway type j;

t = coefficient of traffic volume adjustment.

$$N_{pedr} = N_{br} \times f_{pedr} \tag{6.6}$$

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

where,

f_{pedr} = pedestrian crash adjustment factor;

f_{biker} = bicycle crash adjustment factor.

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

6.3 Sampling Considerations

In order to generate samples for urban arterial segments, a list of all segments for each district and each site type was generated with 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 miles. However, it was not possible to meet this goal for all of the site types due to a lack of a sufficient number of samples. The urban arterial segments were subdivided if the speed limit changed from 30 mph and below to over 30 mph, since the CMF for speed category was based upon these speed limit ranges. The segments were not subdivided based on minor changes in cross section. Urban four-lane divided arterial segments were subdivided based on changes in median type or significant changes in median width. Segments lacking ARAN data were discarded. The specific considerations for each site type are described below.

6.3.1 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. 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 2-LANE. The field DRVD_TRFRNGINFO_YEAR was used to limit the query to 2011 data, since TMS contained AADT data for each year. The AADT data for other years were later obtained 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 provide AADT for 2011 in the query output. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes which 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 through the use of the BEG_DIVIDED_UNDIVIDED and END_DIVIDED_UNDIVIDED fields.

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

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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 2-LANE

Sampling for urban two-lane undivided arterial segments was performed based on the master list generated from the database queries. 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. Ten random samples from each district were generated. Three segments were subdivided due to changes in the speed category within the segment limits. Therefore, the sample set for calibration included 73 sites.

A list of samples for urban two-lane undivided arterial segments is shown in Table 6.3. The samples represent geographic diversity from around the state of Missouri. The sample set included 11 sites from the Central District, 12 sites from the Southwest District, and 10 sites from each of the remaining districts; it also included US highways and Missouri state 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

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
1	CD	RT F	E	9.33	9.59	0.26	Callaway
2	CD	US 40	E	107.52	108.46	0.94	Howard
3	CD	US 40	E	103.57	104.43	0.86	Cooper
4	CD	MO 17	N	136.31	136.86	0.55	Pulaski
5	CD	RT F	E	8.89	9.33	0.44	Callaway
6	CD	MO 5	N	210.76	211.61	0.85	Howard
7	CD	RT B	S	2.20	2.48	0.28	Cooper
8	CD	RT J	E	0.00	0.99	0.99	Dent
9	CD	RT J	E	0.99	1.27	0.28	Dent
10	CD	BU 54	E	4.48	4.86	0.38	Callaway
11	CD	MO 87	S	75.57	75.97	0.40	Miller
12	KC	US 50	E	83.46	84.51	1.05	Pettis
13	KC	MO 41	N	28.12	28.65	0.54	Saline
14	KC	US 65	N	194.14	194.78	0.64	Saline
15	KC	RT O	N	0.27	0.60	0.34	Saline
16	KC	BU 65	S	2.27	2.52	0.25	Saline
17	KC	SP 10	E	0.07	0.60	0.53	Clay
18	KC	RT F	S	2.07	2.49	0.42	Jackson
19	KC	RT N	S	0.54	1.10	0.56	Clay
20	KC	RT F	S	0.83	2.07	1.25	Jackson
21	KC	US 50	E	82.43	83.46	1.03	Pettis
22	NE	MO 15	N	2.38	2.82	0.44	Audrain
23	NE	MO 22	E	23.52	23.86	0.33	Audrain
24	NE	BU 61	N	2.46	4.26	1.80	Pike

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	NE	RT M	E	1.48	1.80	0.32	Randolph
26	NE	BU 61	S	2.01	2.58	0.57	Pike
27	NE	RT J	S	0.63	1.43	0.80	Lincoln
28	NE	BU 63	N	5.29	6.30	1.01	Randolph
29	NE	BU 63	N	8.61	9.59	0.98	Randolph
30	NE	RT P	E	0.24	0.68	0.43	Adair
31	NE	RT B	S	11.69	12.17	0.49	Adair
32	NW	US 69	N	56.72	57.40	0.68	Dekalb
33	NW	RT V	N	0.55	1.12	0.57	Livingston
34	NW	MO 6	E	79.82	80.46	0.64	Grundy
35	NW	US 71	N	294.61	295.06	0.44	Nodaway
36	NW	US 69	S	67.48	67.99	0.51	Clinton
37	NW	MO 46	E	27.11	27.46	0.34	Nodaway
38	NW	US 65	S	34.70	35.73	1.03	Grundy
39	NW	RT V	E	12.53	12.97	0.44	Nodaway
40	NW	RT A	S	1.12	1.64	0.52	Clinton
41	NW	RT V	E	11.75	12.26	0.51	Nodaway
42	SE	RT W	N	3.82	4.25	0.43	Cape Girardeau
43	SE	RT B	S	0.08	0.52	0.44	Perry
44	SE	US 62	E	62.43	63.15	0.72	Scott
45	SE	RT PP	S	0.00	1.03	1.03	Cape Girardeau
46	SE	MO 8	E	70.74	71.16	0.42	St. Francois
47	SE	MO 51	S	15.20	15.54	0.34	Perry
48	SE	RT J	W	0.41	3.28	2.87	Dunklin
49	SE	RT AB	W	4.08	5.73	1.65	Scott
50	SE	MO 114	E	0.48	0.99	0.51	Stoddard

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
51	SE	RT E	E	0.16	2.20	2.04	Dunklin
52	SL	RT E	S	0.13	0.66	0.53	Jefferson
53	SL	RT E	S	0.66	1.52	0.86	Jefferson
54	SL	MO 47	N	48.84	49.50	0.66	Franklin
55	SL	MO 47	N	62.55	63.34	0.80	Franklin
56	SL	MO 185	N	37.12	37.50	0.37	Franklin
57	SL	RT NN	N	0.05	0.53	0.47	Jefferson
58	SL	MO 110	E	1.35	1.87	0.52	Jefferson
59	SL	MO 47	S	65.02	66.65	1.64	Franklin
60	SL	MO 30	E	0.00	0.32	0.32	Franklin
61	SL	MO 185	S	29.05	30.67	1.63	Franklin
62	SW	RT BB	S	0.00	1.61	1.61	Taney
63	SW	RT BB	S	1.61	2.41	0.81	Taney
64	SW	RT K	N	0.85	2.11	1.26	Lawrence
65	SW	US 160	W	177.11	179.37	2.26	Taney
66	SW	US 160	W	176.01	177.11	1.10	Taney
67	SW	BU 60	E	4.48	4.98	0.50	Lawrence
68	SW	RT CC	S	17.24	17.49	0.25	Webster
69	SW	MO 38	E	25.01	28.87	3.86	Webster
70	SW	BU 13	S	0.12	1.10	0.98	Henry
71	SW	RT BB	S	0.08	0.90	0.82	Vernon
72	SW	RT BB	S	0.90	1.55	0.65	Vernon
73	SW	MO 96	E	15.02	15.81	0.79	Jasper

6.3.2 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. These criteria were similar to the criteria used for urban two-lane undivided segments, with a small number of differences. The query utilized the BEG_DIVIDED_UNDIVIDED field to obtain segments that were classified as DIVIDED. The query also excluded interstate segments through the use of the field BEG_FUNCTIONAL CLASS.

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

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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

Sampling was performed from the master list generated from the database queries. 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 a 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 median cable barrier. The sample set for calibration included 66 sites.

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

- 4 samples from the Central District,
- 7 samples from the Kansas City District,
- 13 samples from the Northeast District,
- 2 samples from the Northwest District,
- 28 samples from the Southeast District,
- 3 samples from the Saint Louis District, and
- 9 samples from the Southwest District.

The sample set included arterial segments that represented geographic diversity from around the state of Missouri, although approximately one-third of the samples were from the Southeast District. The sample set included segments from 24 counties in Missouri, including large counties such as Jefferson and small counties such as Clinton. The majority of the segments were on US highways, while the remaining segments were on Missouri 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 (mi)	County
1	CD	LP 44	E	7.40	8.00	0.61	Pulaski
2	CD	LP 44	E	8.00	8.62	0.62	Pulaski
3	CD	LP 44	W	1.59	1.95	0.36	Pulaski
4	CD	US 54	E	140.00	141.10	1.10	Miller
5	KC	MO 7	N	146.16	146.41	0.25	Cass
6	KC	MO 7	S	40.61	42.78	2.17	Cass
7	KC	US 65	S	122.98	123.93	0.95	Saline
8	KC	MO 13	S	73.95	75.58	1.63	Ray
9	KC	US 50	E	61.32	62.55	1.23	Johnson
10	KC	US 50	W	201.95	202.21	0.26	Johnson
11	KC	US 69	S	97.44	98.59	1.15	Clay
12	NE	US 61	S	56.82	59.61	2.79	Marion
13	NE	US 61	S	61.41	63.03	1.63	Marion
14	NE	US 61	S	63.03	64.18	1.15	Marion
15	NE	US 61	S	88.81	89.19	0.38	Pike
16	NE	US 61	S	90.03	91.55	1.52	Pike
17	NE	US 61	S	121.71	124.53	2.82	Lincoln
18	NE	US 61	S	125.31	127.27	1.96	Lincoln
19	NE	US 63	N	252.15	253.76	1.61	Randolph
20	NE	US 63	N	255.02	255.66	0.64	Randolph
21	NE	US 36	E	130.52	130.99	0.47	Macon
22	NE	US 36	E	131.02	132.98	1.96	Macon
23	NE	US 36	W	62.68	63.30	0.62	Macon
24	NE	US 36	W	63.30	64.18	0.88	Macon

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	NW	US 36	E	71.99	72.41	0.42	Livingston
26	NW	US 36	E	72.46	73.46	1.00	Livingston
27	SE	US 61	S	284.45	284.93	0.48	Cape Girardeau
28	SE	US 61	S	284.93	286.17	1.24	Cape Girardeau
29	SE	US 67	N	99.34	100.13	0.79	St. Francois
30	SE	US 67	N	100.86	101.25	0.39	St. Francois
31	SE	US 67	N	102.41	105.65	3.24	St. Francois
32	SE	US 67	N	106.29	107.51	1.22	St. Francois
33	SE	US 67	N	108.17	108.99	0.82	St. Francois
34	SE	US 67	N	109.59	111.65	2.06	St. Francois
35	SE	US 67	N	113.16	113.75	0.59	St. Francois
36	SE	MO 25	S	47.64	48.30	0.66	Stoddard
37	SE	MO 25	S	49.02	49.42	0.40	Stoddard
38	SE	MO 25	N	43.52	47.54	4.02	Stoddard
39	SE	MO 34	E	90.82	91.14	0.32	Cape Girardeau
40	SE	MO 34	E	91.14	91.63	0.49	Cape Girardeau
41	SE	MO 34	E	101.25	102.33	1.08	Cape Girardeau
42	SE	MO 34	E	102.33	102.85	0.52	Cape Girardeau
43	SE	MO 74	E	7.36	8.30	0.95	Cape Girardeau
44	SE	MO 32	E	247.07	248.02	0.95	St. Francois
45	SE	MO 32	E	248.75	249.83	1.08	St. Francois
46	SE	MO 32	E	254.35	254.68	0.33	St. Francois
47	SE	US 412	W	26.26	26.59	0.33	Dunklin
48	SE	US 61	N	101.25	102.28	1.03	Cape Girardeau
49	SE	US 60	E	290.88	291.80	0.91	Stoddard
50	SE	US 60	E	292.41	293.39	0.98	Stoddard

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
51	SE	US 60	E	314.26	316.05	1.80	New Madrid
52	SE	US 60	E	316.05	316.54	0.49	New Madrid
53	SE	MO 74	W	2.26	3.10	0.84	Cape Girardeau
54	SE	BU 67	S	4.58	5.11	0.53	Butler
55	SL	MO 30	E	20.82	21.85	1.03	Jefferson
56	SL	MO 30	E	21.85	24.49	2.64	Jefferson
57	SL	MO 30	W	31.90	32.29	0.39	Jefferson
58	SW	US 65	S	301.06	301.53	0.47	Taney
59	SW	MO 13	S	148.00	149.03	1.03	Henry
60	SW	RT D	E	0.00	1.48	1.48	Newton
61	SW	MO 59	S	19.59	19.97	0.37	Newton
62	SW	MO 59	S	19.97	20.85	0.88	Newton
63	SW	MO 59	S	20.85	22.61	1.76	Newton
64	SW	BU 60	E	0.33	0.63	0.30	Newton
65	SW	US 60	E	73.33	74.11	0.78	Greene
66	SW	US 60	E	75.58	77.49	1.91	Greene

6.3.3 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. These criteria were similar to the criteria used for urban two-lane undivided segments, with a couple of 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.

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

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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

The master list from the database queries 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 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 with two-way left-turn lanes is shown in Table 6.7. The samples were distributed among the seven MoDOT districts as follows:

- 12 samples from the Central District,
- 10 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 Saint Louis District, and
- 10 samples from the Southwest District.

The samples were representative of geographic diversity from around the state of Missouri. The sample set included segments from 21 counties in Missouri, including large counties such as Franklin and small counties such as Livingston. US highways and Missouri state 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	Length (mi)	County
1	CD	US 63	N	123.09	124.47	1.39	Phelps
2	CD	MO 72	E	0.08	0.59	0.50	Phelps
3	CD	MO 72	E	0.59	1.75	1.16	Phelps
4	CD	MO 72	E	1.75	2.34	0.59	Phelps
5	CD	MO 5	S	248.33	249.08	0.75	Laclede
6	CD	MO 5	S	249.08	249.56	0.48	Laclede
7	CD	MO 5	S	249.56	250.03	0.47	Laclede
8	CD	MO 5	S	250.56	250.97	0.41	Laclede
9	CD	MO 5	S	250.97	251.51	0.54	Laclede
10	CD	MO 5	S	251.85	252.16	0.32	Laclede
11	CD	LP 44	E	0.29	1.17	0.88	Laclede
12	CD	LP 44	E	1.17	1.88	0.70	Laclede
13	KC	US 65	S	149.85	150.11	0.26	Pettis
14	KC	US 65	S	150.27	151.21	0.94	Pettis
15	KC	US 65	S	151.21	152.11	0.90	Pettis
16	KC	US 50	E	77.76	78.20	0.44	Pettis
17	KC	US 50	E	78.44	78.81	0.37	Pettis
18	KC	US 50	E	79.03	79.53	0.50	Pettis
19	KC	US 50	E	79.53	79.79	0.25	Pettis
20	KC	US 50	E	79.79	80.22	0.44	Pettis
21	KC	US 50	E	81.38	82.01	0.63	Pettis
22	KC	MO 291	N	0.23	0.67	0.43	Cass
23	NW	US 65	S	55.50	56.69	1.18	Livingston
24	NW	US 65	S	56.69	57.32	0.63	Livingston

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	NW	US 65	S	57.68	58.16	0.48	Livingston
26	NW	US 65	S	58.75	59.02	0.28	Livingston
27	NW	US 65	S	59.02	59.72	0.70	Livingston
28	NW	US 69	N	55.80	56.08	0.29	Dekalb
29	SE	US 63	N	30.34	30.92	0.58	Howell
30	SE	US 63	N	30.93	33.15	2.23	Howell
31	SE	RT K	E	5.64	6.13	0.49	Cape Girardeau
32	SE	BU 60	W	5.45	5.71	0.26	Butler
33	SE	BU 60	W	5.71	7.06	1.36	Butler
34	SE	BU 60	W	7.06	7.47	0.40	Butler
35	SE	MO 32	E	254.81	255.24	0.43	St. Francois
36	SE	MO 32	E	255.43	256.01	0.58	St. Francois
37	SE	MO 32	E	256.01	256.26	0.25	St. Francois
38	SE	MO 32	E	256.26	256.56	0.30	St. Francois
39	SL	MO 47	S	56.98	57.39	0.41	Franklin
40	SL	MO 47	S	57.39	57.87	0.48	Franklin
41	SL	MO 47	S	70.62	71.10	0.48	Franklin
42	SL	US 50	E	216.02	217.00	0.98	Franklin
43	SL	US 50	E	217.00	217.36	0.36	Franklin
44	SW	MO 7	N	107.24	107.49	0.26	Henry
45	SW	MO 7	N	110.22	111.01	0.79	Henry
46	SW	MO 96	E	13.43	13.68	0.25	Jasper
47	SW	US 54	E	14.07	14.59	0.52	Vernon
48	SW	MO 376	W	0.00	1.00	1.00	Taney
49	SW	MO 86	W	91.44	92.95	1.51	Newton
50	SW	MO 248	E	53.90	55.56	1.66	Taney

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
51	SW	BU 65	S	3.31	3.74	0.44	Taney
52	SW	BU 71	S	1.84	2.52	0.69	Vernon
53	SW	US 60	E	71.88	73.16	1.27	Greene
54	NE	US 61	S	60.77	61.03	0.26	Marion
55	NE	MO 47	S	13.74	14.00	0.25	Lincoln
56	NE	MO 47	S	14.10	14.55	0.45	Lincoln
57	NE	MO 47	S	33.61	34.11	0.50	Warren
58	NE	BU 63	N	7.51	8.34	0.83	Randolph
59	NE	US 24	E	135.94	136.28	0.33	Randolph

6.4 Data Collection

A list of the data types collected for urban arterial segments and their sources is shown in Table 6.8. The number of driveways of each type was counted. The HSM defines major driveways as having 50 or more parking spaces. The driveways were classified to be consistent with the HSM definition, based on engineering judgment, by viewing ARAN and aerial photographs. The number of fixed objects and offset for the fixed objects were estimated visually from ARAN. It should be noted that the HSM defines fixed objects as objects that are four inches or greater in diameter and not breakaway. According to MoDOT standard plans (MoDOT a, b 2011), the lighting transformer base should be breakaway. Therefore, light poles were not counted as fixed objects. Even though the HSM definition for a fixed object differed from that of STARS (MSC 2012; MTRC 2002), this did not affect the calibration, since accident type (e.g., fixed object collision) was not involved in the calibration process. STARS treats street light supports as fixed objects in classifying accident types. The type of land use, type of parking, and proportion of curb length with parking were determined separately for each side of the roadway using ARAN. In many cases, the road segments did not contain parking. Because IHSDM requires a value to be set for the type of parking, type of parking was classified as parallel if there was no parking on the segment. This assumption did not affect the results, since 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. The speed limit values were verified visually using ARAN. ARAN was also used to determine whether lighting was present on the segment. MoDOT provided information regarding locations with automated speed enforcement.

Table 6.8 List of data sources for urban arterial segments

Data Description	Source
AADT	State of the System (TMS)
Lane Width	State of the System (TMS)
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/ARAN
Offset to Fixed Objects	ARAN
Fixed Object Density	ARAN
Presence of Lighting	ARAN
Presence of Automated Speed Enforcement	MoDOT
Number of Crashes	TMS

6.4.1 Summary Statistics for Urban Two-Lane Undivided Arterial Segments

Descriptive statistics for urban two-lane undivided arterial segments are shown in Table 6.9. The average AADT was 5,585 vpd, and the standard deviation was 5,377 vpd. Thus, the sample set contained a wide range of AADT values. The average segment length was 0.81 miles, which was greater than the minimum segment length of 0.25 miles. 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 the segments was not common. The average offset to fixed objects was 10.8 feet, and the average fixed object density was 57.9 fixed objects per mile. The standard deviation of the fixed object density was 42.0 fixed objects per mile, indicating the segments had a wide variation in fixed object density. Residential land use was slightly more predominant than commercial land use. Approximately half of the segments had lighting. None of the segments had automated speed enforcement. Only eight of the segments fell under the low speed category. The average number of crashes was 3.5. The standard deviation for the number of crashes was 6.1, indicating that the number of crashes on these segments varied considerably. The total number of crashes on these segments from 2009 to 2011 was 259 (86.33 per year), which was slightly less than the value of 100 crashes per year recommended by the HSM.

Table 6.9 Sample descriptive statistics for urban two-lane undivided arterial segments (Sample size = 73)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	5585	584	40686	5377
Length	0.81	0.25	3.86	0.62
No. of Major Commercial Driveways	0.1	0.0	3.0	0.5
No. of Minor Commercial Driveways	5.5	0.0	70.0	10.0
No. of Major Industrial/Institutional Driveways	0.2	0.0	2.0	0.4
No. of Minor Industrial/Institutional Driveways	2.6	0.0	20.0	4.2
No. of Major Residential Driveways	0.0	0.0	1.0	0.1
No. of Minor Residential Driveways	8.4	0.0	60.0	11.9
No. of Other Driveways	1.2	0.0	6.0	1.5
Proportion of Right Curb Length with Parking	0.01	0.00	0.30	0.04
Proportion of Left Curb Length with Parking	0.01	0.00	0.30	0.04
Offset to Fixed Objects (ft)	10.8	0.0	20.0	3.8
Fixed Object Density (per mi)	57.9	0.0	248.1	42.0
No. of Crashes (3 Years)	3.5	0.0	34.0	6.1
Description				**No. of Segments**
Speed Category = Low				8
Parking Type (Right) = Parallel				72
Parking Type (Left) = Parallel				73
Land Use (Right) = Residential				45
Land Use (Left) = Residential				42
Presence of Lighting				38
Presence of Automated Speed Enforcement				0

6.4.2 Summary Statistics for Urban Four-Lane Divided Arterial Segments

Descriptive statistics for urban four-lane divided arterial segments are shown in Table 6.10. The average AADT was 13,979 vpd, meaning the average urban four-lane AADT was around two-and-a-half times that of the urban two-lane. The standard deviation was 6,487 vpd. Thus, the sample set contained a wide range of AADT values. The average segment length was 1.06 miles, which was greater than the minimum segment length of 0.25 miles. 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 27.9 feet, and the average fixed object density was 21.5 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 18.4 fixed objects per mile, indicating the segments displayed a wide variation in fixed object density. Like two-lane segments, residential land use was slightly more predominant 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 8.6. The standard deviation for the number of crashes was 8.0, indicating that the number of crashes on these segments varied considerably. The total number of crashes on these segments from 2009 to 2011 was 567 (189 per year), which was greater than the 100 crashes per year recommended by the HSM.

Table 6.10 Sample descriptive statistics for urban four-leg divided arterial segments (Sample size = 66)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	13979	5184	32665	6847
Length	1.06	0.25	4.04	0.75
No. of Major Commercial Driveways	0.2	0.0	6.0	0.9
No. of Minor Commercial Driveways	2.1	0.0	24.0	4.9
No. of Major Industrial/Institutional Driveways	0.1	0.0	4.0	0.6
No. of Minor Industrial/Institutional Driveways	0.4	0.0	7.0	1.3
No. of Major Residential Driveways	0.0	0.0	0.0	0.0
No. of Minor Residential Driveways	0.9	0.0	11.0	2.3
No. of Other Driveways	0.5	0.0	9.0	1.5
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)	27.9	0.0	60.0	15.7
Fixed Object Density (per mi)	21.5	0.0	96.2	18.4
No. of Crashes (3 Years)	8.6	0.0	29.0	8.0
Description				**No. of Segments**
Speed Category = Low				0
Parking Type (Right) = Parallel				36
Parking Type (Left) = Parallel				34
Land Use (Right) = Residential				0
Land Use (Left) = Residential				0
Presence of Lighting				12
Presence of Automated Speed Enforcement				0

6.4.3 Summary Statistics for Urban Five-Lane Undivided Arterial Segments

Descriptive statistics for urban five-lane undivided arterial segments are shown in Table 6.11. The average AADT was 15,899 vpd, slightly higher than that of four-lane segments, and the standard deviation was 5,565 vpd. The average segment length was 0.64 miles, which was greater than the minimum segment length of 0.25 miles. 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 17.5 feet, and the average fixed object density was 43.8 fixed objects per mile. Commercial land use was more predominant than residential land use. Approximately half of the segments had lighting. Only seven of the segments fell into the low speed category. The average number of crashes was 12.7, which was higher than two-lane and four-lane segments. The standard deviation for the number of crashes was 20.3, indicating that the number of crashes on these segments varied considerably. The total number of crashes on these segments from 2009 to 2011 was 752 (250 per year), which was greater than the 100 crashes per year recommended by the HSM.

Table 6.11 Sample descriptive statistics for urban five-lane undivided arterial segments (Sample size = 59)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	15899	4300	28672	5565
Length (mi)	0.64	0.25	2.23	0.40
No. of Major Commercial Driveways	2.7	0.0	22.0	3.8
No. of Minor Commercial Driveways	11.2	0.0	40.0	9.6
No. of Major Industrial/Institutional Driveways	0.3	0.0	3.0	0.6
No. of Minor Industrial/Institutional Driveways	2.1	0.0	19.0	3.7
No. of Major Residential Driveways	0.2	0.0	8.0	1.1
No. of Minor Residential Driveways	4.2	0.0	31.0	7.1
No. of Other Driveways	0.0	0.0	1.0	0.2
Proportion of Right Side Curb Length with Parking	0.00	0.00	0.00	0.00
Proportion of Left Side Curb Length with Parking	0.00	0.00	0.00	0.00
Offset to Fixed Objects (ft)	17.5	5.0	50.0	11.9
Fixed Object Density (per mi)	43.8	2.0	109.4	23.0
No. of Crashes (3 Years)	12.7	0.0	122.0	20.3
Description				**No. of Segments**
Speed Category = Low				7
Parking Type (Right) = Parallel				59
Parking Type (Left) = Parallel				59
Land Use (Right) = Residential				14
Land Use (Left) = Residential				17
Presence of Lighting				25
Presence of Automated Speed Enforcement				0

6.5 Results and Discussion

The original models were obtained 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. The details of the methodology are described in further detail in 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, ranging in length from 0.04 to 1.42 mi. The total length of all blocks was 553.3 mi: 303.9 mi in Minnesota with an average block length of 0.12 mi, and 294.4 mi in Michigan with an average block length of 0.14 mi. Most of the data collected from Minnesota were located in the Twin Cities metropolitan area, while the data collected in Michigan were primarily from Oakland County, Michigan. Even though these states were 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 with minimal variation.

6.5.1 Results for Urban Two-Lane Undivided Arterial Segments

The calibration factor for urban two-lane undivided arterial segments in Missouri yielded a value of 0.84. The IHSDM output is shown in Figure 6.1. These results indicate that the number of crashes observed in Missouri was slightly less than the number of crashes predicted by the HSM for this site type.

6.5.2 Results for Urban Four-Lane Divided Arterial Segments

The calibration factor for urban four-lane divided arterial segments in Missouri yielded a calibration factor value of 0.98. The IHSDM output is shown in Figure 6.2. These results indicate that the number of crashes observed in Missouri was consistent with the number of crashes predicted by the HSM for this site type.

6.5.3 Results for Urban Five-Lane Undivided Arterial Segments

Urban five-lane undivided arterial segments in Missouri yielded a calibration factor value of 0.73. The IHSDM output is shown in Figure 6.3. These results indicate that the number of crashes observed in Missouri was less than the number of crashes predicted by the HSM for this site type.

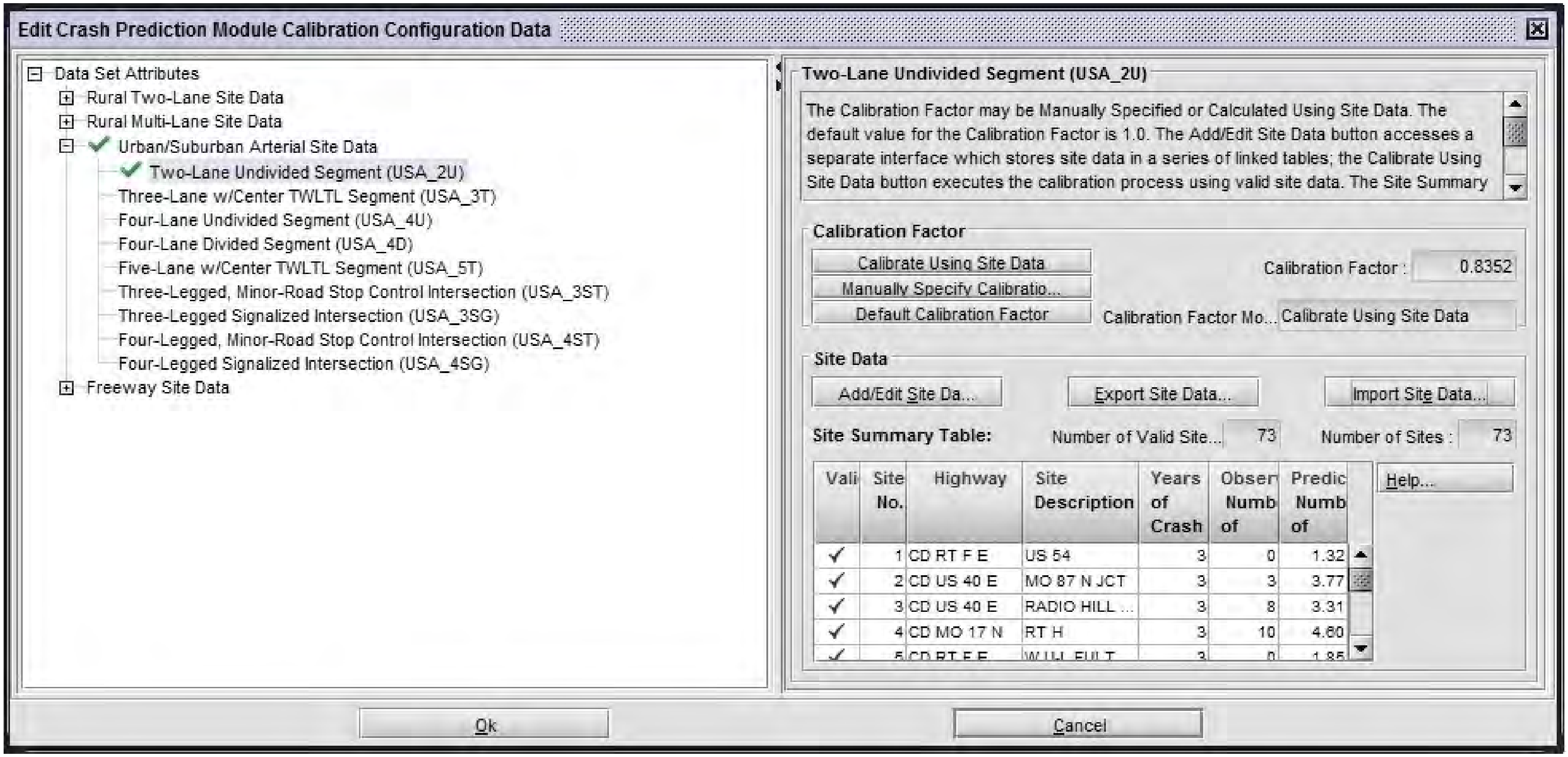


Figure 6.1 Calibration output for urban two-lane undivided arterial segments

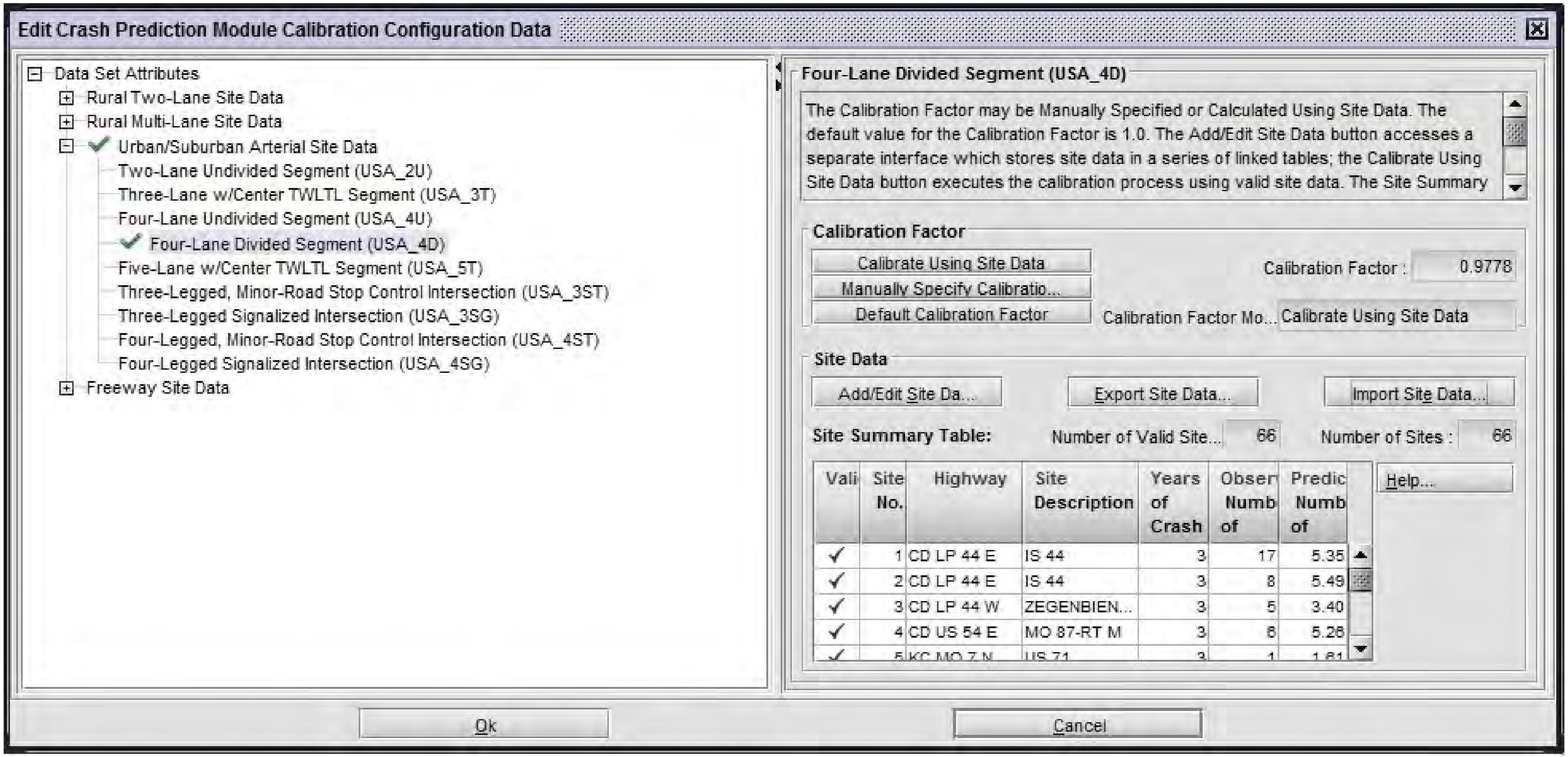


Figure 6.2 Calibration output for urban four-lane divided arterial segments

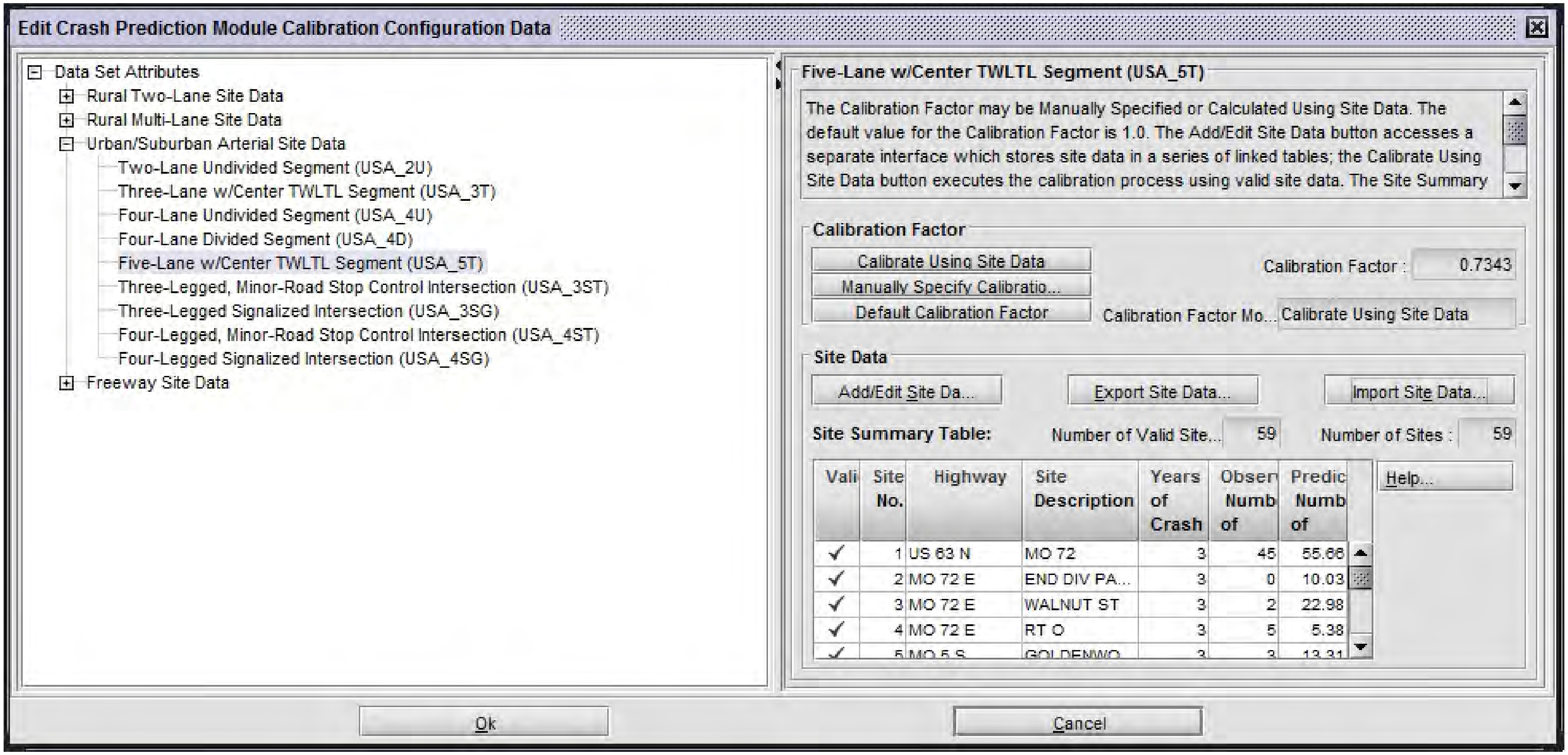


Figure 6.3 Calibration output for urban five-lane undivided arterial segments

Chapter 7 Freeway Segments

7.1 Introduction and Scope

The methodology for crash prediction on freeway segments is, currently, not officially part of the HSM. However, appendix C of the HSM contains the proposed HSM chapter for the predictive method for freeways. Changes to the methodology for crash prediction before this chapter is officially published are not anticipated. Appendix C of the HSM describes the methodology for a variety of freeway segment types, including four-lane divided freeways, six-lane divided freeways, eight-lane divided freeways, and 10-lane divided freeways (urban only). Separate SPFs have been developed for freeway segments in rural areas and freeway segments in urban areas. Because some of these freeway segment types were not common in Missouri, the calibration of freeway segments in this project was performed only for four-lane rural freeway segments, four-lane urban freeway segments, and six-lane freeway segments.

7.2 HSM Methodology

As described in appendix C of 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. The SPFs for freeway segments include four models: property damage only single-vehicle (PDO SV) crashes, property damage only multi-vehicle (PDO MV) crashes, fatal and injury single-vehicle (FI SV) crashes, and fatal and injury multi-vehicle (FI MV) 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 7.1.

$$N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left(CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z}\right) \times C_{w,x,y,z} \quad (7.1)$$

where,

$N_{p, w, x, y, z}$ = 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/yr);

$N_{spf, w, x, y, z}$ = 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);

$CMF_{m, w, x, y, z}$ = crash modification factors 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*; and

$C_{w, x y, z}$ = 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 7.2.

$$N_{p,\ fs,n,at,as} = N_{p,\ fs,n,mv,\ fi} + N_{p,\ fs,n,sv,\ fi} + N_{p,\ fs,n,mv,\ pdo} + N_{p,\ fs,n,sv,\ pdo} \tag{7.2}$$

where,

$N_{p,\ fs,\ n,\ y,\ z}$ = predicted average crash frequency of a freeway segment with *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, *as*: all severities) (crashes/year);

$N_{spf,\ fs,\ n,\ y,\ z}$ = 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).

A general form of each SPF model is given by equation 7.3. 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 7.2.

$$N_{spf,\,fs,n,mv,z} = L^{*} \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{7.3}$$

where,

$N_{spf,\,fs,\,n,\,mv,\,z}$ = 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/yr);

L^{*} = effective length of freeway segment (mi);

$AADT_{fs}$ = AADT volume of freeway segment (veh/day); and

a, *b*, *c* = regression coefficients.

Table 7.1 Base conditions for multi-vehicle (MV) and single-vehicle (SV) 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 > 1000veh/h	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

7.3 Sampling Considerations

In order to generate samples for the freeway segments, the lists of all segments for each district and each site type were generated with TMS database queries. The criteria used for the queries are shown in Table 7.2. The query utilized the BEG_FUNCTIONAL_CLASS field in the TMS Table TMS_TRF_INFO_SEGMENT_VW to obtain segments that were classified as either freeways or interstates. The field DRVD_TRFRNGINFO_YEAR was used to limit the query to 2011 data, since TMS contained AADT data for each year. The AADT data for other years were later obtained 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 provide AADT for 2011 in the query output. The BEG_OVERLAPPING_INDICATOR field was used to exclude secondary routes which overlapped with primary routes.

Table 7.2 Query criteria for freeway segments

Table	Field	Criteria
TMS_TRF_INFO_SEGMENT_VW	DRVD_TRFRNGINFO_YEAR	2011
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_FUNCTIONAL_CLASS	FREEWAY or INTERSTATE

The master lists generated from the database queries were used for the sampling. Duplicate segments were filtered out using a spreadsheet. The segments were separated into urban and rural samples, and were filtered based on a minimum length of 0.5 miles. During the sampling process, an attempt was made to obtain 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 Saint Louis District and Kansas City District. The freeway segments were subdivided for significant changes in cross section, such as a change in median width or median type. The segments were also subdivided if additional ramps were encountered on the segment, since the HSM methodology allows for a maximum of one entrance ramp and one exit ramp on the segment. Specific considerations for each freeway segment type are described below.

7.3.1 Sampling for Rural Four-Lane Freeway Segments

There was a sufficient number of samples to obtain five samples per district. Nine of the segments were subdivided into two or more segments due to changes in median width, changes in median type, or the presence of additional ramps on the segment. Therefore, the sample set for calibration included 47 sites.

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

- 7 samples from the Central District,
- 5 samples from the Kansas City District,
- 11 samples from the Northeast District,
- 5 samples from the Northwest District,
- 7 samples from the Southeast District,
- 7 samples from the Saint Louis District,
- and 5 samples from the Southwest District.

The samples were representative of geographic diversity from around the state of Missouri. The sample set consisted mostly of interstate highways, except for one segment from MO 171 and two segments on US 71 in the Southwest District. One of the US 71 segments was coincident with I-49. Most of the major interstate highways, including I-29, I-35, I-44, I-55, I-70, and I-229, were represented in the sample set. The sample set included freeway segments from 24 counties in Missouri, as well as segments from large counties like Jackson and small counties like Harrison.

Table 7.3 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	189.75	195.62	5.87	Phelps
2	CD	IS 44	E	214.26	218.50	4.24	Crawford
3	CD	IS 44	E	163.84	166.77	2.93	Pulaski
4	CD	IS 44	E	168.01	169.09	1.09	Pulaski
5	CD	IS 70	E	98.01	101.02	3.01	Cooper
6	CD	IS 44	E	118.03	123.01	4.98	Laclede
7	CD	IS 44	E	123.01	126.07	3.06	Laclede
8	KC	IS 35	N	27.23	33.38	6.15	Clay
9	KC	IS 29	N	34.63	40.37	5.74	Platte
10	KC	IS 70	E	71.39	74.61	3.22	Saline
11	KC	IS 70	E	28.68	31.44	2.76	Jackson
12	KC	IS 70	E	49.39	52.84	3.45	Lafayette
13	NE	IS 70	E	188.46	192.96	4.51	Warren
14	NE	IS 70	E	192.96	193.50	0.53	Warren
15	NE	IS 70	E	183.79	188.46	4.67	Montgomery
16	NE	IS 70	E	195.65	198.15	2.51	Warren
17	NE	IS 70	E	198.15	198.96	0.81	Warren
18	NE	IS 70	E	198.96	199.62	0.66	Warren
19	NE	IS 70	E	199.62	200.01	0.39	Warren
20	NE	IS 70	E	179.81	180.79	0.98	Montgomery
21	NE	IS 70	E	180.79	181.75	0.96	Montgomery
22	NE	IS 70	E	181.75	183.79	2.04	Montgomery
23	NE	IS 70	E	170.38	174.98	4.60	Montgomery
24	NW	IS 29	S	88.38	94.13	5.75	Buchanan

Site ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	NW	IS 35	N	65.24	68.89	3.65	Daviess
26	NW	IS 35	N	78.31	80.66	2.35	Daviess
27	NW	IS 229	S	0.27	3.69	3.42	Andrew
28	NW	IS 35	N	100.07	106.56	6.50	Harrison
29	SE	IS 55	N	162.12	165.04	2.91	Ste. Genevieve
30	SE	IS 155	S	6.77	8.00	1.23	Pemiscot
31	SE	IS 155	S	8.00	9.28	1.28	Pemiscot
32	SE	IS 155	S	9.28	10.72	1.44	Pemiscot
33	SE	IS 55	N	14.49	17.67	3.18	Pemiscot
34	SE	IS 55	N	17.79	19.08	1.29	Pemiscot
35	SE	IS 55	N	0.00	1.13	1.13	Pemiscot
36	SL	IS 55	S	38.77	44.83	6.06	Jefferson
37	SL	IS 44	E	227.41	230.25	2.83	Franklin
38	SL	IS 44	E	230.25	234.44	4.19	Franklin
39	SL	IS 44	E	234.44	236.10	1.66	Franklin
40	SL	IS 44	E	236.10	237.75	1.65	Franklin
41	SL	IS 44	W	67.75	71.73	3.98	Franklin
42	SL	IS 55	N	171.09	174.60	3.58	Jefferson
43	SW	IS 44	E	70.17	72.48	2.31	Greene
44	SW	MO 171	N	1.44	3.53	2.09	Jasper
45	SW	US 71	S	214.00	217.66	3.66	Vernon
46	SW	US 71	N	20.91	24.44	3.53	Mcdonald
47	SW	IS 44	E	58.80	61.97	3.17	Lawrence

7.3.2 Sampling for Urban Four-Lane Freeway Segments

There was a sufficient number of samples to obtain five samples per district. Four of the segments were subdivided into two or more segments due to changes in median width, changes in median type, or the presence of additional ramps on the segment. Therefore, the sample set for calibration included 39 sites.

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

- 5 samples from the Central District,
- 6 samples from the Kansas City District,
- 6 samples from the Northeast District,
- 6 samples from the Northwest District,
- 5 samples from the Southeast District,
- 6 samples from the Saint Louis District,
- and 5 samples from the Southwest District.

The samples were representative of geographic diversity from around the state of Missouri. The sample set consisted mostly of interstate highways, although US highways such as US 36, US 54, US 60, US 65, and US 71 were also represented in the sample set. Five of the US 71 segments were coincident with I-49. Most of the major interstate highways, including I-29, I-44, I-55, I-70, I-72, I-229, and I-435, were represented in the sample set. The sample set included freeway segments from 18 counties in Missouri, as well as segments from large counties such as St. Charles and small counties such as Christian.

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

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
1	CD	IS 44	W	163.11	164.16	1.05	Laclede
2	CD	US 54	W	104.89	105.66	0.77	Cole
3	CD	IS 44	E	223.47	224.57	1.10	Crawford
4	CD	IS 70	E	101.79	103.56	1.77	Cooper
5	CD	IS 70	E	101.02	101.79	0.77	Cooper
6	KC	US 71	S	153.76	154.66	0.90	Cass
7	KC	US 71	S	154.66	155.42	0.76	Cass
8	KC	US 71	S	155.42	156.04	0.62	Cass
9	KC	IS 29	N	5.29	5.99	0.70	Clay
10	KC	US 71	N	178.13	179.36	1.23	Cass
11	KC	IS 435	S	22.10	24.87	2.77	Clay
12	NE	US 36	E	189.36	190.48	1.12	Marion
13	NE	IS 70	E	193.86	195.65	1.79	Warren
14	NE	IS 72	W	0.83	2.05	1.22	Marion
15	NE	IS 70	E	200.01	200.73	0.72	Warren
16	NE	IS 70	E	200.73	203.76	3.03	Warren
17	NE	US 36	E	187.92	189.36	1.44	Marion
18	NW	IS 29	N	52.60	55.29	2.69	Buchanan
19	NW	IS 229	N	2.94	3.57	0.63	Buchanan
20	NW	IS 229	N	3.57	4.08	0.51	Buchanan
21	NW	IS 29	N	48.94	50.59	1.65	Buchanan
22	NW	US 36	E	3.16	3.78	0.62	Buchanan
23	NW	IS 229	S	5.68	7.44	1.76	Buchanan
24	SE	IS 55	N	89.87	92.03	2.16	Scott

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	SE	IS 55	N	99.83	102.31	2.48	Cape Girardeau
26	SE	IS 55	N	69.38	73.30	3.92	Scott
27	SE	IS 55	N	66.27	67.44	1.17	Scott
28	SE	IS 55	N	96.46	99.83	3.37	Cape Girardeau
29	SL	IS 64	W	39.36	40.14	0.78	St. Charles
30	SL	IS 44	W	51.39	52.20	0.81	Franklin
31	SL	IS 44	W	52.20	53.22	1.02	Franklin
32	SL	IS 44	W	42.54	43.06	0.52	Franklin
33	SL	IS 55	N	178.74	180.96	2.22	Jefferson
34	SL	IS 44	W	65.66	67.75	2.09	Franklin
35	SW	US 71	N	105.08	106.03	0.95	Vernon
36	SW	IS 44	E	6.60	8.75	2.15	Newton
37	SW	US 60	E	84.89	86.21	1.32	Greene
38	SW	US 71	S	263.48	264.67	1.20	Jasper
39	SW	US 65	S	274.80	276.09	1.29	Christian

7.3.3 Sampling for Urban Six-Lane Freeway Segments

For urban six-lane freeway segments, most of the segments were located in the Saint Louis and Kansas City areas. Therefore, it was not possible to obtain five samples per district. The general sampling approach involved attempting to obtain 35 at-large samples from the state of Missouri, then subdividing the segments as needed. Several of the segments were subdivided into two or more segments due to changes in median width, changes in median type, or the presence of additional ramps on the segment. Therefore, the sample set for calibration included 54 sites.

A list of the samples for urban six-lane freeway segments is shown in Table 7.5. The sample set included 27 segments from the Kansas City District, 26 samples from the Saint Louis District, and one sample from the Southwest District. The sample set consisted mostly of interstate highways, although segments from MO 370, US 65, and US 71 were also represented in the sample set. One of the US 71 segments was coincident with I-49. Most of the major interstate highways, including I-29, I-35, I-44, I-64, I-70, I-170, I-255, I-435, I-470, and I-670, were represented in the sample set. The sample set included freeway segments from seven counties in Missouri.

Table 7.5 List of sites for urban six-lane freeway segments

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
1	KC	IS 70	E	8.41	8.69	0.28	Jackson
2	KC	IS 70	E	8.69	9.07	0.38	Jackson
3	KC	IS 70	E	14.10	15.37	1.27	Jackson
4	KC	IS 70	E	18.57	20.19	1.63	Jackson
5	KC	US 71	N	180.76	181.74	0.98	Jackson
6	KC	US 71	N	196.93	197.69	0.76	Jackson
7	KC	US 71	N	197.69	198.01	0.32	Jackson
8	KC	US 71	N	198.01	198.62	0.61	Jackson
9	KC	IS 70	W	244.45	244.83	0.38	Jackson
10	KC	IS 70	W	244.83	245.53	0.70	Jackson
11	KC	IS 70	W	245.53	245.67	0.14	Jackson
12	KC	IS 70	W	245.67	245.93	0.26	Jackson
13	KC	IS 70	W	245.93	246.53	0.60	Jackson
14	KC	IS 70	W	246.53	246.75	0.22	Jackson
15	KC	IS 70	W	247.08	247.17	0.09	Jackson
16	KC	IS 70	W	246.75	247.08	0.33	Jackson
17	KC	IS 70	W	247.17	247.47	0.30	Jackson
18	KC	IS 35	S	113.59	113.99	0.40	Jackson
19	KC	IS 35	S	113.99	114.36	0.37	Jackson
20	KC	IS 29	N	3.22	4.22	1.00	Clay
21	KC	IS 29	N	4.22	4.44	0.22	Clay
22	KC	IS 29	N	19.75	21.49	1.74	Platte
23	KC	IS 435	N	8.28	9.41	1.13	Jackson
24	KC	IS 670	E	0.04	0.43	0.38	Jackson

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
25	SL	IS 44	E	266.57	267.70	1.13	St. Louis
26	SL	IS 70	E	234.76	235.04	0.28	St. Louis
27	SL	IS 70	E	234.21	234.76	0.56	St. Louis
28	SL	IS 70	E	236.88	237.56	0.68	St. Louis
29	SL	MO 370	E	2.69	5.11	2.42	St. Charles
30	SL	MO 370	E	5.11	7.83	2.72	St. Charles
31	SL	IS 170	E	6.79	7.79	1.00	St. Louis
32	SL	IS 170	E	7.79	8.75	0.96	St. Louis
33	SL	IS 64	E	39.12	39.37	0.25	St. Louis City
34	SL	IS 64	E	38.86	39.12	0.26	St. Louis City
35	SL	IS 64	W	20.97	21.15	0.18	St. Louis
36	SL	IS 64	W	21.15	21.79	0.64	St. Louis
37	SL	IS 64	W	21.92	22.27	0.35	St. Louis
38	SL	IS 64	W	22.27	23.42	1.15	St. Louis
39	SL	IS 64	W	23.42	24.61	1.19	St. Louis
40	SL	IS 255	N	0.63	1.59	0.96	St. Louis
41	SL	IS 255	S	3.42	3.97	0.55	St. Louis
42	SW	US 65	S	265.39	267.07	1.68	Greene
43	SL	IS 170	E	8.75	9.31	0.55	St. Louis
44	SL	IS 170	E	9.35	9.86	0.51	St. Louis
45	SL	IS 64	E	36.83	37.01	0.18	St. Louis City
46	SL	IS 64	E	37.01	37.83	0.82	St. Louis City
47	SL	IS 70	W	26.36	27.51	1.16	St. Charles
48	SL	IS 70	W	27.57	28.09	0.52	St. Charles
49	KC	IS 70	W	240.82	241.36	0.54	Jackson
50	KC	IS 70	W	240.35	240.82	0.46	Jackson

Segment ID	District	Description	Primary Direction	Primary Begin Log	Primary End Log	Length (mi)	County
51	KC	IS 470	W	10.52	11.69	1.18	Jackson
52	SL	IS 70	E	211.96	213.96	2.00	St. Charles
53	SL	IS 70	E	240.50	240.79	0.29	St. Louis
54	SL	IS 70	E	236.03	236.67	0.64	St. Louis

7.4 Data Collection

A list of the data types collected for freeway segments, and their sources, is presented in Table 7.6. TMS was used to obtain data regarding segment length, lane width, and crashes. ARAN was used to estimate roadway and geometric data that were not available in TMS, 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 weave 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 ARAN. 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 (CARES 2013; Google 2013). 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 also required input. The HSM values for the base conditions were used for the clear zone width and proportion of high volume, since these data were not available from other sources.

Table 7.6 List of data sources for freeway segments

Data Description	Source
AADT (2011)	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

One challenge faced during the data collection process was difficulty in finding AADT for some of the ramps in TMS. Ramp AADT was a required input for the IHSDM calibration, being used in the calculation of a CMF for lane changing in the vicinity of an interchange. In some cases, the ramps were located outside of Missouri because the nearest upstream entrance ramp or downstream exit ramp was located on the other side of the Missouri state line. AADT data for these ramps were obtained from agency sources in Illinois, Tennessee, and Arkansas. For the locations in Missouri with missing AADT data in TMS, MoDOT was consulted in an effort to obtain the missing ramp AADT data. MoDOT was able to provide AADT for approximately half of these ramps, including ramps at rest areas and weigh stations. However, MoDOT did not have data for all of these ramps, because it began to collect traffic counts for ramps in 2012 and currently collects traffic counts for ramps on a six-year cycle.

Therefore, AADT for the remaining ramps had to be estimated. For these remaining ramps, local agencies were contacted to determine whether they had conducted their own traffic counts. Local agencies did not have their own ramp traffic accounts available, with one exception: the city of Springfield provided traffic counts for one ramp on US 65. For the remaining ramps, AADT was estimated based upon two methods. In the first method, where AADT data was missing for only one ramp at an interchange, the AADT of the ramp was assumed to be the same as the AADT of the other ramp at the same interchange. In cases where AADT data were missing for both ramps at an interchange, ramp AADT was assumed to be 10 percent of the crossroad AADT, which was obtained from TMS. This assumption was not expected to have a significant effect on the results for two reasons. First, the percentage of ramps with missing AADT data was small, as shown in Table 7.7. Second, the ramp AADT was not part of the SPF calculation, but rather was a part of a CMF calculation for lane changing that also included a variable for the distance to the ramp. Minor differences in ramp AADT values would not lead to significant differences in the predicted number of crashes.

Table 7.7 Percentage of ramps with missing AADT data

Freeway Segment Type	Ramp AADT Obtained from Other Agencies	Ramp AADT Estimated Based on AADT of Other Ramp at Interchange	Ramp AADT Based on Crossroad AADT
Rural Four-Lane	2.7%	0.0%	5.3%
Urban Four-Lane	0.0%	0.6%	1.3%
Urban Six-lane	0.0%	3.7%	6.9%

There were several important considerations for the collection of freeway crash data that needed to be taken into account. The first consideration related to the classification of crashes that occurred within the limits of a speed-change lane. HSM freeway models are divided into segments and speed-change lanes. A speed-change lane is either an entrance or an exit ramp with limits extending from the beginning or end of the taper to the gore point. But how should crashes that occurred on freeway segments adjacent to ramps be treated? On one hand, such crashes are physically located on a segment and not on a ramp; on the other, crashes occurring on mainline lanes adjacent to ramps could be a result of ramp traffic and associated 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.

In addition, it was necessary to separate the number of crashes by both severity and the number of vehicles for the freeway segments. The TMS Accident Browser provides information regarding crash severity in its output. However, the summary output from the TMS Accident Browser does not provide information regarding the number of vehicles that were involved in a crash. However, the number of vehicles is indicated by the field NO_OF_VEHICLES in the TMS table HP_ACCIDENT_VW. Therefore, crash data for freeway segments were obtained by querying the TMS Table TMS_HP_ACCIDENT_VW in order to obtain information regarding the number of vehicles involved in the crash. The criteria for the queries were based on the following fields: ACCIDENT_YR, TRAVELWAY_ID, and Log. The ACCIDENT_YR field was used to obtain crash data from 2009-2011. The TRAVELWAY_ID field identified the segment for obtaining crash data. The Log field was used to locate the crash along the segment based on the distance from the beginning of the segment to the crash site.

Another challenge encountered during the process of collecting crash data for freeways involved overlapping routes. The crash data output from the queries for segments with overlapping routes frequently showed crashes on both the primary route and secondary route. For example, a segment on Interstate 70 (primary route) in Kansas City included overlap with US 40 (secondary route). Some crashes on this segment were coded using Interstate 70 log miles, while other crashes were coded using US 40 log miles. To resolve this problem, the TMS table TMS_LR_OVERLAP was used to determine the conversions between the primary and secondary routes. The conversions were used to transform the log miles for the segment endpoints and speed change lane locations from the primary route log mile coordinate system to the secondary route log mile coordinate system, so that crashes coded on the secondary route could be located correctly.

7.4.1 Summary Statistics for Rural Four-Lane Freeway Segments

Descriptive statistics for rural four-lane freeway segments are shown in Table 7.8. The average AADT was 24,730 vpd, with a standard deviation of 8,955 vpd. Thus, the sample set contained a wide range of AADT values. The average length of the segments was 3.02 miles, with a standard deviation of 1.67 miles. The segments were relatively uniform with respect to lane width, inside shoulder width, and outside shoulder width. The average effective median width was 34.7 feet, with a standard deviation of 12.6 feet. Most of the segments contained median barrier, as indicated by the average value of 0.69 for the proportion of segment with median barrier. The presence of outside barrier was not as common, as is revealed by the average value of 0.10 for the proportion of segment with outside barrier. All of the segments contained both outside and inside rumble strips. None of the segments contained a type B weaving section. The distance to the nearest upstream entrance ramp or downstream exit ramp varied from zero miles to 5.88 miles. The average ramp AADT varied from 962 vpd to 1,305 vpd. The segments were relatively flat with respect to horizontal curvature, as indicated by the average value of 9,441 feet for the horizontal curve radius.

Table 7.8 Sample descriptive statistics for rural four-lane freeway segments (Sample size = 47)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	24730	4445	37250	8955
Length (mi)	3.02	0.39	6.50	1.67
Effective Length (mi)	2.87	0.34	6.27	1.66
Average Lane Width (ft)	12.0	12.0	12.0	0.0
Effective Median Width (ft)	34.7	3.0	50.0	12.6
Average Inside Shoulder Width (ft)	2.5	1.0	4.0	0.8
Average Outside Shoulder Width (ft)	10.0	10.0	10.0	0.0
Proportion of Segment Length with Median Barrier	0.69	0.0	1.0	0.44
Average Median Barrier Offset	13.9	0.0	29.0	9.0
Outside Barrier Length (ft)	2886	0	13670	3126
Proportion of Segment Length with Outside Barrier	0.10	0.00	0.46	0.11
Average Outside Barrier Offset (ft)	7.4	0.0	10.0	4.4
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 (mi)	0.49	0.00	4.34	1.00
AADT Entrance Ramp Increasing Direction (2010)	1305	107	5574	1414
Distance to Exit Ramp Increasing Direction (mi)	0.73	0.00	5.88	1.40

Description	Average	Min.	Max.	Std. Dev.
AADT Exit Ramp Increasing Direction (2010)	962	114	3468	834
Distance to Entrance Ramp Decreasing Direction (mi)	0.65	0.00	5.79	1.29
AADT Entrance Ramp Decreasing Direction (2010)	976	102	3439	843
Distance to Exit Ramp Decreasing Direction (mi)	0.38	0.00	4.34	0.95
AADT Exit Ramp Decreasing Direction (2010)	1182	102	5529	1321
Horizontal Curve Radius (ft)	9441	1922	162457	18328
Horizontal Curve Length within Site (ft)	1710	317	5423	1088
No. of PDO SV Crashes (3 Years)	26.1	1.0	115.0	22.8
No. of PDO MV Crashes (3 Years)	13.7	1.0	51.0	12.0
No. of FI SV Crashes (3 Years)	5.7	0.0	34.0	5.6
No. of FI MV Crashes (3 Years)	3.2	0.0	18.0	3.4

A summary of crash statistics for rural four-lane freeway segments is shown in Table 7.9. The table includes total crashes for all four crash types. PDO crashes occurred at a higher rate than FI crashes. The total number of PDO was greater than 100 crashes per year, while the total number of FI crashes was less than 100 crashes per year. According to Appendix C of the HSM, the calibration process for freeways follows the similar HSM calibration process as described in Section B.1 of Appendix B to HSM Part C.

Table 7.9 Summary of total observed crashes for rural four-lane freeway segments

Crash Type	Total Crashes (3 Years)
PDO SV	1229
PDO MV	645
FI SV	268
FI MV	150

7.4.2 Summary Statistics for Urban Four-Lane Freeway Segments

Descriptive statistics for urban four-lane freeway segments are shown in Table 7.10. The average AADT was 29,027 vpd, with a standard deviation of 15,334 vpd. Thus the sample set contained a wide range of AADT values. The average length of the segments was 1.46 miles, with a standard deviation of 0.85 miles. The segments were relatively uniform with respect to lane width, inside shoulder width, and outside shoulder width. The average effective median width was 32.2 feet, with a standard deviation of 13.6 feet. Most of the segments contained median barrier, as indicated by the average value of 0.80 for the proportion of segment with median barrier. Outside barriers were less common, as indicated by the average value of 0.20 for the proportion of segment 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 distance to the nearest upstream entrance ramp or downstream exit ramp varied from zero miles to 7.49 miles. The average ramp AADT varied from 2,170 vpd to 3,041 vpd. The segments had an average value of 6,346 feet for the horizontal curve radius.

Table 7.10 Sample descriptive statistics for urban four-lane freeway segments (Sample size = 39)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	29027	4207	68508	15334
Length (mi)	1.46	0.51	3.92	0.85
Effective Length (mi)	1.26	0.18	3.77	0.87
Average Lane Width (ft)	12.0	12.0	12.0	0.0
Effective Median Width (ft)	32.2	1.0	50.0	13.6
Average Inside Shoulder Width (ft)	10.0	10.0	10.0	0.0
Average Outside Shoulder Width (ft)	3.0	1.0	7.0	1.3
Proportion of Segment Length with Median Barrier	0.8	0.0	1.0	0.4
Average Median Barrier Offset	15.6	0.0	28.0	8.5
Outside Barrier Length (ft)	2688	0	10187	2688
Proportion of Segment Length with Outside Barrier	0.20	0.00	0.70	0.17
Average Outside Barrier Offset (ft)	9.2	0.0	10.0	2.7
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 (mi)	0.40	0.00	5.18	1.10
AADT Entrance Ramp Increasing Direction (2010)	2557	107	11660	2264
Distance to Exit Ramp Increasing Direction (mi)	0.58	0.00	7.46	1.47
AADT Exit Ramp Increasing Direction (2010)	2170	107	8068	1939

Description	Average	Min.	Max.	Std. Dev.
Distance to Entrance Ramp Decreasing Direction (mi)	0.62	0.00	7.49	1.49
AADT Entrance Ramp Decreasing Direction (2010)	3041	101	29001	4723
Distance to Exit Ramp Decreasing Direction (mi)	0.35	0.00	4.71	0.94
AADT Exit Ramp Decreasing Direction (2010)	2561	101	11828	2270
Horizontal Curve Radius (ft)	6346	737	36556	6623
Horizontal Curve Length within Site (ft)	1473	116	6225	1148
No. of PDO SV Crashes (3 Years)	14.9	0.0	54.0	14.6
No. of PDO MV Crashes (3 Years)	17.2	0.0	98.0	21.1
No. of FI SV Crashes (3 Years)	3.6	0.0	15.0	3.3
No. of FI MV Crashes (3 Years)	3.9	0.0	41.0	7.9

A summary of crash statistics for urban four-lane freeway segments is found in Table 7.11. The table includes total crashes for all four crash types. PDO crashes occurred at a higher rate than FI crashes, which can be shown by the higher total number of crashes. The total number of PDO crashes was greater than the 100 crashes per year recommended by the HSM, while the total number of FI crashes was less than 100 crashes per year.

Table 7.11 Summary of total observed crashes for urban four lane freeway segments

Crash Type	Total Crashes (3 Years)
PDO SV	583
PDO MV	669
FI SV	142
FI MV	153

7.4.3 Summary Statistics for Urban Six-Lane Freeway Segments

Descriptive statistics for urban six-lane freeway segments are shown in Table 7.12. The average AADT was 86,757 vpd, with a standard deviation of 22,793 vpd. Thus, the sample set contained a wide range of AADT values. The average length of the segments was 0.75 miles, with a standard deviation of 0.58 miles. The segments were relatively uniform with respect to lane width and outside shoulder width; however, the inside shoulder width varied with an average width of 6.9 ft and a standard deviation of 5.2 ft. The effective median width varied significantly, with an average of 26.8 feet with a standard deviation of 29.9 feet, ranging from 2.0 to 150.0 ft. Almost all of the segments contained median barrier, as indicated by the average value of 0.98 for the proportion of segment with median barrier. Outside barriers were less common, as indicated by the average value of 0.36 for the proportion of segment with outside barrier. All of the segments contained inside rumble strips; however, outside rumble strips were less common, as indicated by the average value of 0.04 for the proportion of segment with outside rumble strips. None of the segments contained a type B weaving section. The distance to the nearest upstream entrance ramp or downstream exit ramp varied from zero miles to 2.23 miles. The average ramp AADT varied from 4,944 vpd to 5,031 vpd. The segments had an average value of 4,862 feet for the horizontal curve radius.

Table 7.12 Sample descriptive statistics for urban six-lane freeway segments (Sample size = 54)

Description	Average	Min.	Max.	Std. Dev.
AADT (2011)	86757	41623	165022	22793
Length (mi)	0.75	0.09	2.72	0.58
Effective Length (mi)	0.57	0.06	2.26	0.49
Average Lane Width (ft)	12.0	12.0	12.0	0.0
Effective Median Width (ft)	26.8	2.0	150.0	29.9
Average Inside Shoulder Width (ft)	6.9	1.0	20.0	5.2
Average Outside Shoulder Width (ft)	9.3	3.0	10.0	1.7
Proportion of Segment Length with Median Barrier	0.98	0.53	1.00	0.09
Average Median Barrier Offset	20.2	2.5	80.8	15.7
Outside Barrier Length (ft)	2236	0	10160	2416
Proportion of Segment Length with Outside Barrier	0.36	0.00	1.00	0.31
Average Outside Barrier Offset (ft)	9.3	0.0	10.0	2.6
Outside Clear Zone Width (ft)	30	30	30	0
Proportion of Segment with Inside Rumble Strips	1.00	1.00	1.00	0.00
Proportion of Segment with Outside Rumble Strips	0.04	0.00	1.00	0.19
Proportion of High Volume	0.00	0.00	0.00	0.00
Proportion of Weave Increasing Direction	0.00	0.00	0.00	0.00
Length of Weave Increasing Direction	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	0.00	0.00	0.00	0.00
Distance to Entrance Ramp Increasing Direction (mi)	0.21	0.00	1.06	0.31
AADT Entrance Ramp Increasing Direction (2010)	3739	750	11133	2264
Distance to Exit Ramp Increasing Direction (mi)	0.34	0.00	2.23	0.55
AADT Exit Ramp Increasing Direction (2010)	4944	552	48895	6811
Distance to Entrance Ramp Decreasing Direction (mi)	0.23	0.00	2.21	0.42

Description	Average	Min.	Max.	Std. Dev.
AADT Entrance Ramp Decreasing Direction (2010)	5031	400	53878	7420
Distance to Exit Ramp Decreasing Direction (mi)	0.17	0.00	1.45	0.36
AADT Exit Ramp Decreasing Direction (2010)	4201	581	15618	3124
Horizontal Curve Radius (ft)	4862	797	19974	4701
Horizontal Curve Length within Site (ft)	949	32	3062	581
No. of PDO SV Crashes (3 Years)	8.8	0.0	43.0	9.1
No. of PDO MV Crashes (3 Years)	27.4	0.0	180.0	31.0
No. of FI SV Crashes (3 Years)	3.8	0.0	19.0	3.8
No. of FI MV Crashes (3 Years)	7.9	0.0	29.0	7.4

A summary of crash statistics for urban six-lane freeway segments is found in Table 7.13. The table includes total crashes for all four crash types. PDO crashes occurred at a higher rate than FI crashes, which can be shown by the higher total number of crashes. The total number of PDO crashes and FI MV crashes was greater than the 100 crashes per year recommended by the HSM, while the total number of crashes for FI SV crashes was less than 100 crashes per year.

Table 7.13 Summary of total observed crashes for urban six lane freeway segments

Crash Type	Total Crashes (3 Years)
PDO SV	477
PDO MV	1482
FI SV	206
FI MV	424

7.5 Results and Discussion

The original models were developed using data from California, Maine, and Washington. The details of the model development are described in Bonneson et al. (2012). Some descriptive statistics for the data used to develop the HSM model for freeway segments are shown in Table 7.14. In summary, the HSM freeway data consisted of 1,880 segments covering 510 miles in three different states. The crash data included crashes between 2005 and 2007 for Washington and California, and between 2004 and 2006 for Maine.

Table 7.14 Descriptive statistics for data used to develop HSM model for freeway segments

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

7.5.1 Results for Rural Four-Lane Freeway Segments

The calibration factors for rural four-lane freeway segments are shown in Table 7.15. The IHSDM output is shown in Figures 7.1-7.4. These results indicate that the number of PDO crashes observed in Missouri was greater than the number of crashes predicted by the HSM freeway methodology, while the number of FI crashes was less than the number of crashes predicted by the HSM methodology. There could be many reasons for these differences. Drivers in Missouri may behave differently than drivers in California, Maine, and Washington. There could also be differences in the way that the severity of crashes is coded. The HSM models do not include some of the characteristics of freeways, such as vertical grades, superelevation, and pavement condition that may differ between California, Maine, Washington, and Missouri. Finally, there could be differences in driver behavior that manifested in the crash data sometime between the development of the HSM methodology (2004 to 2007) and the period of the crash data used to calibrate the HSM for Missouri (2009 to 2011). In particular, distracted driving, especially cell phone use and texting, has become more prevalent.

Table 7.15 Calibration results for rural four-lane freeway segments

Model	Calibration Factor
PDO SV	1.51
PDO MV	1.98
FI SV	0.77
FI MV	0.91

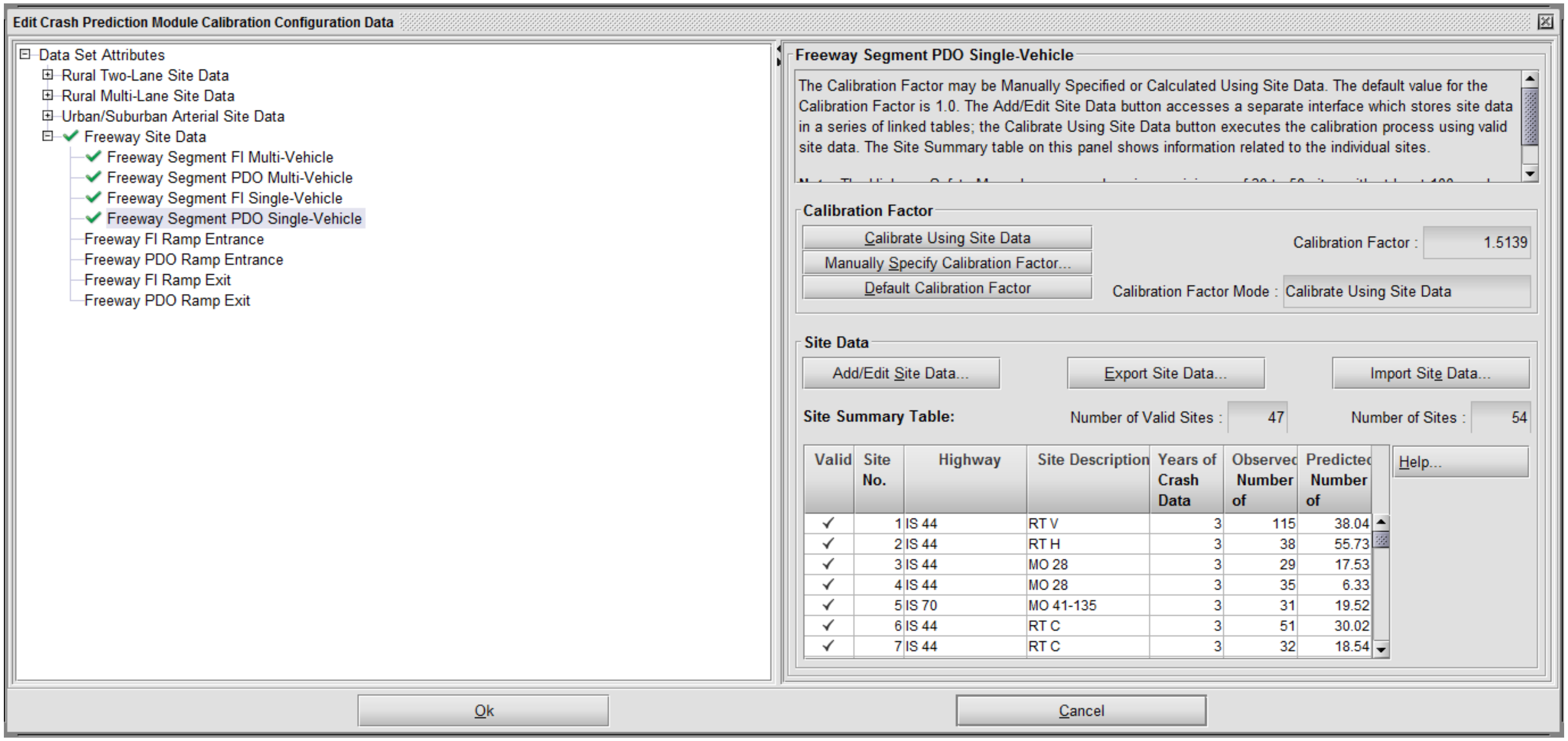


Figure 7.1 Calibration output for rural four-lane freeway segments (PDO SV crashes)

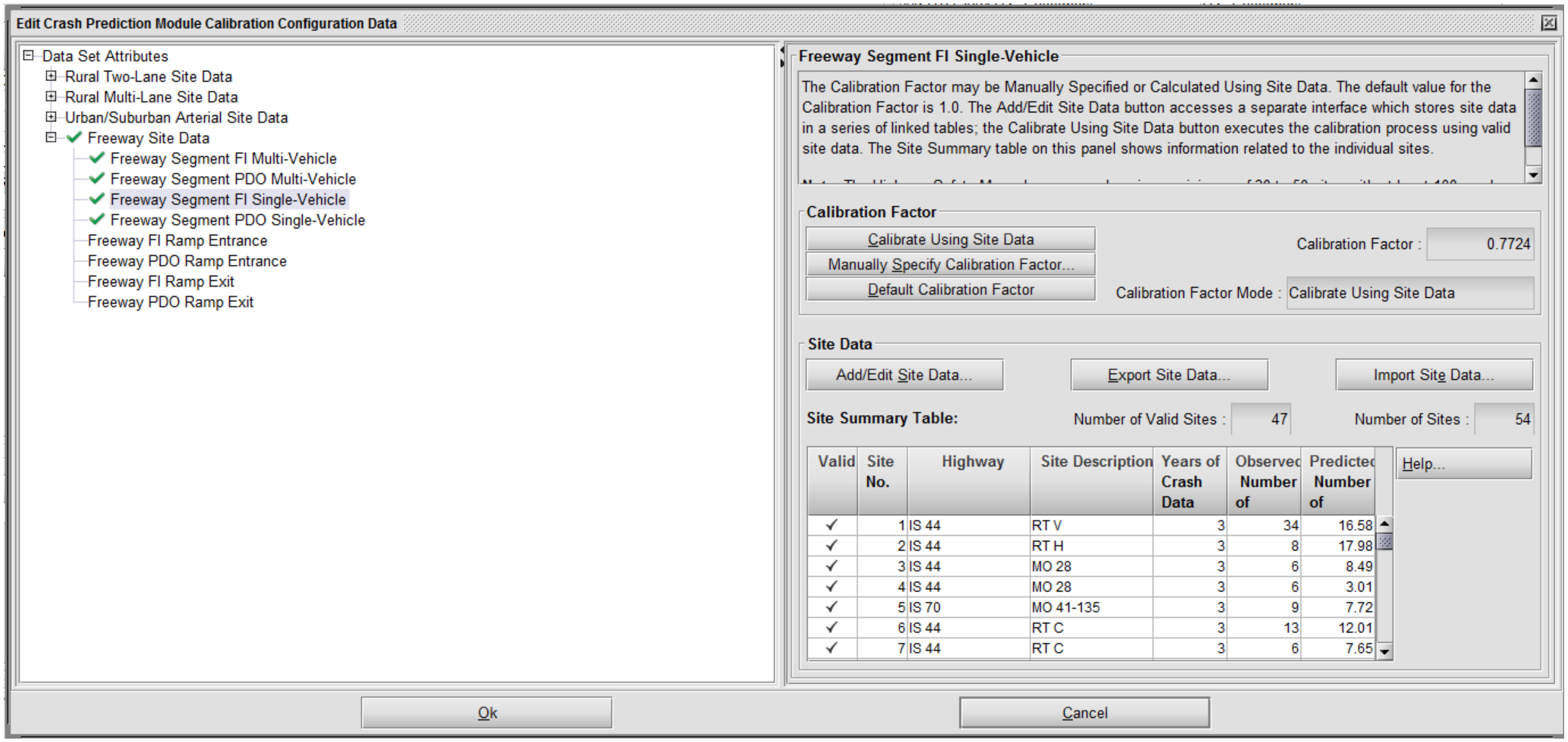
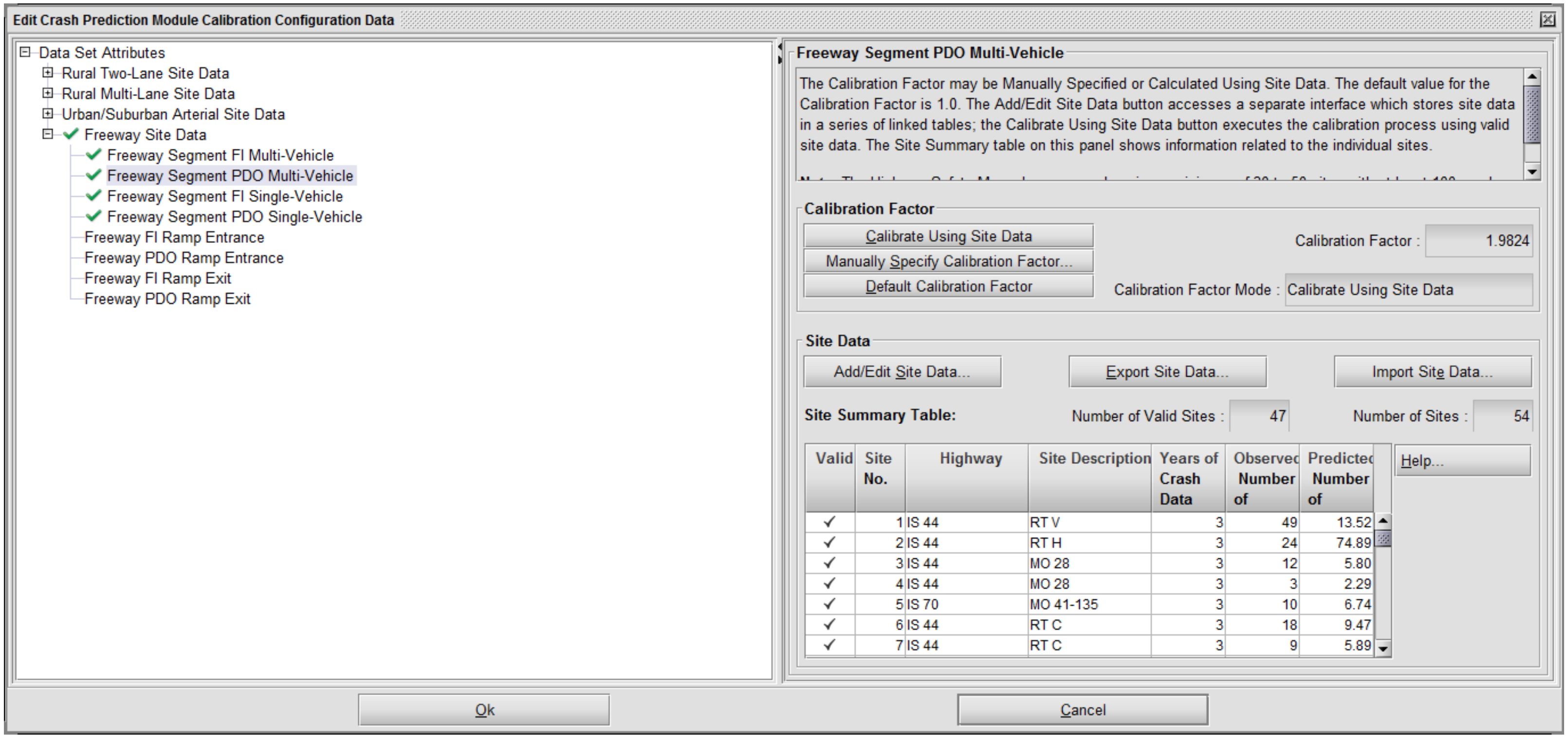


Figure 7.2 Calibration output for rural four-lane freeway segments (FI SV crashes)



Valid	Site No.	Highway	Site Description	Years of Crash Data	Observed Number of	Predicted Number of
✓	1	IS 44	RT V	3	49	13.52
✓	2	IS 44	RT H	3	24	74.89
✓	3	IS 44	MO 28	3	12	5.80
✓	4	IS 44	MO 28	3	3	2.29
✓	5	IS 70	MO 41-135	3	10	6.74
✓	6	IS 44	RT C	3	18	9.47
✓	7	IS 44	RT C	3	9	5.89

Figure 7.3 Calibration output for rural four-lane freeway segments (PDO MV crashes)

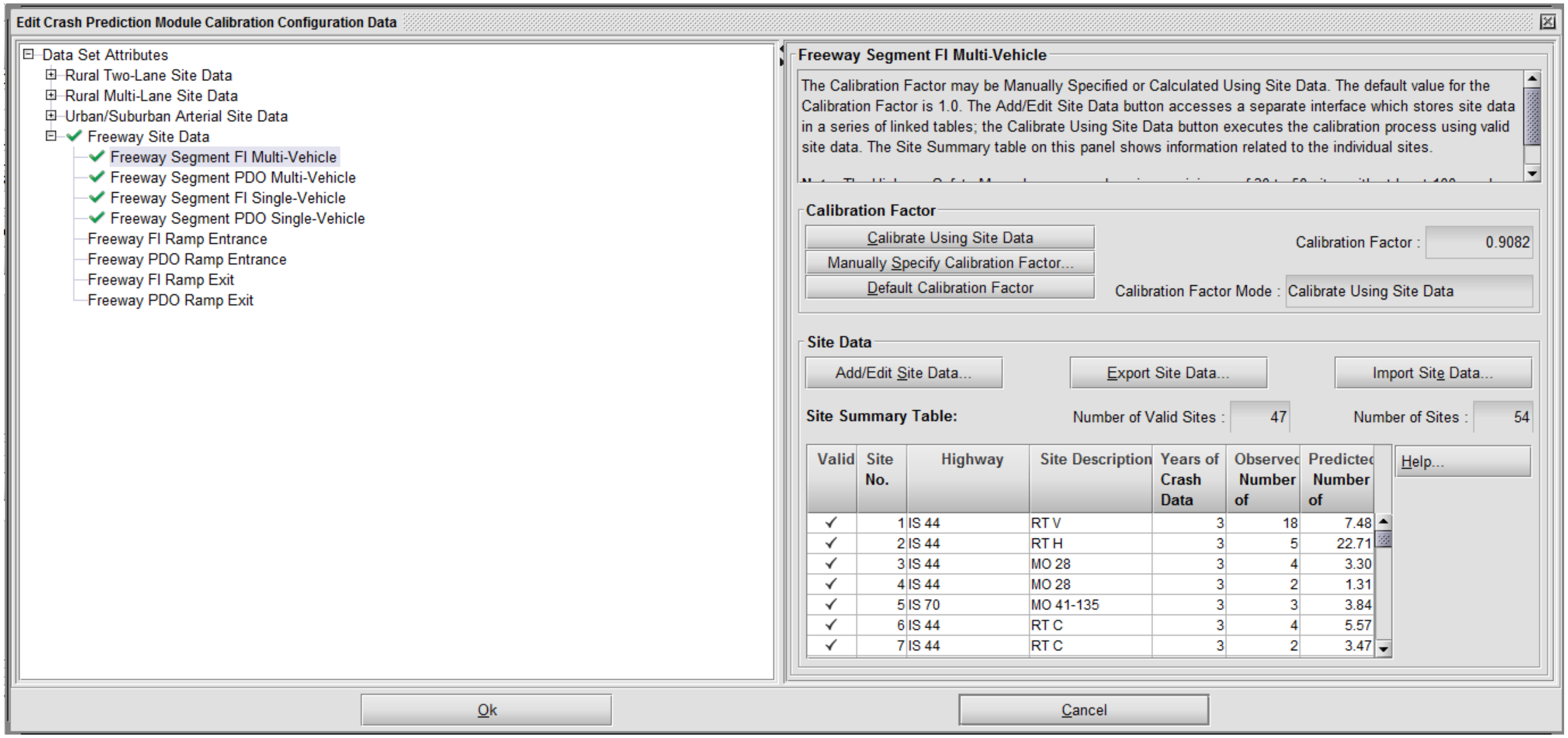


Figure 7.4 Calibration output for rural four-lane freeway segments (FI MV crashes)

7.5.2 Results for Urban Four-Lane Freeway Segments

The calibration factors for urban four-lane freeway segments are shown in Table 7.16. The IHSDM output is shown in Figures 7.5-7.8. These results indicate that the number of PDO crashes and FI MV crashes observed in Missouri was greater than the number of crashes predicted by the HSM freeway methodology, while the number of FI SV crashes was less than the number of crashes predicted by the HSM methodology. There could be many reasons for these differences, as was discussed previously in the section detailing the results for rural four-lane freeways.

Table 7.16 Calibration results for urban four-lane freeway segments

Model	Calibration Factor
PDO SV	1.62
PDO MV	3.59
FI SV	0.70
FI MV	1.40

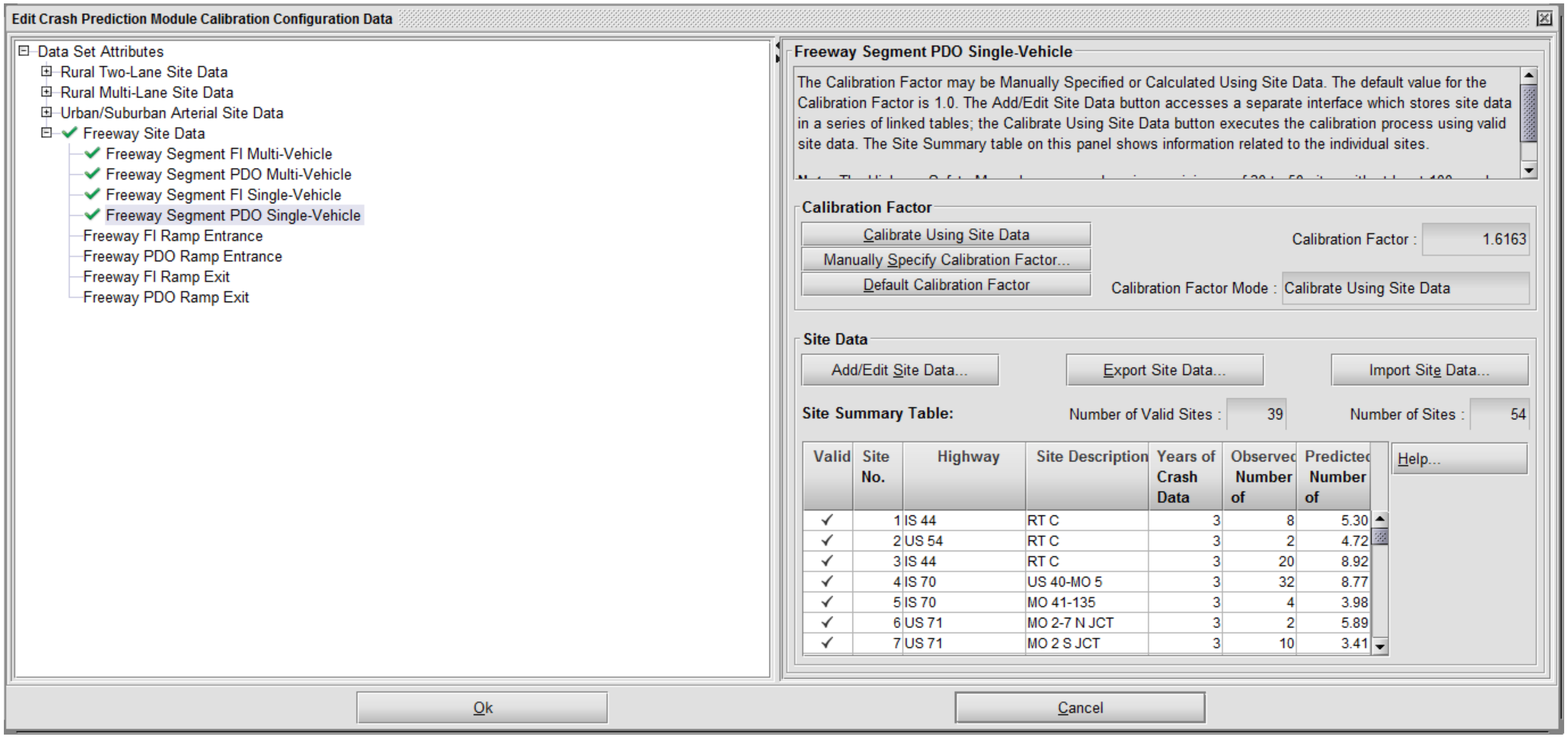


Figure 7.5 Calibration output for urban four-lane freeway segments (PDO SV crashes)

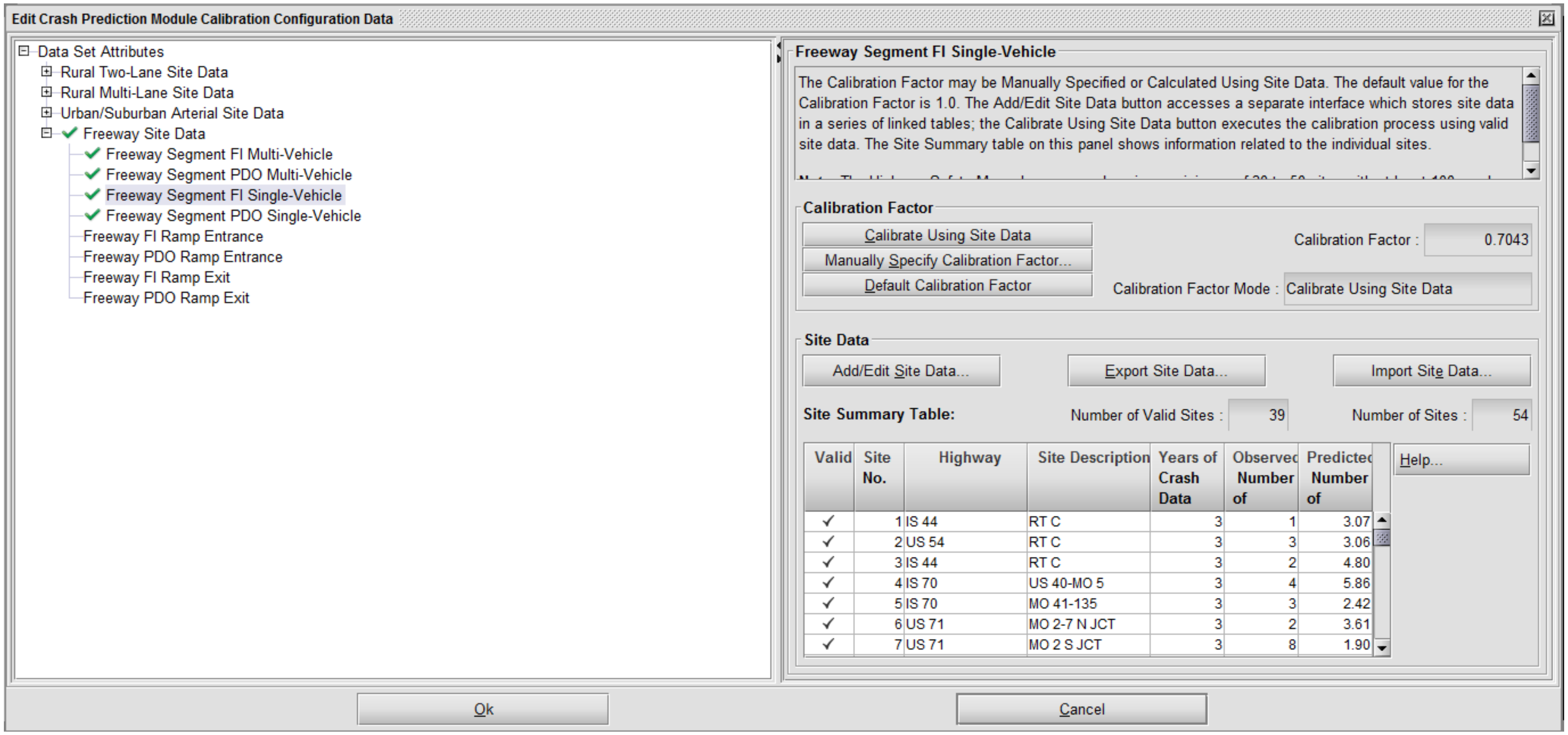


Figure 7.6 Calibration output for urban four-lane freeway segments (FI SV crashes)

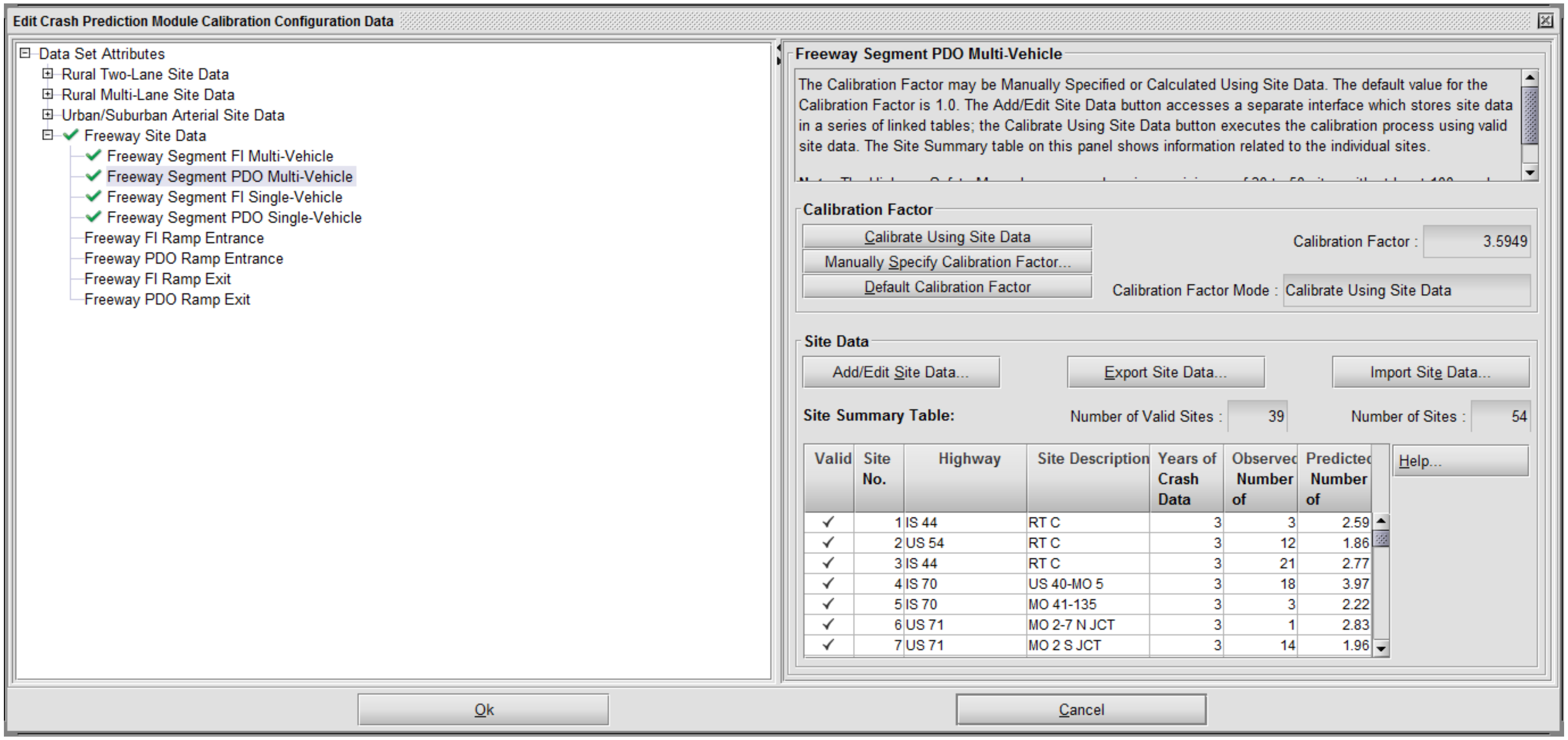
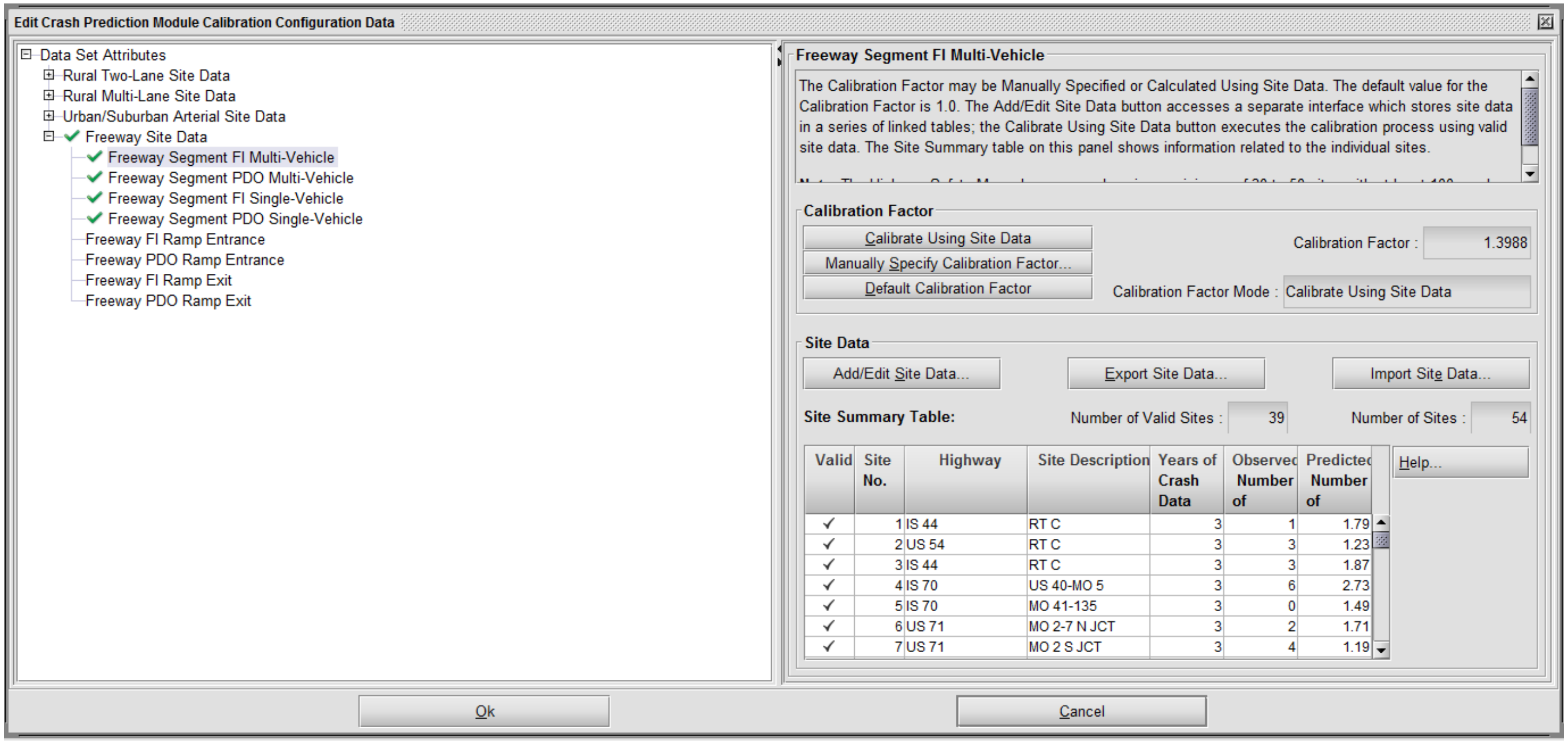


Figure 7.7 Calibration output for urban four-lane freeway segments (PDO MV crashes)



Valid	Site No.	Highway	Site Description	Years of Crash Data	Observed Number of	Predicted Number of
✓	1	IS 44	RT C	3	1	1.79
✓	2	US 54	RT C	3	3	1.23
✓	3	IS 44	RT C	3	3	1.87
✓	4	IS 70	US 40-MO 5	3	6	2.73
✓	5	IS 70	MO 41-135	3	0	1.49
✓	6	US 71	MO 2-7 N JCT	3	2	1.71
✓	7	US 71	MO 2 S JCT	3	4	1.19

Figure 7.8 Calibration output for urban four-lane freeway segments (FI MV crashes)

7.5.3 Results for Urban Six-Lane Freeway Segments

The calibration factors for urban six-lane freeway segments are shown in Table 7.17. The IHSDM output is shown in Figures 7.9-7.12. These results indicate that the number of PDO SV crashes was slightly less than the number of crashes predicted by the HSM methodology, while the number of FI SV crashes was approximately the same as the number of crashes predicted by the HSM methodology. The number of PDO MV crashes and FI MV crashes was greater than the number of crashes predicted by the HSM methodology. Thus, for urban six-lane freeways, the HSM methodology provided a reasonable estimate of the number of single-vehicle crashes, but overestimated the number of multiple-vehicle crashes. The overestimation of multiple-vehicle crashes could be due to differences in driver behavior and interactions between vehicles. There could be many other reasons for these differences, as was discussed in the previous section on the results for rural four-lane freeways.

Table 7.17 Calibration results for urban six-lane freeway segments

Model	Calibration Factor
PDO SV	0.88
PDO MV	1.63
FI SV	1.01
FI MV	1.20

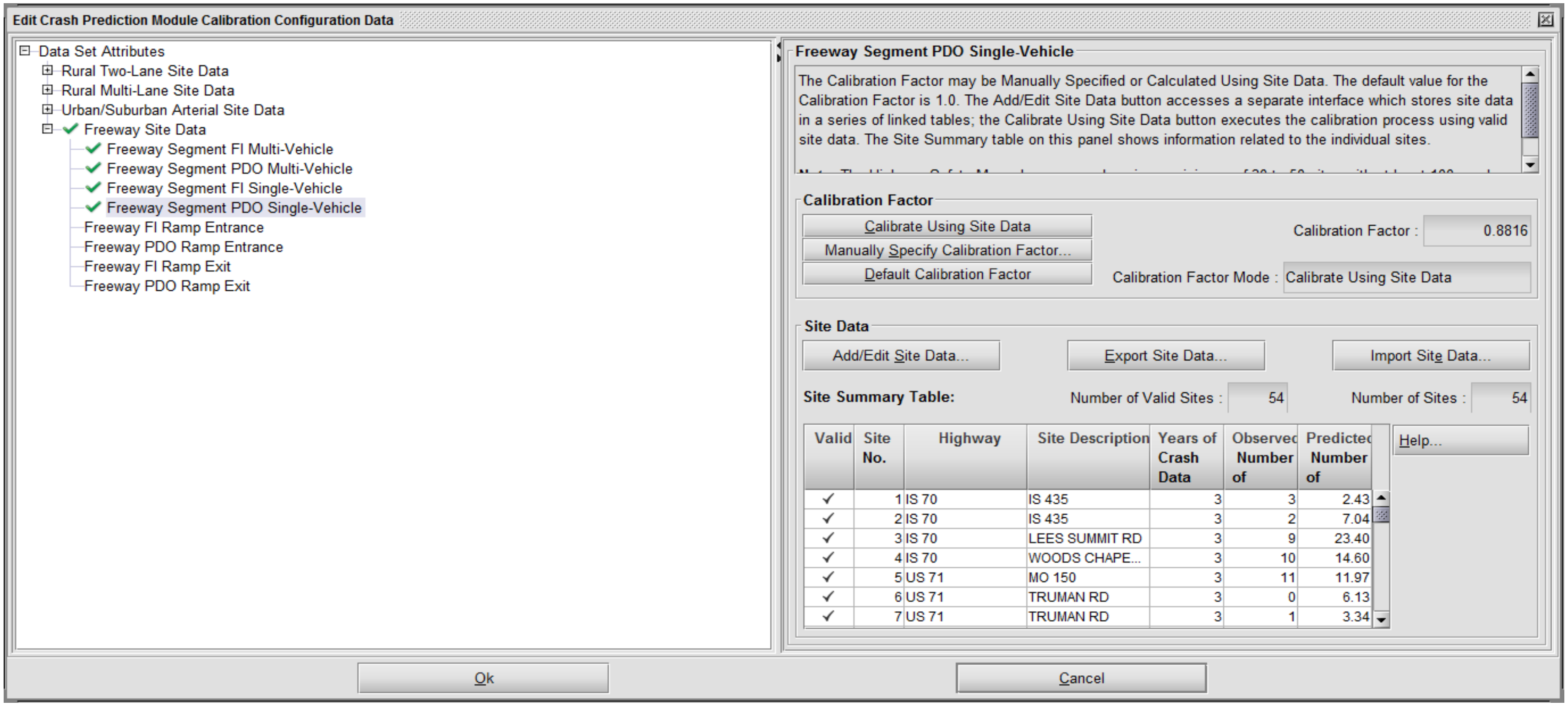


Figure 7.9 Calibration output for urban six-lane freeway segments (PDO SV crashes)

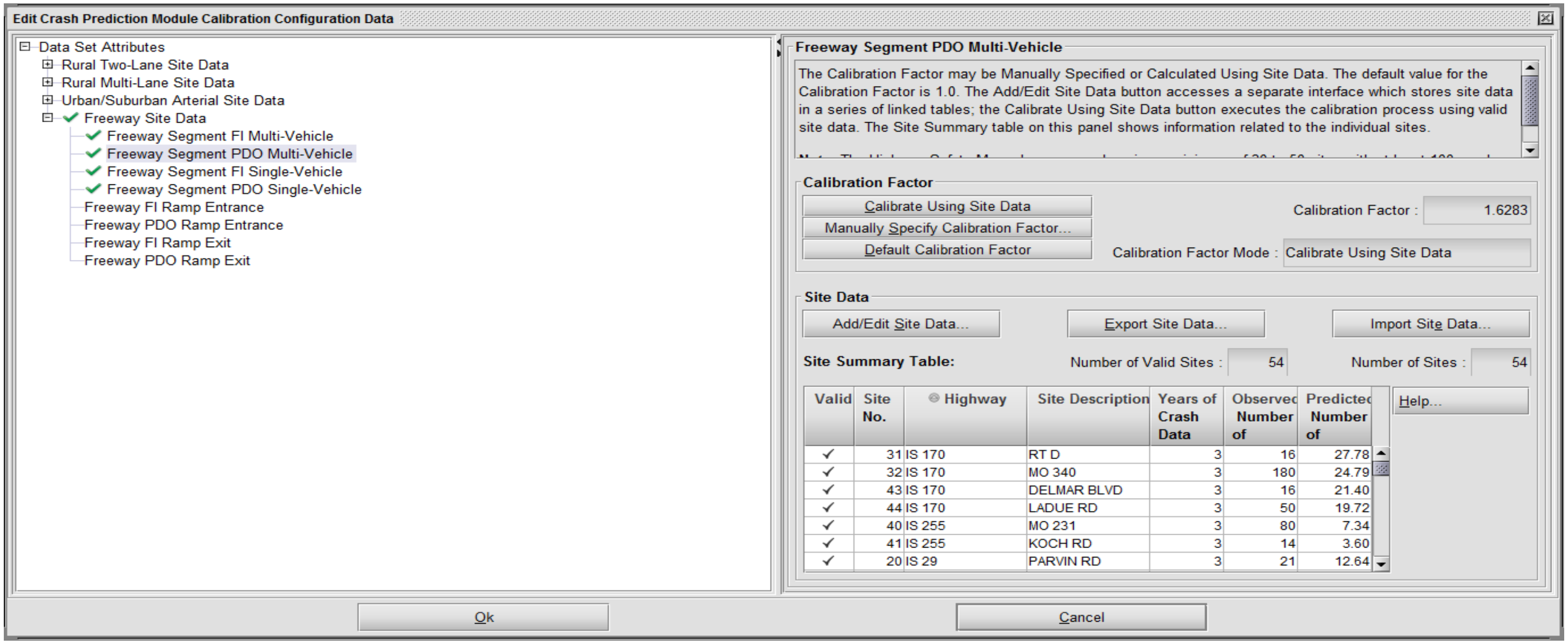
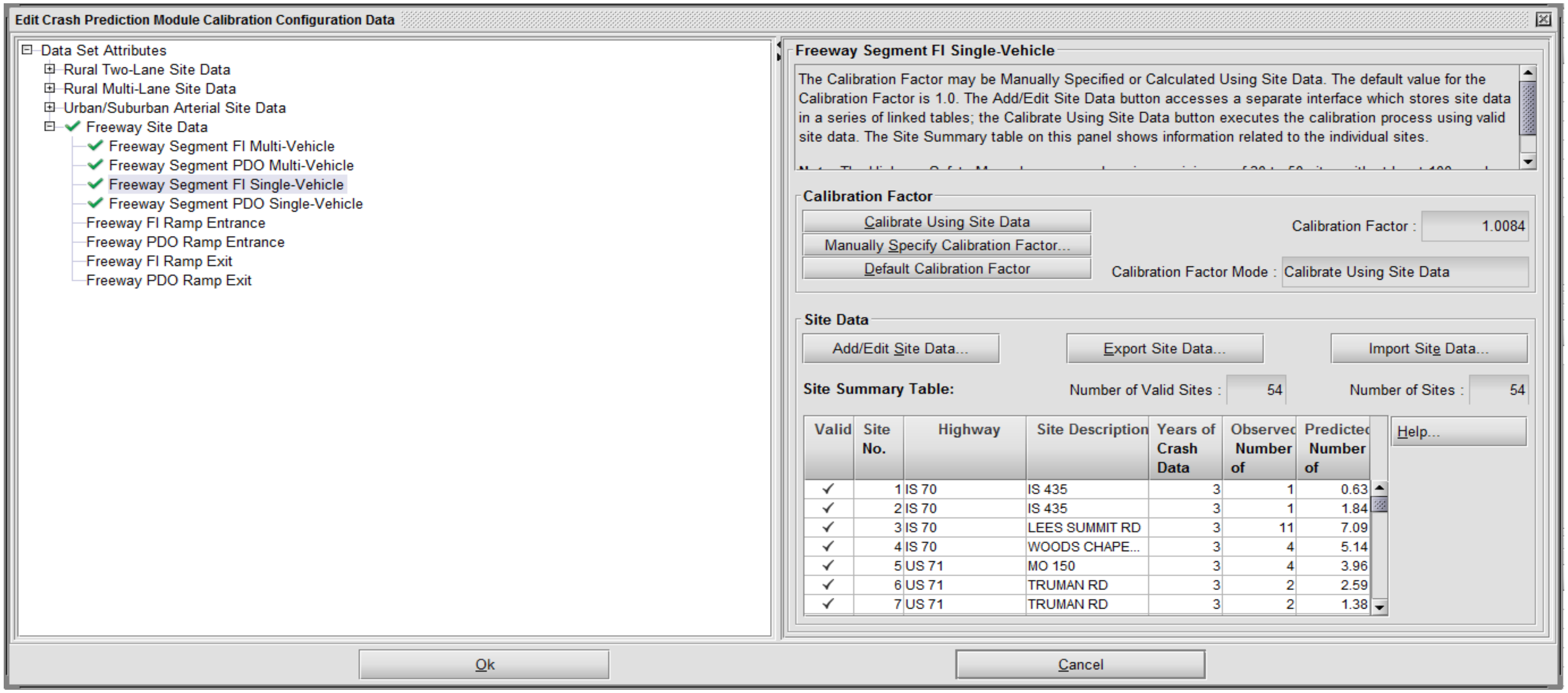


Figure 7.10 Calibration output for urban six-lane freeway segments (PDO MV crashes)



Valid	Site No.	Highway	Site Description	Years of Crash Data	Observed Number of	Predicted Number of
✓	1	IS 70	IS 435	3	1	0.63
✓	2	IS 70	IS 435	3	1	1.84
✓	3	IS 70	LEES SUMMIT RD	3	11	7.09
✓	4	IS 70	WOODS CHAPE...	3	4	5.14
✓	5	US 71	MO 150	3	4	3.96
✓	6	US 71	TRUMAN RD	3	2	2.59
✓	7	US 71	TRUMAN RD	3	2	1.38

Figure 7.11 Calibration output for urban six-lane freeway segments (FI SV crashes)

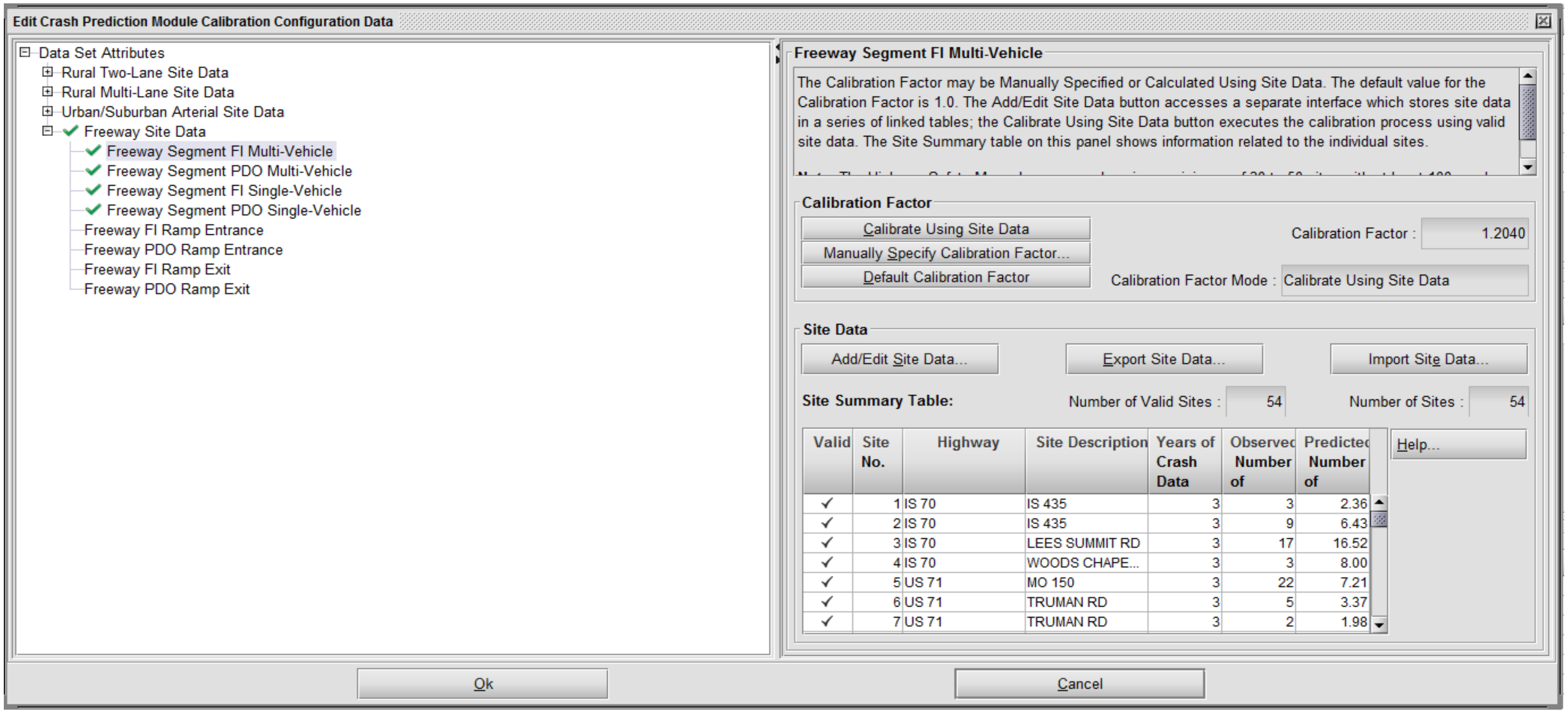


Figure 7.12 Calibration output for urban six-lane freeway segments (FI MV crashes)

Chapter 8 Urban Signalized Intersections

8.1 Introduction and Scope

Chapter 12 of the HSM describes the methodology for crash prediction for signalized intersections, including both three-leg and four-leg signalized intersections. Both of these urban signalized intersection types were calibrated as part of this project.

8.2 HSM Methodology

As described in chapter 12 of the HSM, 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 AADT and minor AADT 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}.

where,

N_{bimv} = predicted average number of multiple vehicle crashes for base conditions;

N_{bisv} = predicted average number of single vehicle crashes for base conditions;

N_{pedi} = predicted average number of pedestrian involved crashes for base conditions;

N_{bikei} = 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 relationships are applied.

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

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

where,

$N_{\text{predicted } int}$ = predicted average crash frequency within an intersection for a selected year;

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

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

The general form of the SPF is given by:

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

$$N_{bimv} = exp(a + b \text{ x } ln(AADT_{maj}) + c \text{ x } ln(AADT_{min})) \quad (8.4)$$

where,

$AADT_{maj}$ = annual average daily traffic (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = annual average daily traffic (vehicles/day) for minor road (both directions of travel combined); and

a, b, c = regression coefficients.

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

$$N_{pedi} = N_{pedbase} \text{ x } CMF_{1p} \text{ x } CMF_{2p} \text{ x } CMF_{3p} \tag{8.5}$$

where,

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

$CMF_{1p}...CMF_{3p}$ = crash modification factors for vehicle-pedestrian collisions at signalized intersections.

Values for $N_{pedbase}$ depended on total AADT, minor AADT, major AADT, pedestrian volume, and maximum number of lanes crossed by pedestrian. The predicted number of vehicle-pedestrian crashes at stop-controlled intersections over a given year was determined by the following:

$$N_{bikei} = N_{bi} \text{ x } f_{bikei} \tag{8.6}$$

where,

f_{pedi} = pedestrian crash adjustment factor.

For an accident to be classified as an intersection crash, various criteria have to be met in relation to the intersection. Table 8.1 shows the criteria used by the HSM in part C A.2.4. Furthermore, the HSM states that if the “intersection-related” field is not available on the crash report, as is the case in Missouri, then characteristics of the crash may be considered; but there are no strict rules for assigning crashes as intersection-related. The NCHRP 129 report (Harwood et al. 2007), which documents the development of signalized intersection SPFs, used an additional threshold of 250 feet.

Table 8.1 Criteria used by HSM for intersection crash classification

Location of Crash	Classification
Within curb limits of intersection	At Intersection
On intersection legs and are intersection-related	At Intersection
Outside curb limits and not intersection-related	Roadway segment

Table 8.2 shows the base conditions used as crash modification factors for each intersection.

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 signal phasing
Intersection Right-Turn Lanes	Not Present
Right-Turn-on-Red	Permitting
Lighting	Not Present
Red-Light Cameras	Not Present

8.3 Sampling Considerations

In order to generate samples for signalized intersections, queries were run on the SS_INTERSECTION table provided by MoDOT. Each record of the SS_INTERSECTION table corresponded to a leg of an intersection. The query criteria used to generate the list of four-leg signalized intersections is shown in Table 8.3. The DISTRICT_ABBR was used to run a separate query for each MoDOT district. The CONTROL_IN_OVERLAP field was utilized to include intersections only on the primary route in cases where there was route overlap. The database query was limited to 2011 data with the SS_INTRSC_YEAR field. Finally, the query was limited to signalized intersections only through use of the SIGNALIZED_FLAG field. After some preliminary queries were performed, it was determined the field NO_OF_APPRCH_LEGS in the SS_INTERSECTION table did not always contain the correct number of legs. For example, an intersection coded as a 3-leg intersection could actually be a 4-leg intersection in which the fourth leg was a signalized driveway. Therefore, the field NO_OF_APPRCH_LEGS was not used as part of the query criteria for urban four-leg signalized intersections.

Table 8.3 Query criteria for urban four-leg signalized intersections

Table	Field	Criteria
TMS_SS_INTERSECTION	DISTRICT_ABBR	Varies
TMS_SS_INTERSECTION	CONTROL_IN_OVERLAP	Y
TMS_SS_INTERSECTION	SS_INTRSC_YEAR	2011
TMS_SS_INTERSECTION	SIGNALIZED_FLAG	Y

The query criteria used to generate the list of three-leg signalized intersections is shown in Table 8.4. These criteria were similar to the criteria used for four-leg signalized intersections, with one modification. Since the number of three-leg signalized intersections, in comparison to the number of four-leg signalized intersections, was relatively small, the sampling for three-leg signalized intersections was performed using only intersections with a value of 3.0 in the NO_OF_APPRCH_LEGS field of the SS_INTERSECTION table.

Table 8.4 Query criteria for urban three-leg signalized intersections

Table	Field	Criteria
TMS_SS_INTERSECTION	DISTRICT_ABBR	Varies
TMS_SS_INTERSECTION	CONTROL_IN_OVERLAP	Y
TMS_SS_INTERSECTION	SS_INTRSC_YEAR	2011
TMS_SS_INTERSECTION	SIGNALIZED_FLAG	Y
TMS_SS_INTERSECTION	NO_OF_APPRCH_LEGS	3

During the sampling process for both three-leg and four-leg signalized intersections, visual verification of the samples was performed to ensure that each intersection had the proper number of legs and traffic control type. The AREA_DESG_NAME field was used to classify the intersections as rural or urban. Intersections with values of METROPOLITAN, URBAN, or URBANIZED in this field were classified as urban.

One challenge related to the sampling of intersections involved the availability of left turn phasing data for signalized intersections. It was determined that the signal data might not be available for signalized intersections that are not maintained by MoDOT. However, left-turn phasing data for intersections maintained by MoDOT were available. Thus, samples were limited to signalized intersections that were maintained by MoDOT.

8.3.1 Sampling for Urban Three-Leg Signalized Intersections

Another challenge encountered during intersection sampling was difficulty in locating samples for urban three-leg signalized intersections. Less than five percent of signalized intersections that were classified as three-leg in the MoDOT intersection database could actually be used as samples. Many intersections classified as three-leg in the database were actually four-leg intersections, because they contained a “fourth leg” that was also signalized and was frequently a commercial driveway entrance, a parking lot, or a leg offset by a short distance. This difficulty illustrates the need for visual inspection of potential calibration samples. Verification consisted of using aerial photographs and ARAN videos to observe different intersection features to validate intersections’ inclusion in the sample set.

A list of samples for urban three-leg signalized intersections is shown in Table 8.5. Only one sample was found each for the Northeast District and Northwest District. At-large samples were taken from the rest of the state to make up for the eight samples that could not be found in the Northeast District and Northwest District. Therefore, the sample set included six samples from the Southeast District, seven samples from the Southwest District, and 10 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. 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 also represented in the sample set.

8.3.2 Sampling for Urban Four-Leg Signalized Intersections

A list of samples for urban four-leg signalized intersections is shown in Table 8.6. 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 also represented in the sample set.

Table 8.5 List of sites for urban three-leg signalized intersections

Site No.	District	Description	Intersection 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	US 69 and Ramp I-35 N to US 69 (Exit 13)	132535	Pleasant Valley	Clay
9	KC	MO 291 (NE Cookingham Dr.) and N Flintlock Road	123483	Liberty	Clay
10	KC	US 40 and Entrance to Blue Ridge Crossing	929297	Kansas City	Jackson
11	NE	MO 15 and Boulevard St.	143089	Mexico	Audrain
12	NW	RT YY (Mitchell Ave.) and Woodbine Dr.	68340	St. Joseph	Buchanan

Site No.	District	Description	Intersection No.	City	County
13	SL	RT HH and Ramp RT HH W to MO 141 S	280553	Town and Country	St. Louis
14	SL	MO 100 and Woodgate Dr.	288254	St. Louis	St. Louis
15	SL	MO 231 (Telegraph Rd.) and Black Forest Dr.	324301	St. Louis	St. Louis
16	SE	US 61 and Old Orchard Rd.	489147	Jackson	Cape Girardeau
17	SE	US 62 (E Malone Rd) and Ramp IS 55 S to US 62	573057	Sikeston	Scott
18	SE	RT K and Siemers Dr.	496486	Cape Girardeau	Cape Girardeau
19	SE	US 61 and Smith Ave.	574289	Sikeston	Scott
20	SE	Business 60 and Walmart Entrance	588152	Dexter	Stoddard
21	SL	MO 94 and Ramp MO370W TO MO94	219957	St. Charles	St. Charles
22	SL	US 50 and Independence Dr.	653651	Union	Franklin
23	SL	RT B (Natural Bridge Rd.) and Fee Fee Rd.	928641	St. Louis	St. Louis
24	SL	MO 180 and Stop n Save (St. John Crossing)	251803	St. John	St. Louis
25	SL	MO 267 (Lemay Ferry Rd.) and Victory Dr.	313246	St. Louis	St. Louis

Site No.	District	Description	Intersection No.	City	County
26	SL	MO 47(W. Gravois Ave.) and MO 30 (Commercial Ave.)	347423	St. Clair	Franklin
27	SE	BU 60 (N Westwood Blvd.) and Valley Plaza Entrance	651105	Poplar Bluff	Butler
28	SW	LP 49B/BU 60/BU 71 (N Rangeline Rd.) and Turkey Creek Road (North Park Ln)	543380	Joplin	Jasper
29	SL	RT D and Page Industrial Blvd.	257667	St. Louis	St. Louis
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

Table 8.6 List of sites for urban four-leg signalized intersections

Site No.	District	Description	Intersection 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

Site No.	District	Description	Intersection No.	City	County
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	US 59 (S 6th St.) and Atchison St.	926385	St. Joseph	Buchanan
20	NW	MO 6 (E 9th St.) and Harris Ave.	41614	Trenton	Grundy
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) and RT K (William St.)	496355	Cape Girardeau	Cape Girardeau
24	SE	MO 47 and Ramp US 67 S to MO 47	412022	Bonne Terre	St. Francois
25	SE	MO 53 and MO 142/RT WW	599957	Poplar Bluff	Butler

Site No.	District	Description	Intersection No.	City	County
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	US 60 (W Sunshine St) and Ramp US 60 W to US 60 W/MO 413 S/W Sunshine St.	528475	Republic	Greene
34	SW	MO 18 (Ohio St.) and BU 13 (S 2nd St.)	345687	Clinton	Henry
35	SW	MO 14 (W Mt. Vernon St.) and RT M (N Nicholas Rd.)	554723	Nixa	Christian

8.4 Data Collection

A list of the data types collected for urban signalized intersections and their sources is shown in Table 8.7. Aerial photographs were used to determine the number of approaches with turn lanes, the maximum number of lanes crossed by pedestrians, the number of bus stops within 1,000 feet, the number of schools within 1,000 feet, and the number of alcohol sales establishments within 1,000 feet. ARAN, along with aerial and street view photographs from Google, was used to determine the presence of lighting at the 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. Due to the lack of availability of pedestrian volume data, the HSM default values for medium levels of pedestrian volumes (400 crossings per day for urban three-leg signalized intersections and 700 crossings per day for urban four-leg signalized intersections) were used.

Table 8.7 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)	HSM Default for Medium
Max. Number of Lanes Crossed by Pedestrians	Aerials
Number of Bus Stops within 1000'	Aerials
Number of Schools within 1000'	Aerials
Number of Alcohol Sales Establishments within 1000'	Aerials
Presence of Lighting	ARAN and Street View
Presence of Red-Light Running Cameras	MoDOT
No. of Crashes	TMS

Several challenges were encountered during the collection of data for signalized intersections. One such challenge concerned the determination of the type of left-turn phasing. The HSM requires a single input for left-turn phasing, but some intersections had different left-turn phasing during different times of the day. Different options, such as using the left-turn phasing in the peak hour, using the most predominant left-turn phasing, or using an average CMF based on both peak hour and predominant phasing were considered. Since IHSDM does not have a tool for averaging CMFs in the calibration process and requires the number of approaches with each type of left-turn phasing as the input data, it was decided not to use the average CMF option. Most of the data received from the MoDOT districts indicated only one type of left-turn phasing. The use of the predominant phase based on time in operation seemed to be the most straightforward and consistent with the way that users of the HSM would interpret this data field. Therefore, the use of the most predominant left-turn phasing based on time in operation was determined to be the best approach.

Another question related to the application of the CMFs for left-turn phasing. In this case, the use of engineering judgment was necessary to supplement the information contained in the HSM. The calibration of three-leg and four-leg signalized intersections required data for the number of approaches with a given type of left-turn phasing treatment. However, the HSM contained some conflicting information regarding whether this data should be collected for all approaches or for major approaches only. Chapter 12 of the HSM (Predictive Method for Urban and Suburban Arterials) indicated that this data should be collected for major approaches only. However, the discussion of left turn phasing in chapter 14 of the HSM (Intersections) states that the Crash Modification Factors (CMFs) for left turn phasing can be applied to all approaches. Based on HSM chapter 14, it seemed reasonable that left turn phasing data should be collected for all approaches, since the CMFs could be applied to all approaches. The AASHTO helpdesk was consulted for guidance, and confirmed that left turn phasing data should be collected for all approaches.

Another question that arose during the collection of data for signalized intersections was how to count alcohol sales establishments that were located within 1,000 feet of a signalized intersection. The HSM recommendation that any type of establishment that could sell alcohol, including convenience stores, gas stations, liquor stores, and grocery stores, was followed.

8.4.1 Summary Statistics for Urban Three-Leg Signalized Intersections

Descriptive statistics for urban three-leg signalized intersections are shown in Table 8.8. The average AADT for the major approaches was 17,551 vpd, and the average AADT for the minor approach was 2,795 vpd. The average number of approaches with left turn lanes was 1.8, and the average number of approaches with right turn lanes was 1.4, 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. The average value for the maximum number of lanes crossed by pedestrians 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 1.0. The average number of crashes was 15.2. The standard deviation was 13.0, indicating that the number of crashes at these intersections varied considerably. The total number of crashes for these intersections was 531, which was greater than the minimum of 300 crashes recommended by the HSM. All of these intersections had lighting, while none of the intersections had red-light running cameras.

Table 8.8 Sample descriptive statistics for urban three-leg signalized intersections (Sample size = 35)

Description	Average	Min.	Max.	Std. Dev.
Major AADT (2011)	17551	4704	44707	8845
Minor AADT (2011)	2795	199	7439	1653
No. of Approaches With Left Turn Lanes	1.8	1.0	3.0	0.5
No. of Approaches with Right Turn Lanes	1.4	0.0	2.0	0.7
No. of Approaches with Permissive Left Turn Phasing	0.1	0.0	1.0	0.2
No. of Approaches with Protected/Permissive Left Turn Phasing	0.5	0.0	1.0	0.5
No. of Approaches with Protected Left Turn Phasing	1.4	1.0	2.0	0.5
No. of Approaches with Prohibited RTOR	0.1	0.0	1.0	0.2
Pedestrian Volumes Crossing All Intersection Legs	400	400	400	0
Max. Number of Lanes Crossed by Pedestrians	4.4	3.0	6.0	0.9
No. of Bus Stops within 1000'	0.6	0.0	5.0	1.3
No. of Schools within 1000'	0.1	0.0	1.0	0.4
No. of Alcohol Sales Establishments within 1000'	0.6	0.0	3.0	0.8
No. of Crashes (3 Years)	15.2	0.0	64.0	13.0
Description				**No. of Intersections**
Lighting				35
Presence of red-light running cameras				0

8.4.2 Summary Statistics for Urban Four-Leg Signalized Intersections

Descriptive statistics for urban four-leg signalized intersections are shown in Table 8.9. The average AADT for the major approaches was 16,399 vpd, similar to urban three-leg intersections, and the average AADT for the minor approaches was 7,801 vpd. The average number of approaches with left turn lanes was 3.1 (1.7 times larger than three-leg), and the average number of approaches with right turn lanes was 1.7, indicating that the presence of turn lanes was common at these intersections. The sampled intersections had some variation in left turn phasing, with protected left turn phasing being the most common. There was only one intersection approach at which right-turn-on-red was prohibited. The average value for the maximum number of lanes crossed by pedestrians was 4.5, 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 1.0. The average number of crashes was 38.5, indicating that four-leg intersections experienced more crashes than did three-leg intersections. The standard deviation for the number of crashes was 29.2, indicating that the number of crashes at these intersections varied considerably. The total number of crashes was 1,347, 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.

Table 8.9 Sample descriptive statistics for urban four-leg signalized intersections (Sample size = 35)

Description	Average	Min.	Max.	Std. Dev.
Major AADT (2011)	16399	4287	35406	6616
Minor AADT (2011)	7801	1432	21203	5568
No. of Approaches With Left Turn Lanes	3.1	1.0	4.0	1.1
No. of Approaches with Right Turn Lanes	1.7	0.0	4.0	1.6
No. of Approaches with Permissive Left Turn Phasing	1.1	0.0	4.0	1.5
No. of Approaches with Protected/Permissive Left Turn Phasing	1.3	0.0	4.0	1.6
No. of Approaches with Protected Left Turn Phasing	1.6	0.0	4.0	1.7
No. of Approaches with Prohibited RTOR	0.0	0.0	1.0	0.2
Pedestrian Volumes Crossing All Intersection Legs	700.0	700.0	700.0	0.0
Max. Number of Lanes Crossed by Pedestrians	4.5	2.0	7.0	1.2
No. of Bus Stops within 1000'	0.6	0.0	8.0	1.6
No. of Schools within 1000'	0.1	0.0	1.0	0.3
No. of Alcohol Sales Establishments within 1000'	0.8	0.0	3.0	0.9
No. of Crashes (3 Years)	38.5	1.0	121.0	29.2
Description				**No. of Intersections**
Lighting				35
Presence of red-light running cameras				1

8.5 Results and Discussion

The original data were obtained from a number of intersections in Minnesota and North Carolina. The process of intersection selection and measure of suitability is described in greater detail in Harwood et al. (2007). A total of 363 intersections were analyzed, of which 182 were in Minnesota and 181 were in North Carolina. Of the 363 intersections analyzed, 184 were signalized, of which 76 were three-leg intersections and 108 were four-leg intersections. In Minnesota, the observed accident rate was averaged to be $0.32/10^6$ entering vehicles for three-leg intersections and $0.48/10^6$ entering vehicles for four-leg intersections. In North Carolina, the observed accident rate was averaged to be $0.89/10^6$ entering vehicles for three-leg intersections and $1.34/10^6$ entering vehicles for four-leg intersections.

The calibration factor for urban three-legged signalized intersections in Missouri yielded a calibration factor value of 3.03. The IHSDM output is shown in Figure 8.1. The calibration factor for urban four-leg signalized intersections in Missouri yielded a calibration factor value of 4.91. The IHSDM output is shown in Figure 8.2. 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 this site type. For comparison, calibration results for a few other states are shown in Table 8.10.

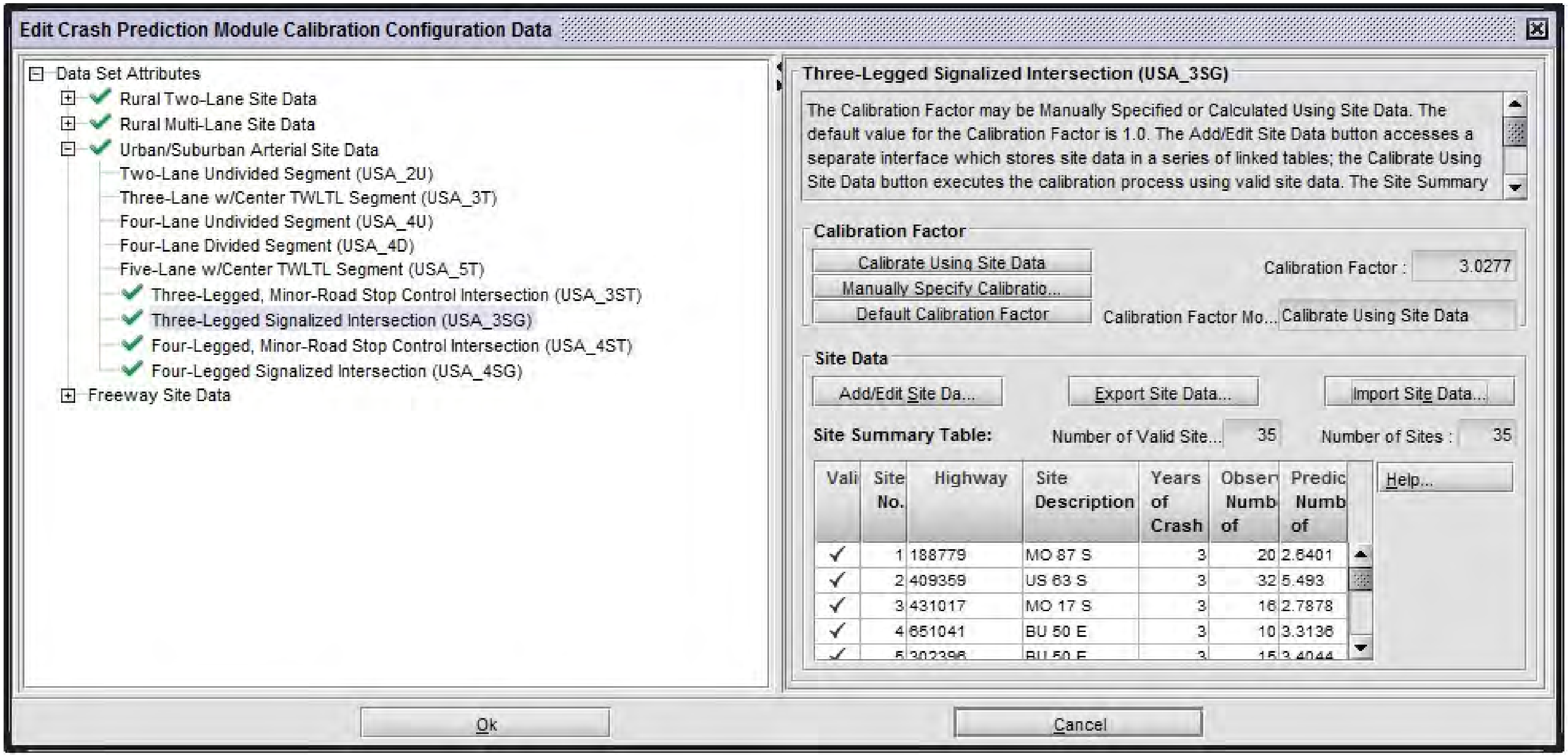


Figure 8.1 Calibration output for urban three-leg signalized intersections

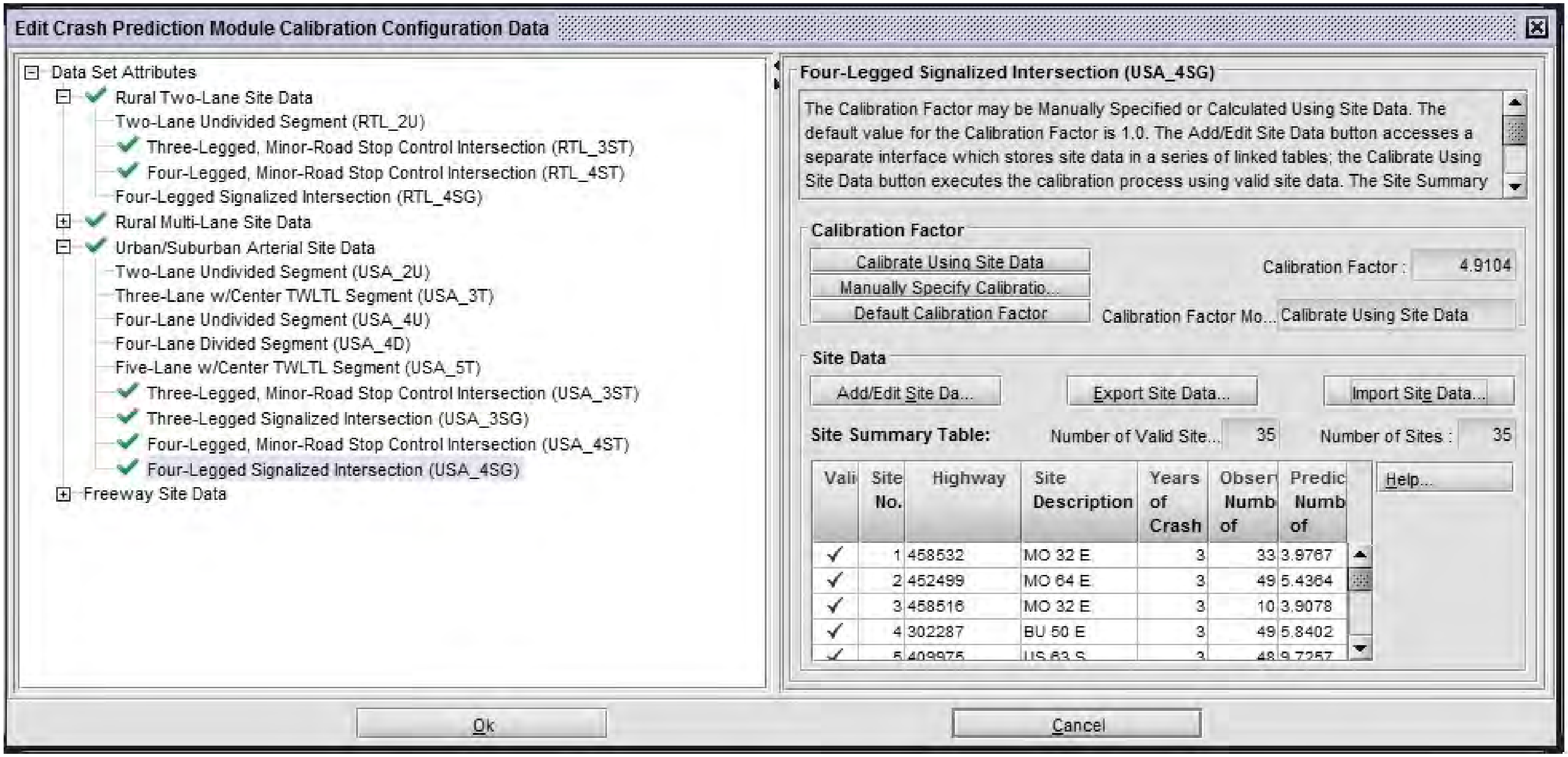


Figure 8.2 Calibration output for urban four-leg signalized intersections

Table 8.10 Calibration results from other states

State	Description	Years of Data	Calibration Factor
Oregon (Xie et al. 2011)	U3SG	2004-2006	0.74
	U4SG	2004-2006	1.04
Florida (Sivaramakrishnan 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

Due to the high values of the calibration factors for signalized intersections, data checks and additional investigations were performed. The calibration process was re-checked to ensure that this was not the result of error in the calibration process. Specifically, the log mile locations of each crash were verified to be at the same location as the intersection, thus ruling out the possibility of crashes from nearby intersections being incorrectly included.

To further investigate the results, computation error in the IHSDM software was eliminated as a factor. Computations using HSM Part C AASHTO spreadsheets were tested for comparison with IHSDM. Manual calculations were also performed following the step-by-step HSM instructions as a third option. The calibration factor was included in the calculations. One three-leg sample (Site No. 1: RT B/MO 87/Main St. and MO 87/Bingham Rd.) and one four-leg sample (Site No. 1: MO 32 and MO 19/Main St.) were chosen to be tested using the three different calculation methods. The results, shown in Table 8.11, were almost identical among the three calculation methods, with only minor differences.

Table 8.11 Comparison of three computation methods

	AASHTO Spreadsheet	IHSDM	Manual calculation
Three-leg Calibration Value (RT B/MO 87/Main St. and MO 87/Bingham Rd.)	0.9	0.9372	0.93724
Four-leg Calibration Value (MO 32 and MO 19/Main St.)	1.3	1.3223	1.32530
Number of alcohol sales	0, 1 – 8, > 9	Any number	Any number
Bus stop	0, 1 – 2, > 3	Any number	Any number
Pedestrian Volumes	240 or 700	Any number	Any number

Several reasons exist for the minor differences observed between the three calculation methods. First, the AASHTO spreadsheet rounds off to one decimal place, whereas IHSDM keeps four decimal places. Second, for the number of alcohol sales, IHSDM allows the input of any observed number, while the AASHTO spreadsheets give three choices (0, 1 ~ 8, > 9). For bus stop information, IHSDM again allows the input of any observed number, while the AASHTO spreadsheets give three choices (0, 1 ~ 2, > 3). For pedestrian volumes, the AASHTO spreadsheets give two options (240 and 700), while IHSDM allows the input of any observed number. Because similar results were obtained from the three computation methods, the calculation methods of the IHSDM were verified. For the calibration of multiple sites, IHSDM offers some advantages over the AASHTO spreadsheets. IHSDM allows for the import of text files, and can handle all samples at once while minimizing data entry errors from typing and clicking. The AASHTO spreadsheets require the individual input of data for each sample, which could cause input errors.

Three possible remaining explanations for the large 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. Because of these differences, it may be desirable for Missouri to develop its own SPFs for urban four-legged and three-legged signalized intersections. Some possible reasons for the high calibration factor are explored in the following sections.

8.5.1 Differences in Definition of Intersection Crash

One possible contributing factor to the high calibration factor was the difference between Missouri and the HSM in the definition of an intersection crash. According to the Missouri STARS Manual, 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 some other states, does not have a checkbox for an officer to indicate that the crash was "intersection-related." The new STARS Manual (MSC 2012) was revised on January 1, 2012, thus, it was not applicable to the data collected before that date. The new manual was reviewed to determine whether changes were made to the intersection definition. The new manual also had similar instructions for marking "AT" for the "LOCATION" field, with a slightly different description of "if the crash occurred within the confines of the intersection…" According to Myrna Tucker from MoDOT Transportation Management System (TMS), if a crash occurred within 132 feet 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. Therefore, the TMS Accident Browser classified a crash that occurs within 132 feet of an intersection as an intersection crash.

The HSM SPFs for signalized intersections were developed by 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 this set of criteria is to ensure that only accidents that occurred because the intersection was present would be attributed to the intersection.

It is clear that the Missouri criteria for an intersection crash differ from that used for HSM SPF development. The two main differences are the "intersection-related" checkbox and the difference in distance threshold. But it is unclear how much of the large calibration factor can be attributable to the intersection criteria differences. On the one hand, the omission of "intersection-related" crashes means that Missouri over-classifies some crashes, since not all crashes within 132 feet are intersection-related. For example, driveway-related crashes within 132 feet would be misclassified as intersection crashes. On the other hand, Missouri's threshold is smaller, thus it would under-classify intersection-related crashes that occurred between 132 and 250 feet; for example, a queue-related rear end crash could be misclassified.

8.5.2 Differences in Data

In addition to differences in the definition of an intersection crash, there were also 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 number of study intersections is shown in Table 8.12. The totals of 96 and 108 intersections represent a significant, but not very large, number of intersections. The crash data for Minnesota were obtained from 1998 to 2002, and 1997 to 2003 in the case of North Carolina.

Table 8.12 Number of study intersections

Intersection Type	Minnesota	North Carolina	Total
3SG	34	42	96
4SG	64	44	108

The use of Charlotte and the Twin Cities for HSM SPF development could introduce many possible explanations for the high calibration factor. First, the HSM models were based on data from highly populated urban areas. According to United States census data, the city of Charlotte had an estimated population of 735,780 in 2010, and the cities of Minneapolis and St. Paul had an estimated combined population of 683,650 in 2010 (U.S. Census Bureau). The HSM definition of urban areas is much broader, and is based on FHWA guidelines which define urban areas as having a population of 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 greater diversity in the size of urban areas with smaller cities such as Troy (estimated 2010 city population = 10,540, U.S. Census Bureau) and larger cities such as St. Louis (estimated 2010 city population = 318,172, U.S. Census Bureau) than the HSM calibration data set. 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, since the Missouri data set included samples from smaller urban areas. The regression coefficients in the HSM models may have been different if the sample set had included greater diversity in the size of the urban areas. The HSM models did not include some of the characteristics of signalized intersections, such as turn lane lengths, length of all-red interval, size of signal heads, and presence of flashing yellow arrows, that may differ between Minnesota, North Carolina, and Missouri. These missing characteristics could lead to differences in predicted crashes. There may also be differences in the way that crashes are reported in Missouri, Charlotte, and the Twin Cities such as differences in the threshold for a PDO crash.

It is unclear to what degree differences between the state of Missouri and the states of 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, since they were chosen as candidate sites for SPF development.

8.5.3 Changes in Driver Behavior Over Time

Another possible explanation for the high calibration factor 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 with drivers who text and talk on cell phones. Distracted driving could be a significant factor in rear end crashes at intersections.

Chapter 9 Unsignalized Intersections

9.1 Introduction and Scope

Multiple chapters of the HSM describe the methodology for crash prediction on the different types of unsignalized intersections. The different types include:

9.1.1 Rural Two-Lane Three-Leg Unsignalized Intersections (Chapter 10 of HSM)

9.1.2 Rural Two-Lane Four-Leg Unsignalized Intersections (Chapter 10 of HSM)

9.1.3 Rural Multilane Three-Leg Unsignalized Intersections (Chapter 11 of HSM)

9.1.4 Rural Multilane Four-Leg Unsignalized Intersections (Chapter 11 of HSM)

9.1.5 Urban Three-Leg Unsignalized Intersections (Chapter 12 of HSM)

9.1.6 Urban Four-Leg Unsignalized Intersections (Chapter 12 of HSM)

All of these unsignalized intersection types were calibrated as part of this project.

9.2 HSM Methodology

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

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

In chapter 10 of the HSM, the SPFs for rural two-lane three- and four-leg unsignalized intersections include the effect of major and minor stop control road traffic volumes (AADTs) for the prediction of average crash frequency for intersection related crashes within the limits of a particular intersection and on the intersection legs. The SPFs consider rural two-way stop controlled intersections with two lanes only, in both the major and minor road legs, without including the turning lanes.

The SPFs for both intersection types are given by:

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

(Eq. 10-8, Vol. 2, HSM 2010)

$$N_{spf\ 4ST} = \exp\left[-8.56 + 0.60 \times \ln\left(AADT_{maj}\right) + 0.61 \times \ln(AADT_{min})\right] \quad (9.1)$$

(Eq. 10-9, Vol. 2, HSM 2010)

where,

$N_{spf\ 3ST}$ = estimate of intersection related predicted average crash frequency for base conditions for rural three-leg stop-controlled intersections;

$N_{spf\ 4ST}$ = estimate of intersection related predicted average crash frequency for base conditions for rural four-leg stop-controlled intersections;

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

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

In Table 9.1, the following parameters applicable for both equations are listed.

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

Intersection Type	**Rural Unsignalized**	
	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 considered for both SPFs are described in Table 9.2.

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
Lightning	None

9.2.2 Rural Multilane Three- and Four-Leg Unsignalized Intersections

In chapter 11 of the HSM, the SPFs for rural multilane three- and four-leg unsignalized intersections include the effect of the major and minor stop control road traffic volumes (AADTs) for the prediction of average crash frequency for intersection related crashes within the limits of a particular intersection and on the intersection legs. The SPFs consider rural multilane highway facilities with four through lanes and stop control on minor road approaches. The SPFs for both intersection types are given by:

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

(Eq. 11-11, Table 11-7, 3ST Total, Vol. 2, HSM 2010)

$$N_{spf\ 4ST} = \exp[-10.008 + 0.848 \times \ln(AADT_{maj}) + 0.448 \times \ln(AADT_{min})] \quad (9.2)$$

(Eq. 11-11, Table 11-7, 4ST Total, Vol.2, HSM 2010)

where,

$N_{spf\ 3ST}$ = estimate of intersection related predicted average crash frequency for base conditions for multilane three-leg stop-controlled intersections;

$N_{spf\ 4ST}$ = estimate of intersection related predicted average crash frequency for base conditions for multilane four-leg stop-controlled intersections;

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

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

In Table 9.3, the following parameters are applicable for both equations are listed.

Table 9.3 SPFs Rural unsignalized multilane three/four-leg stop-controlled int. 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

The base conditions considered for both SPFs are described in Table 9.4.

Table 9.4 SPFs Multilane unsignalized three/four-leg stop-controlled int. 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

9.2.3 Urban Three- and Four-Leg Unsignalized Intersections

In chapter 11 of the HSM, the SPFs for urban three- and four-leg unsignalized intersections include the effect of the major and minor stop control road traffic volumes (AADTs) for the prediction of average crash frequency for intersection related crashes within the limits of a particular intersection and on the intersection legs. The SPFs consider intersections on urban and suburban arterials with stop control on minor road approaches. Finally, the SPF is divided in two components accounting for multiple-vehicle collisions and single-vehicle collisions for base conditions. The SPFs for both intersection types are given by:

$$N_{spf\ int} = N_{bimv} + N_{bisv} \tag{9.3}$$

(Eq. 12-7, Vol. 2, HSM 2010)

where,

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

N_{bimv} = predicted average number of multiple-vehicle collisions for base conditions;

N_{bisc} = predicted average number of single-vehicle collisions for base conditions.

Multiple-Vehicle Collisions

$$N_{bimv\ 3ST} = \exp\left[-13.36 + 1.11 \times \ln\left(AADT_{maj}\right) + 0.41 \times \ln(AADT_{min})\right] \qquad (9.4)$$

(Eq. 12-21, Table 12-10, Total Crashes 3ST, Vol. 2, HSM 2010)

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

(Eq. 12-21, Table 12-10, Total Crashes 4ST, Vol.2, HSM 2010)

where,

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

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

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

Single-Vehicle Crashes

$$N_{bisv\ 3ST} = \exp\left[-6.81 + 0.16 \times \ln\left(AADT_{maj}\right) + 0.51 \times \ln(AADT_{min})\right] \qquad (9.5)$$

(Eq. 12-24, Table 12-12, Total Crashes 3ST, Vol. 2, HSM 2010)

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

(Eq. 12-24, Table 12-12, Total Crashes 4ST, Vol.2, HSM 2010)

where,

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

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

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

In Table 9.5, the following overdispersion parameters are applicable for the equations are listed.

Table 9.5 SPFs Urban unsignalized multiple-vehicle collision overdispersion parameters

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

The SPFs are applicable to the following AADTs rages listed in Table 9.6.

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

9.3 Sampling Considerations

In order to generate samples for signalized intersections, the lists of all intersections for each district from the SS_INTERSECTION table provided by MoDOT were queried by the UNSIGNALIZED_FLAG field to obtain lists of signalized intersections for each district. These lists were used for the sampling of unsignalized intersections. During the sampling process, visual verification of the samples was performed visually to ensure that each intersection had the proper number of legs and stop control in the minor road. The AREA_DESG_NAME field was used to classify the intersections as rural or urban. Intersections with values of

METROPOLITAN, URBAN, or URBANIZED in this field were classified as urban. The AADT field was used to reduce the query exclusively to intersections that contained values for all legs.

9.3.1 Sampling for Unsignalized Intersections

Different challenges were encountered during the sampling of unsignalized intersections. Initially, it was essential to use visual identification to verify the existence of stop control in the minor road only. Out of all classifications, it was considerably more difficult to perform stop control verification for rural areas, since neither ARAN records nor Google Earth images existed; these samples, therefore, were not included . In general, sampling for all unsignalized intersections in rural areas was more difficult than for urban, due to the difficulty 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 considerations were taken to attempt 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. Although it remained difficult to find rural multilane unsignalized three-leg intersections, since some districts did not have a large set of intersections along the facility within the district's region, the lack of samples was compensated for by using available samples from other districts. As a result of the sampling process, a total of 420 unsignalized intersections were sampled. The lists of intersections can be found in Tables 9.7-9.12.The tables contain the intersection number that was used for the identification and collection of the data. The locations (county and district) of intersections were also included. The lists display the 10 intersections that were collected for each district. As mentioned previously, when a district lacked sufficient samples for rural multilane intersections, the deficit was compensated for with samples from other districts. This can be observed in the list of intersections in Tables 9.11 and 9.12.

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, Dent, Missouri 65560	462095	Dent
5	CD	Blank Rd, Hwy Hh, Vanpool Rd, Burris Fork, Moniteau, MO 65074	313734	Moniteau
6	CD	County Road 432, Hwy 240, Howard, MO	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	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	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	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	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, ew Florence, Montgomery, MO 63363	200260	Montgomery
30	NE	Pike 57, Pike 58, RA, Pike, MO 63441	98338	Pike

Site No.	District	Description	Intersection No.	County
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	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, Hopkins, 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, Duoglas, 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	Ste. Genevieve
46	SE	State Hwy U, Hwy 76, Miller, Douglas, MO	563643	Douglas
47	SE	Hwy 160, 3rd St, Ozark, MO	659340	Ozark
48	SE	County Road 223, Hwy M, Stoddard, MO	564661	Stoddard
49	SE	County Road 95-142, Hwy 95, Wood, 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, House Springs, 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, Pacific, 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
60	SL	Dutch Creek Rd, Byrnesville Rd, Cedar Hill, Jefferson, MO 63016	338859	Jefferson

Site No.	District	Description	Intersection No.	County
61	SW	19th St, Cassville, Hwy 37, Main St, Barry, MO	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, Missoury T, Turnback, Lawrence, MO	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	452012	Cedar
70	SW	Wilson Rd, Hwy Zz, Lincoln, Christian, MO	548004	Christian

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, Route F, Lebanon, 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, Salem, 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, Boulware, Gasconade, MO 65041	941340	Gasconade
10	CD	Humphrey Creek Road, Hwy A, Osage, Miller, MO	376560	Miller

Site No.	District	Description	Intersection No.	County
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, ERD Mize Rd, Oak Grove, 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, Harrisonville, 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, Liberty, 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, Unionville, 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, Marceline, 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

Site No.	District	Description	Intersection No.	County
41	SE	State Hwy F, Luyster St (School), Koshkonong, Oregon, MO 65692	626406	Oregon
42	SE	Pcr 452, Hwy A, Chirch St, Brazeau, Perry, MO	453325	Perry
43	SE	County Road 738, 702, Hwy Y, Wayne, 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, Cape 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, La Font, New Madrid, MO 63873	640131	New madrid
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, Boone, St. Charles, 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, Hwy V, 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, Boeuf, 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, Saint 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, East Madison, Polk, 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, Sparta, Christian, MO 65753	562392	Christian
70	SW	1st St, Hwy P, St. Clair, MO 64724	375649	St. Clair

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

Site No.	District	Description	Intersection No.	County
1	CD	State Hwy K, Hwy 50, Walker, Moniteau, MO 65018	4740966	Moniteau
2	CD	3rd St, Hwy 54, Camdenton, Camden, MO 65020	4929775	Camden
3	CD	State Hwy D, Hwy 54, Lohman, Cole, MO	4563556	Cole
4	CD	5th St, Hwy 54, Camdenton, Camden, MO 65020	4585157	Camden
5	CD	Iowa St (Lake Ave), Hwy 54, Camdenton, Camden, MO 65020	4836929	Camden
6	CD	Grant Ave, Hwy 54, Camdenton, Camden, MO 65020	4718708	Camden
7	CD	Missouri A, Hwy 54, Candem, MO	4583408	Camden
8	CD	County Road 348, Hwy 54, New Bloomfield, Callaway, MO 65063	4618863	Callaway
9	CD	4th Street, Hwy 54, Camdenton, Camden, MO 65020	4280116	Camden
10	CD	County Rd 158, Hwy 54, Jackson, Callaway, MO 65231	4787742	Callaway
11	KC	NW 375th Rd, Hwy 50, Johnson, MO	4547236	Johnson
12	KC	OR 50 (Old Highway 50), Hwy 50, Dresden, Pettis, Missouri 65301	4382682	Pettis
13	KC	Elm Hills Blvd, Hwy 65, Sedalia, Pettis, MO 65301	4218518	Pettis
14	KC	Missouri TT, Hwy 7, Harrisonville, Cass, Missouri 64701	4859780	Cass
15	KC	Hwy H, Hwy 65, Saline, MO	4785366	Saline
16	NE	State Hwy J, Hwy 24, Ralls, MO	4519663	Ralls
17	NE	State Hwy Dd, Hwy 24 (Hwy 36), Marion, MO	4770604	Marion
18	NE	State Hwy Hh, Hwy 61, Clay, Ralls, MO	4092878	Ralls
19	NE	Rte J, Hwy 63, Macon, MO	4635556	Macon
20	NE	Kensington Pl, Hwy 63, Macon, MO 63552	4734131	Macon
21	NE	State Hwy H, Hwy 24, South River, Marion, MO	4524282	Marion
22	NE	Thompson St, Hwy 24, Hwy 61, Palmyra, Marion, MO 63461	4618618	Marion
23	NE	County Road 263, Hwy 24, South River, Marion, MO	4618845	Marion
24	NE	Hwy F, Hwy 61, Eolia, Lincoln, MO 63344	4844477	Lincoln
25	NE	Hwy Ww, Hwy 61, Cuivre, Pike, MO	4115777	Pike
26	NE	County Road 494, Hwy 61, Canton, Lewis, MO 63448	4398324	Lewis
27	NW	County Road 139, Hwy 71, Rosendale, Andrew, MO 64483	4723639	Andrew
28	NW	County Road 140, Hwy 71, Bolckow, Andrew, MO 64427	4600549	Andrew
29	NW	400th Street, Hwy 71, White Cloud, Nodaway, MO	4900099	Nodaway
30	NW	Iris Trail, Hwy 71, White Cloud, Nodaway, MO	4063988	Nodaway

Site No.	District	Description	Intersection No.	County
31	NW	Hwy 33, Hwy 36, Dekaleb, MO	4886547	Dekalb
32	NW	Ava Dr, Hwy 36, Wheeling, Livingston, MO 64688	4087825	Livingston
33	NW	State Hwy Ab, Hwy 31, Hwy 36, Easton, Buchanan, MO 64443	4085487	Buchanan
34	NW	112 SE, Hwy 36, Easton, Buchanan, Missouri 64443	4706377	Buchanan
35	NW	County Road 364, Hwy 59 (71), Savannah, Andrew, MO 64485	4543630	Andrew
36	NW	County Road 54, Hwy 71, Rosendale, Andrew, MO 64483	4072624	Andrew
37	SE	County Road 547, Hwy 67, Black River, Wayne, MO 63967	4444336	Wayne
38	SE	Hwy EE, Hwy 67, Cedar Creek, Wayne, MO	4311154	Wayne
39	SE	County Road 303, Hwy 67, Madison, MO	4772296	Madison
40	SE	County Road 220, Hwy 67, Mine La Motte, Madison, MO 63645	4583279	Madison
41	SE	Pike Run Rd, Hwy 67, Big River, St. Francois, MO	4584548	St. Francois
42	SE	Tower Rd, Hwy 67, Big River, St. Francois, MO 63628	4281942	St. Francois
43	SE	Valles Mines Rd, Hwy 67, Valles Mines, MO 63087	4583395	St. Francois
44	SE	County Road 417, Hwy 67, Central, Madison, MO 63645	4308029	Madison
45	SE	County Road 454, 450, Hwy 67, Twelvemile, Madison, MO 63964	4804309	Madison
46	SE	County Road 452, Hwy 67, Twelvemile, Madison, MO 63964	4445327	Madison
47	SE	County Road 302, Hwy 67, Cedar Creek, Wayne, MO 63636	4649531	Wayne
48	SL	Elizabeth Anne Ln, Hwy 100, Franklin, MO	4485283	Franklin
49	SL	Cinder Rd, Hwy 67, West Alton, St. Charles, MO 63386	4724687	St. Charles
50	SL	Wise Rd, Hwy 67, West Alton, St. Charles, MO 63386	4761197	St. Charles
51	SW	Northwest 351 Road, Hwy 7, Fields Creek, Henry, MO 64735	4730099	Henry
52	SW	NW Hwy DD, Hwy 7, Honey Creek, Henry, MO	4844849	Henry
53	SW	NW 1401 Rd, Hwy 7, Bogard, Henry, MO 64788	4605617	Henry
54	SW	Frisch Avenue, Hwy 65, Lincoln, Benton, MO 65338	4563647	Benton
55	SW	Jenny Ln, Hwy 65, Lincoln, Benton, MO 65338	4757519	Benton
56	SW	Airport Rd, Hwy 65, Lincoln, Benton, MO 65338	4256681	Benton
57	SW	Lamine St, Hwy 65, Benton, MO 65338	4450449	Benton
58	SW	Locust St, Hwy 65, Lincoln, Benton, MO 65338	4570507	Benton
59	SW	Northwest 311 Road, Hwy 7, Fields Creek, Henry, MO 64735	4255378	Henry
60	SW	State Hwy Ac, Hwy 65, Benton, MO	4256983	Benton

Site No.	District	Description	Intersection No.	County
61	SW	Meyer Rd, Hwy 65, North Lindsey, Benton, MO	4835836	Benton
62	SW	Cedargate Dr, Hwy 65, Benton, MO	4566012	Benton
63	SW	NE Old 13 Hwy, Hwy 13, St. Clair, MO	4652554	St. Clair
64	SW	Crossroads Dr, Hwy 65, South Benton, Dallas, MO 65622	4755546	Dallas
65	SW	Foose Rd, Hwy 65, Jackson, Dallas, MO 65622	4795758	Dallas
66	SW	Branson Creek Boulevard, Hwy 65, Hollister, Taney, MO 65672	4621144	Taney
67	SW	Hwy UU, Hwy 13, St. Clair, MO	4756365	St. Clair
68	SW	Woodstock Rd, Hwy 65, Dallas, MO	4307024	Dallas
69	SW	Rocks Dale Rd, Hwy 65, Dallas, MO	4819426	Dallas
70	SW	State Hwy O, Diggins, Webster, MO 65746	4781599	Webster

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

Site No.	District	Description	Intersection No.	County
1	CD	State Hwy K, Hwy 50, Walker, Moniteau, MO 65018	4740966	Moniteau
2	CD	3rd St, Hwy 54, Camdenton, Camden, MO 65020	4929775	Camden
3	CD	State Hwy D, Hwy 54, Lohman, Cole, MO	4563556	Cole
4	CD	5th St, Hwy 54, Camdenton, Camden, MO 65020	4585157	Camden
5	CD	Iowa St (Lake Ave), Hwy 54, Camdenton, Camden, MO 65020	4836929	Camden
6	CD	Grant Ave, Hwy 54, Camdenton, Camden, MO 65020	4718708	Camden
7	CD	Missouri A, Hwy 54, Candem, MO	4583408	Camden
8	CD	County Road 348, Hwy 54, New Bloomfield, Callaway, MO 65063	4618863	Callaway
9	CD	4th Street, Hwy 54, Camdenton, Camden, MO 65020	4280116	Camden
10	CD	County Rd 158, Hwy 54, Jackson, Callaway, MO 65231	4689459	Camden

Site No.	District	Description	Intersection No.	County
11	KC	NW 375th Rd, Hwy 50, Johnson, MO	4547236	Johnson
12	KC	OR 50 (Old Highway 50), Hwy 50, Dresden, Pettis, Missouri 65301	4382682	Pettis
13	KC	Elm Hills Blvd, Hwy 65, Sedalia, Pettis, MO 65301	4218518	Pettis
14	KC	Missouri TT, Hwy 7, Harrisonville, Cass, Missouri 64701	4859780	Cass
15	KC	Hwy H, Hwy 65, Saline, MO	4785366	Saline
16	NE	State Hwy J, Hwy 24, Ralls, MO	4519663	Ralls
17	NE	State Hwy Dd, Hwy 24 (Hwy 36), Marion, MO	4770604	Marion
18	NE	State Hwy Hh, Hwy 61, Clay, Ralls, MO	4092878	Ralls
19	NE	Rte J, Hwy 63, Macon, MO	4635556	Macon
20	NE	Kensington Pl, Hwy 63, Macon, MO 63552	4734131	Macon
21	NE	State Hwy H, Hwy 24, South River, Marion, MO	4524282	Marion
22	NE	Thompson St, Hwy 24, Hwy 61, Palmyra, Marion, MO 63461	4618618	Marion
23	NE	County Road 263, Hwy 24, South River, Marion, MO	4618845	Marion
24	NE	Hwy F, Hwy 61, Eolia, Lincoln, MO 63344	4844477	Lincoln
25	NE	Hwy Ww, Hwy 61, Cuivre, Pike, MO	4115777	Pike
26	NE	County Road 494, Hwy 61, Canton, Lewis, MO 63448	4398324	Lewis
27	NW	County Road 139, Hwy 71, Rosendale, Andrew, MO 64483	4723639	Andrew
28	NW	County Road 140, Hwy 71, Bolckow, Andrew, MO 64427	4600549	Andrew
29	NW	400th Street, Hwy 71, White Cloud, Nodaway, MO	4900099	Nodaway
30	NW	Iris Trail, Hwy 71, White Cloud, Nodaway, MO	4063988	Nodaway
31	NW	Hwy 33, Hwy 36, Dekaleb, MO	4886547	Dekalb
32	NW	Ava Dr, Hwy 36, Wheeling, Livingston, MO 64688	4087825	Livingston
33	NW	State Hwy Ab, Hwy 31, Hwy 36, Easton, Buchanan, MO 64443	4085487	Buchanan
34	NW	112 SE, Hwy 36, Easton, Buchanan, Missouri 64443	4706377	Buchanan
35	NW	County Road 364, Hwy 59, Savannah, Andrew, MO 64485	4543630	Andrew
36	NW	County Road 54, Hwy 71, Rosendale, Andrew, MO 64483	4072624	Andrew
37	SE	County Road 547, Hwy 67, Black River, Wayne, MO 63967	4444336	Wayne
38	SE	County Road 209, Hwy 67, Cedar Creek, Wayne, MO	4311154	Wayne
39	SE	County Road 303, Hwy 67, Madison, MO	4772296	Madison
40	SE	County Road 220, Hwy 67, Mine La Motte, Madison, MO 63645	4583279	Madison

Site No.	District	Description	Intersection No.	County
41	SE	Pike Run Rd, Hwy 67, Big River, St. Francois, MO	4584548	St. Francois
42	SE	Tower Rd, Hwy 67, Big River, St. Francois, MO 63628	4281942	St. Francois
43	SE	Valles Mines Rd, Hwy 67, Valles Mines, MO 63087	4583395	St. Francois
44	SE	County Road 417, Hwy 67, Central, Madison, MO 63645	4308029	Madison
45	SE	County Road 454, 450, Hwy 67, Twelvemile, Madison, MO 63964	4804309	Madison
46	SE	County Road 452, Hwy 67, Twelvemile, Madison, MO 63964	4445327	Madison
47	SE	County Road 302, Hwy 67, Cedar Creek, Wayne, MO 63636	4649531	Wayne
48	SL	Elizabeth Anne Ln, Hwy 100, Franklin, MO	4485283	Franklin
49	SL	Cinder Rd, Hwy 67, West Alton, St. Charles, MO 63386	4724687	St. Charles
50	SL	Wise Rd, Hwy 67, West Alton, St. Charles, MO 63386	4761197	St. Charles
51	SW	Northwest 351 Road, Hwy 7, Fields Creek, Henry, MO 64735	4730099	Henry
52	SW	NW Hwy DD, Hwy 7, Honey Creek, Henry, MO	4844849	Henry
53	SW	NW 1401 Rd, Hwy 7, Bogard, Henry, MO 64788	4605617	Henry
54	SW	Frisch Avenue, Hwy 65, Lincoln, Benton, MO 65338	4563647	Benton
55	SW	Jenny Ln, Hwy 65, Lincoln, Benton, MO 65338	4757519	Benton
56	SW	Airport Rd, Hwy 65, Lincoln, Benton, MO 65338	4256681	Benton
57	SW	Lamine St, Hwy 65, Benton, MO 65338	4450449	Benton
58	SW	Locust St, Hwy 65, Lincoln, Benton, MO 65338	4570507	Benton
59	SW	Northwest 311 Road, Hwy 7, Fields Creek, Henry, MO 64735	4255378	Henry
60	SW	State Hwy Ac, Hwy 65, Benton, MO	4256983	Benton
61	SW	McDaniel Rd, Hwy 65, North Lindsey, Benton, MO	4835836	Benton
62	SW	Cedargate Dr, Hwy 65, Benton, MO	4566012	Benton
63	SW	NE Old 13 Hwy, Hwy 13, St. Clair, MO	4652554	St. Clair
64	SW	Crossroads Dr, Hwy 65, South Benton, Dallas, MO 65622	4755546	Dallas
65	SW	Foose Rd, Hwy 65, Jackson, Dallas, MO 65622	4795758	Dallas
66	SW	Branson Creek Boulevard, Hwy 65, Hollister, Taney, MO 65672	4621144	Taney
67	SW	Hwy UU, Hwy 13, St. Clair, MO	4756365	St. Clair
68	SW	Woodstock Rd, Hwy 65, Dallas, MO	4306601	Dallas
69	SW	Rocks Dale Rd, Hwy 65, Dallas, MO	4819426	Dallas
70	SW	State Hwy O, Diggins, Webster, MO 65746	4781599	Webster

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 Ketucky Rd, Jackson, Missouri 64050	147308	Jackson
21	NE	Sparks Avenue, Buchanan St, Moberly, Randolph, MO 65270	1031957	Randolph
22	NE	Daugherty St, Rollings 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

Site No.	District	Description	Intersection No.	County
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
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

Site No.	District	Description	Intersection No.	County
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 List of sites for urban four-leg unsignalized intersections

Site No.	District	Description	Intersection 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

Site No.	District	Description	Intersection No.	County
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 RdKansas 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, Pricenton 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

Site No.	District	Description	Intersection No.	County
41	SE	Mary Street, Hwy 61, Jackson, Cape Girardeau, MO 63755	484881	Cape girardeau
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

9.4 Data Collection

The data required for 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 9.7. Aerial photographs were used to determine the presence of either left of right turning lanes, the number of legs, and the skew angle. ARAN, along with aerial and street view photographs from Google, were used to determine the presence of lighting at the intersections. The AADTs and total crashes were collected from the TSM system.

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

Several challenges were encountered during the collection of data for unsignalized intersections. The major issue encountered occurred when the AADT data collection was initiated. Several of the sampled intersections did not have AADT data for any of the intersection legs. Consequently, the decision was made to resample all rural unsignalized intersections, since it would require less effort than verifying the existing set of samples and replacing the intersections lacking data, with the possibility of multiple errors that could occur during the process. The new samples were generated from intersections with AADT data available. Another challenge involved accident data collection. For all classifications of rural unsignalized intersections, the total number of accidents for the time period in consideration was considerably less than 100 (the HSM recommends a value of at least 100 accidents), and in most cases did not exceed 20 accidents. Therefore, the number of samples was increased (doubled) in order to try to reach the minimum recommended number of accidents. Unfortunately, even though the intersection samples were increased, the minimum recommendation was still not reached.

9.4.1 Summary Statistics for Unsignalized Intersections

Descriptive statistics for all unsignalized intersections are shown in Table 9.14. It can be seen that the average AADT was low for rural two-lane facilities major approach, intermediate for urban unsignalized intersections, and higher for rural multilane intersections.

Table 9.14 Sample descriptive statistics for unsignalized intersections (Sample size = 70 per intersection type)

Description	**Ave.**	**Min.**	**Max.**	**Std. Dev.**	**Ave.**	**Min.**	**Max.**	**Std. Dev.**	**Ave.**	**Min.**	**Max.**	**Std. Dev.**
Intersection Type	R2L 3ST				RML 3ST				U 3ST			
Major AADT (2011)	1421	40	6828	1722	11069	3098	27185	6340	4381	14	19732	4396
Minor AADT (2011)	72	2	639	102	342	5	1279	299	303	11	4464	605
No. of App. W/ Left-Turn Lanes	0.0	0.0	2.0	0.3	0.7	0.0	1.0	0.4	0.1	0.0	1.0	0.4
No. of App.W/ Right-Turn Lanes	0.1	0.0	9.0	1.1	0.1	0.0	1.0	0.3	0.0	0.0	1.0	0.1
Skew Angle	13.9	0.0	70.0	21.0	5.2	0.0	45.0	10.9	2.9	0.0	50.0	8.9
Crashes	0.4	0.0	6.0	1.0	0.7	0.0	10.0	1.9	0.7	0.0	13.0	1.9
No. of Crashes (3 Years)	25				46				52			
No. of Intersections W/ Lighting	4				8				50			
Description	**Ave.**	**Min.**	**Max.**	**Std. Dev.**	**Ave.**	**Min.**	**Max.**	**Std. Dev.**	**Ave.**	**Min.**	**Max.**	**Std. Dev.**
Intersection Type	R2L 4ST				RML 4ST				U 4ST			
Major AADT (2011)	1785	48	9992	2253	9831	4260	31080	4392	4547	16	19776	4338
Minor AADT (2011)	182	4	1424	250	483	68	2412	352	636	26	5901	883
No. of App. w/ Left-Turn Lanes	0.0	0.0	0.0	0.0	1.6	0.0	2.0	0.8	0.2	0.0	2.0	0.6
No. of App.W/ Right-Turn Lanes	0.0	0.0	0.0	0.0	0.2	0.0	1.0	0.4	0.0	0.0	1.0	0.1
Skew Angle	5.6	0.0	60.0	12.1	3.1	0.0	30.0	7.3	2.7	0.0	40.0	9.2
Crashes	0.7	0.0	6.0	1.3	1.3	0.0	18.0	2.4	2.6	0.0	24.0	3.6
No. of Crashes (3 Years)	49				94				179			
No. of Intersections W/ Lighting	1				5				63			

R2L 3ST *Rural Two-Lane Three-Leg Unsignalized Intersections*
R2L 4ST *Rural Two-Lane Four-Leg Unsignalized Intersections*
RML 3ST *Rural Multilane Three-Leg Unsignalized Intersections*
RML 4ST *Rural Multilane Four-Leg Unsignalized Intersections*
U 3ST *Urban Three-Leg Unsignalized Intersections*
U 4ST *Urban Four-Leg Unsignalized Intersections*

The number of crashes followed the same trends as the AADT. The highest average skew angle observed was 13.9 degrees for the rural two-lane with three legs intersection. The average number of approaches with left turn lanes was more representative for rural multilane intersections, with 0.7 (three-leg) and 1.6 (four-leg), indicating the presence of left turn lanes was common at these intersections. As can be observed in the previous table, the only two types of intersections that were either close to or above the recommended 100 crashes were rural multilane four-leg intersections (94 crashes) and urban four-leg intersections (179 crashes).

9.5 Results and Discussion

This section contains a brief description of the model development and considerations for the different unsignalized intersections, followed by results and a discussion of the findings of this study.

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

The base SPF models developed for rural two-lane unsignalized intersections with stop control in the minor road considered accidents 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 accident data (1985-1989), and 324 four-leg stop controlled intersections, also from Minnesota, which included five years of accident data (1985-1989) for each intersection (Harwood et al. 2000).

The calibration factor for rural two-lane unsignalized intersections in Missouri yielded the calibration factor values of 0.77 (three-leg) and 0.49 (four-leg). The IHSDM outputs are shown in Figure 9.1 and 9.2. These results indicate that the number of crashes observed at rural two-lane/three-leg and four-leg unsignalized intersections in Missouri were less than the number of crashes predicted by the HSM for this site type.

Figure 9.1 Calibration output for rural two-lane three-leg unsignalized intersections

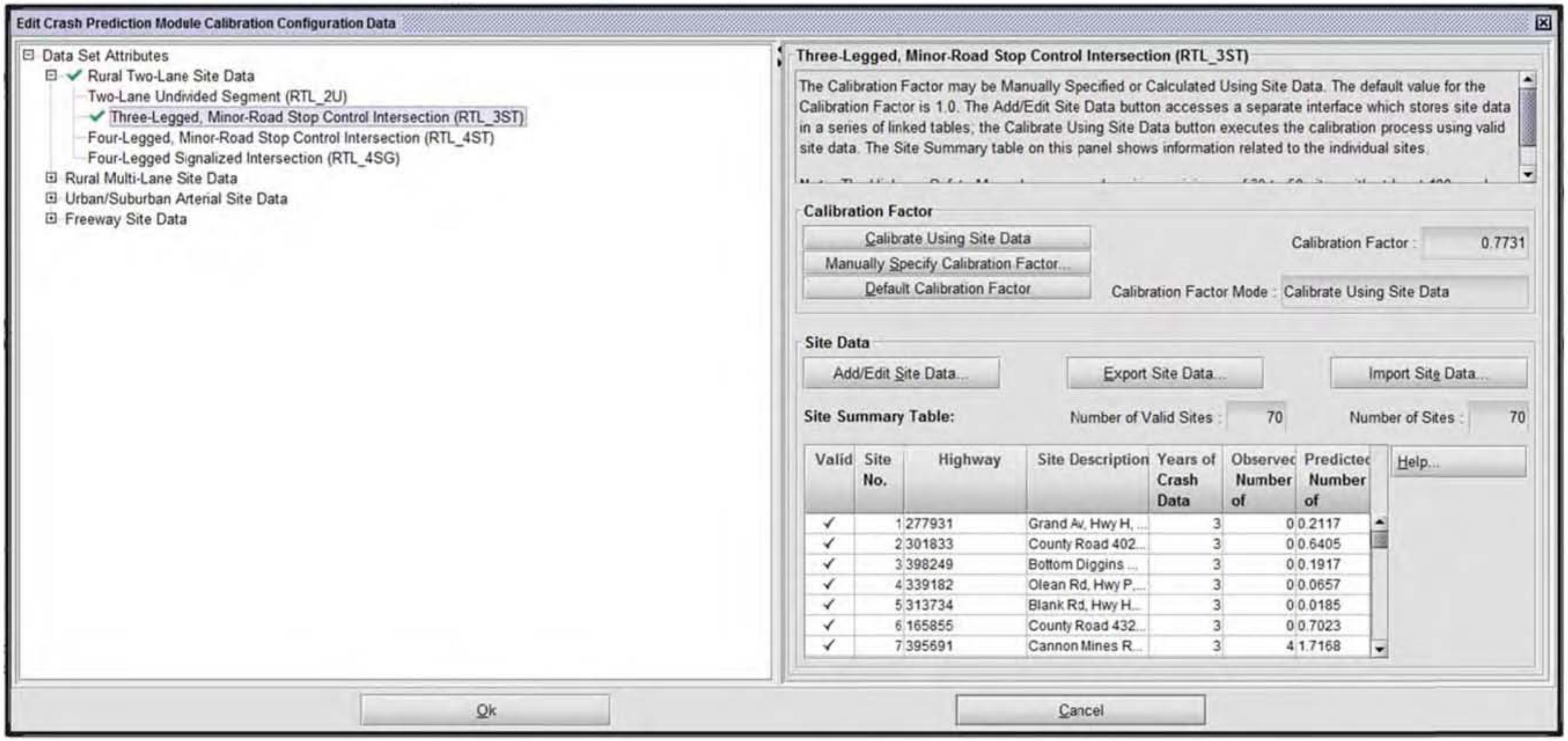
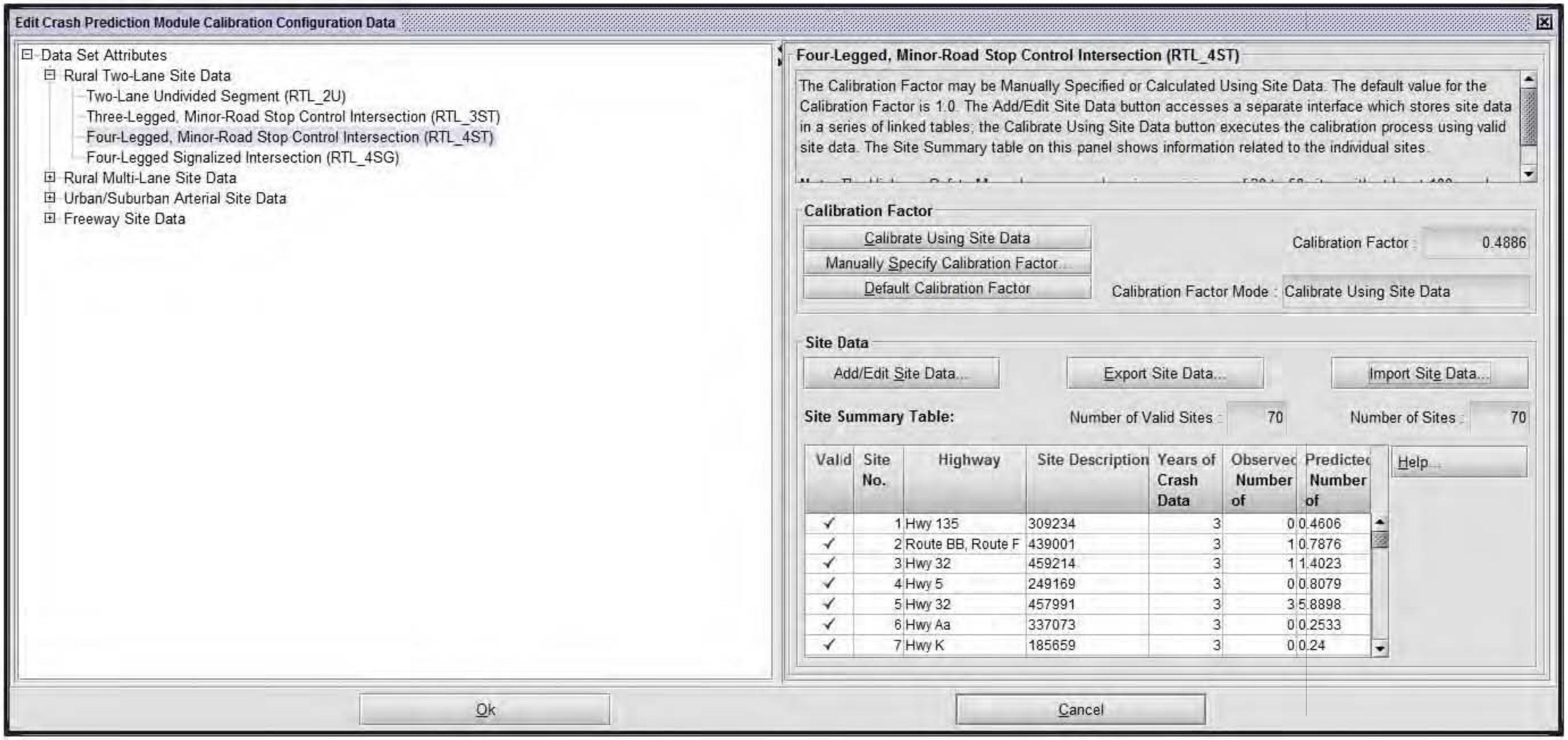


Figure 9.2 Calibration output for rural two-lane four-leg unsignalized intersections



Valid	Site No.	Highway	Site Description	Years of Crash Data	Observed Number of	Predicted Number of
✓	1	Hwy 135	309234	3	0	0.4606
✓	2	Route BB, Route F	439001	3	1	0.7876
✓	3	Hwy 32	459214	3	1	1.4023
✓	4	Hwy 5	249169	3	0	0.8079
✓	5	Hwy 32	457991	3	3	5.8898
✓	6	Hwy Aa	337073	3	0	0.2533
✓	7	Hwy K	185659	3	0	0.24

9.5.2 Rural Multilane Three- and Four-Leg Unsignalized Intersections

The base SPF models developed for rural multilane unsignalized intersections with stop control in the minor road considered accidents within 250 ft (76 m) of a particular intersection. The selected model for the regression analysis was the negative binomial, since it offered an alternative to accommodate the overdispersion commonly found in crash data. The data used for the regression analysis were obtained from 574 three-leg stop controlled intersections and 491 four-leg stop controlled intersections in California and Minnesota. Depending upon the observation, between three years to 10 years of collected data were included (Lord et al. 2008).

The calibration factor for rural multilane unsignalized intersections in Missouri yielded the calibration factor values of 0.28 (three-leg) and 0.39 (four-leg). The IHSDM outputs are shown in Figure 9.3 and 9.4. These results indicated that the number of crashes observed at rural multilane three-leg and four-leg unsignalized intersections in Missouri was considerably less than the number of crashes predicted by the HSM for this site type. There could be several reasons for the low calibration factor for rural multilane unsignalized intersections. One possible reason could be data differences between Missouri, California, and Minnesota. There could also be differences in crash reporting thresholds. Differences in methods for the classification of crashes as intersection crashes could also be a contributing factor. In addition, driver behavior has changed over time.

Figure 9.3 Calibration output for rural multilane three-leg unsignalized intersections

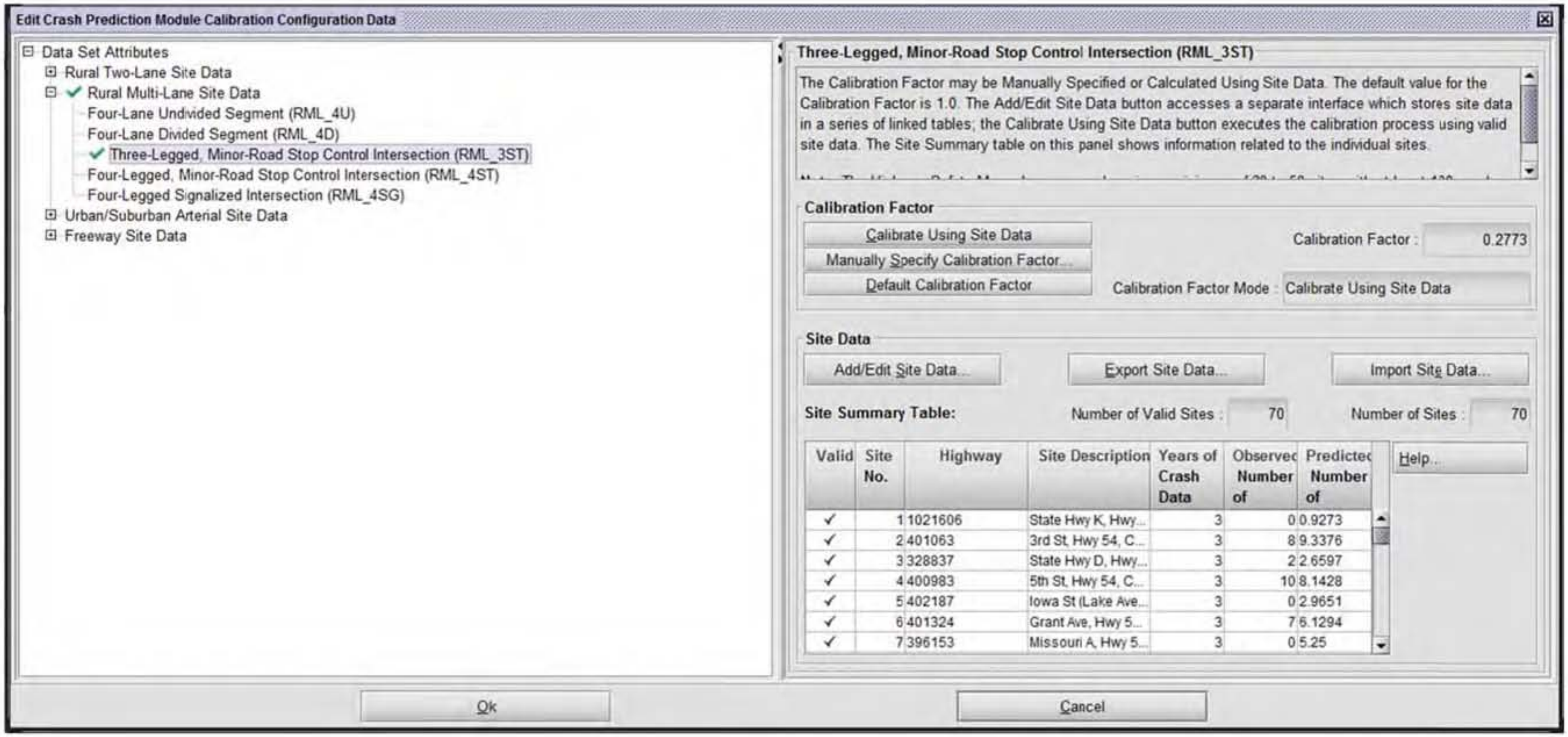
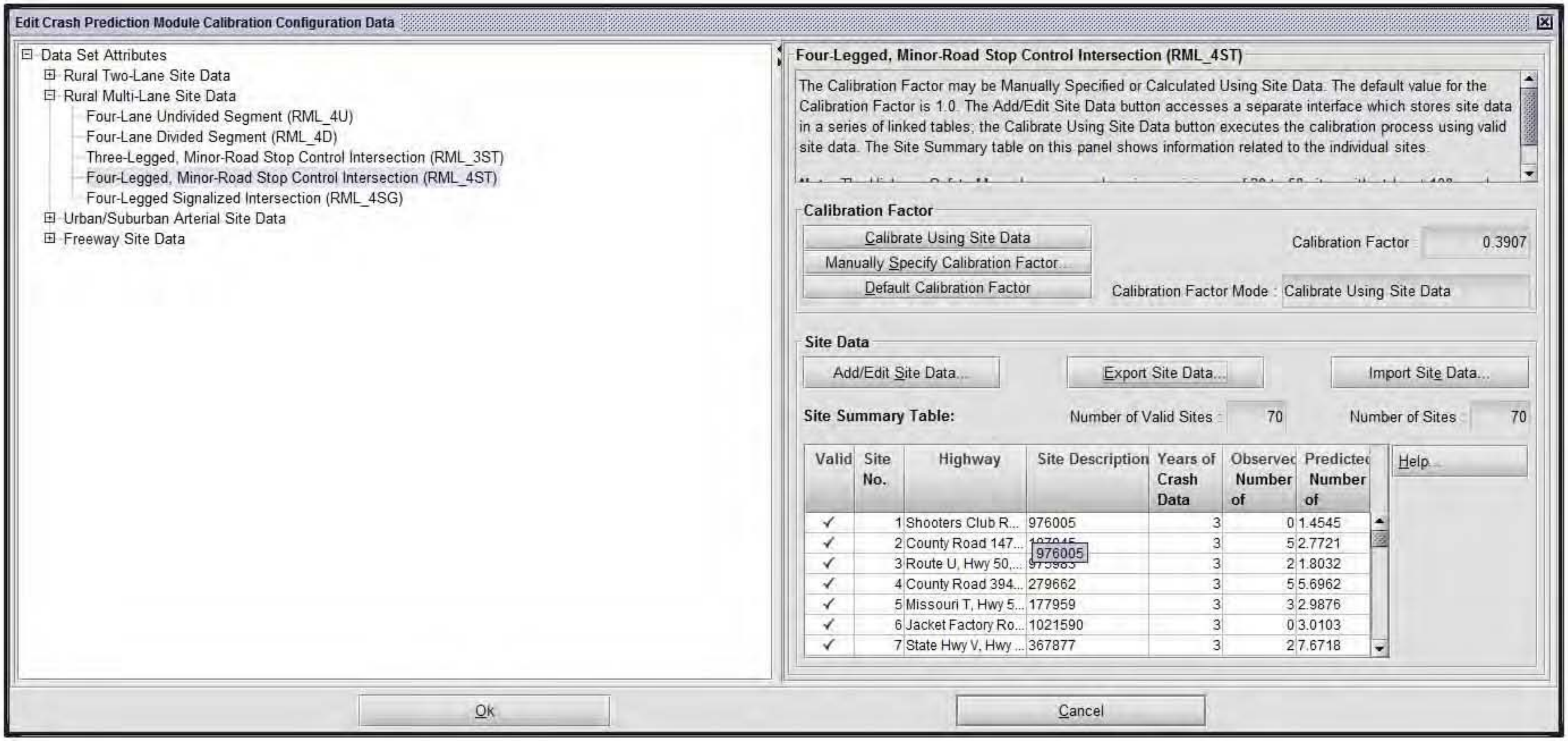


Figure 9.4 Calibration output for rural multilane four-leg unsignalized intersections



9.5.3 Urban Three- and Four-Leg Unsignalized Intersections

The base SPF models developed for urban unsignalized intersections with stop control in the minor road considered accidents within 250 ft (76 m) of a particular intersection but only those which the officer determined was intersection-related. Different SPFs were developed using regression analysis with the negative binomial. The different SPFs included: multiple-vehicle collisions, single-vehicle collisions, vehicle-pedestrians collisions, and vehicle-bicycle collisions. The data used for the regression analysis were obtained from 83 (36 Minnesota, and 47 North Carolina) three-leg stop controlled intersections, and 96 (48 Minnesota, and 48 North Carolina) four-leg stop controlled intersections. The accident data obtained for the study consisted of four years (1998-2002) of Minnesota intersection data and six years (1997-2003) of North Carolina intersection data (Harwood et al. 2007).

The calibration factor for urban unsignalized intersections in Missouri yielded the calibration factor values of 1.06 (three-leg) and 1.30 (four-leg). The IHSDM outputs are shown in Figure 9.5 and 9.6. These results indicated that the number of crashes observed at urban three-leg and four-leg unsignalized intersections in Missouri were higher than the number of crashes predicted by the HSM for this site type.

Figure 9.5 Calibration output for urban three-leg unsignalized intersections

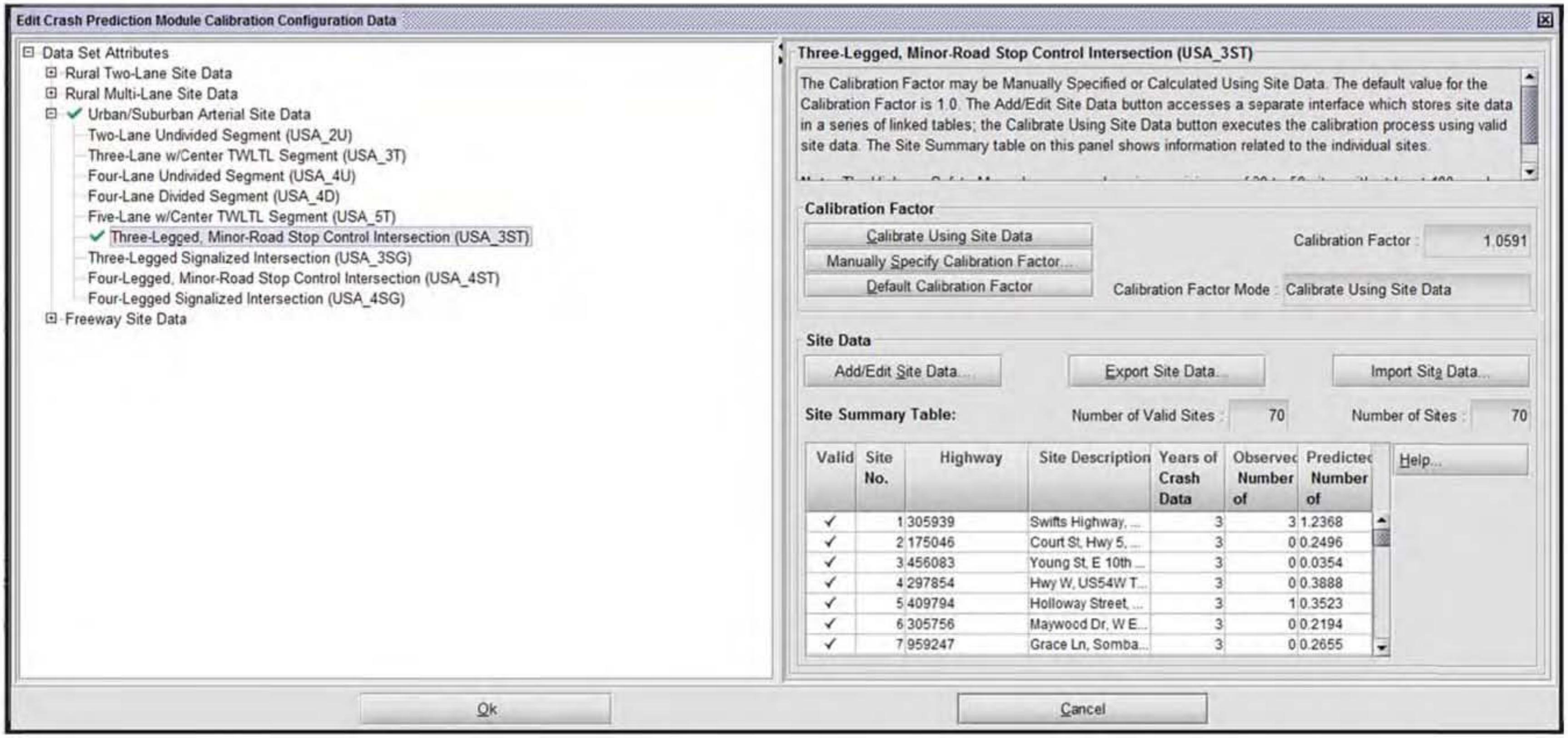
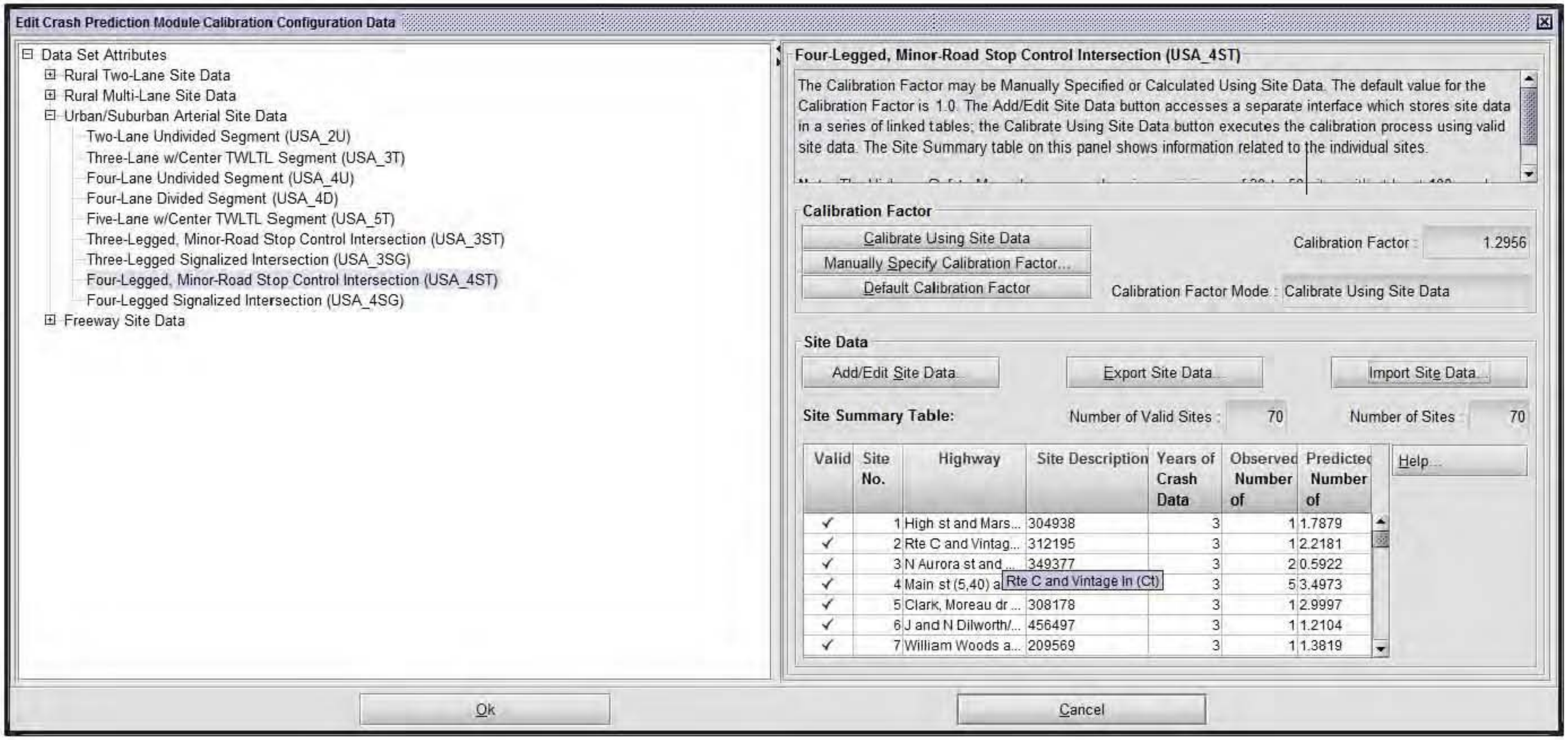


Figure 9.6 Calibration output for urban four-leg unsignalized intersections



Chapter 10 Summary and Conclusions

10.1 Summary of Methodology

This report discussed the efforts related to a statewide calibration of the HSM for Missouri. In Missouri, site types were chosen using a criterion of high priority site types with a sufficient number of samples. Minimum segment lengths of 0.5 miles (0.8 km) for rural segments and 0.25 miles (0.4 km) for urban segments were used. The segments were subdivided to ensure homogeneity based on major changes in cross section or other factors such as horizontal curvature or speed category. In contrast, some other states used much longer segments, such as 10 miles (16 km) in Kansas and one to two miles (1.6 to 3.2 km) in Illinois.

The data required for the HSM calibration were collected from a variety of sources, including aerial photographs, the MoDOT TMS database, ARAN viewer, and other MoDOT data sources. Some types of data, such as superelevation, vertical grades, clear zone, and pedestrian volumes, were not readily available. Missing data types were addressed either through the development of other methods to obtain the data or through the use of default values. A method was developed to use CAD to estimate horizontal curve data from aerial photographs.

10.2 Summary of Results

The calibration results are summarized in Table 10.1. There were 25 site types composed of two rural highway segments, three urban arterial segments, four rural freeway segments, eight urban freeway segments, four urban intersections, and four rural intersections. A total of 1,481 sites and 11,346 crashes were used for calibration. The median calibration factor was 0.98, and the average was 1.35, with a standard deviation of 1.06. The calibration values ranged between 0.28 and 4.91.

Table 10.1 Summary of HSM calibration results for Missouri

Site type	Number of Sites	Number of Observed Crashes (3 Years)	Calibration Factor
Rural Two-Lane Undivided Highway Segments	196	302	0.82
Rural Multilane Divided Highway Segments	37	715	0.98
Urban Two-Lane Undivided Arterial Segments	73	259	0.84
Urban Four-Lane Divided Arterial Segments	66	567	0.98
Urban Five-Lane Undivided Arterial Segments	59	752	0.73
Rural Four-Lane Freeway Segments (PDO SV)	47	1229	1.51
Rural Four-Lane Freeway Segments (PDO MV)	47	645	1.98
Rural Four-Lane Freeway Segments (FI SV)	47	268	0.77
Rural Four-Lane Freeway Segments (FI MV)	47	150	0.91
Urban Four-Lane Freeway Segments (PDO SV)	39	583	1.62
Urban Four-Lane Freeway Segments (PDO MV)	39	669	3.59
Urban Four-Lane Freeway Segments (FI SV)	39	142	0.70
Urban Four-Lane Freeway Segments (FI MV)	39	153	1.40
Urban Six-Lane Freeway Segments (PDO SV)	54	477	0.88
Urban Six-Lane Freeway Segments (PDO MV)	54	1482	1.63
Urban Six-Lane Freeway Segments(FI SV)	54	206	1.01
Urban Six-Lane Freeway Segments (FI MV)	54	424	1.20
Urban Three-Leg Signalized Intersections	35	531	3.03
Urban Four-Leg Signalized Intersections	35	1347	4.91
Urban Three-Leg Stop-Controlled Intersections	70	52	1.06
Urban Four-Leg Stop-Controlled Intersections	70	179	1.30
Rural Two-Lane Three-Leg Stop-Controlled Intersections	70	25	0.77
Rural Two-Lane Four-Leg Stop-Controlled Intersections	70	49	0.49
Rural Multilane Three-Leg Stop-Controlled Intersections	70	46	0.28
Rural Multilane Four-Leg Stop-Controlled Intersections	70	94	0.39

The results indicated that the number of crashes predicted by the HSM was generally consistent with the number of crashes observed in Missouri for non-freeway segments. For freeway segments, the number of crashes predicted by the methodology in Appendix C of the HSM was generally consistent with the number of crashes observed in Missouri, with some exceptions. In particular, the HSM appeared to underestimate the number of PDO MV freeway crashes in Missouri. There could be several reasons for this disparity, such as differences in driver behavior, differences in the way that crash severity was coded, and an increase in distracted driving since the time the HSM was calibrated.

The calibration factors for urban signalized intersections were high, indicating that the number of crashes at signalized intersections in Missouri was greater than the number of crashes predicted by the HSM. Some reasons for this disparity included 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 an increase in mobile device use. The calibration factors for most of the rural unsignalized intersection types were low, indicating that the number of crashes at rural unsignalized intersections in Missouri was fewer than the number of crashes predicted by the HSM. The reasons for the low Missouri numbers are unclear; perhaps they are due to differences in driver behavior, data , and intersection crash definitions between Missouri and the states that were used to develop the SPFs.

10.3 Conclusions

The results of this research demonstrate many important aspects of HSM calibration. First, a thorough understanding of both the HSM itself and the available data are important components of HSM calibration. The experiences from the HSM calibration in Missouri demonstrate the need to compile data from a variety of sources. In addition, the calibration illustrated some of the tradeoffs that may be required, such as the tradeoff between segment homogeneity and minimum segment length. Finally, this report illustrates the importance of shared knowledge between agencies that are working with the HSM. The application of the HSM is both an art and a science, and requires the thoughtful use of engineering judgment. HSM users can benefit greatly from sharing their experiences.

The outcomes of this project suggest that many possible areas for future research exist, both in terms of statewide HSM calibration and the general application of the HSM. One potential area of research for the general application of the HSM could include a sensitivity analysis to investigate the effects of different levels of data and modeling detail on HSM calibration. Sensitivity analysis could also investigate the effect of segment length, left-turn phasing treatment, and curve data sources. The calibration of the HSM for Missouri showed that for some site types, such as signalized intersections, there were significant differences between the number of crashes predicted by the HSM and the number of crashes observed in Missouri. For these site types, the development of statewide SPFs for Missouri could be explored.

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Appendix A: Photographs of Urban Signalized Intersections

<u>Three-Legged Signalized Intersections</u>

Figure A.1 Site No. 1, Intersection 188779, Rt. B/MO 87 (Main St.) and MO 87 (Bingham Rd.), Boonville in Cooper County (Google 2013)

Figure A.2 Site No. 2, Intersection 409359, US 63 (N Bishop Ave.) and Rt. E (University Ave.), Rolla in Phelps County (Google 2013)

Figure A.3 Site No. 3, Intersection 431017, Lp. 44 and MO 17, Waynesville in Pulaski County (Google 2013)

Figure A.4 Site No. 4, Intersection 651041, BU (Missouri Blvd.) and Seay Place – Wal-Mart (724 W Stadium Blvd.), Jefferson City in Cole County (Google 2013)

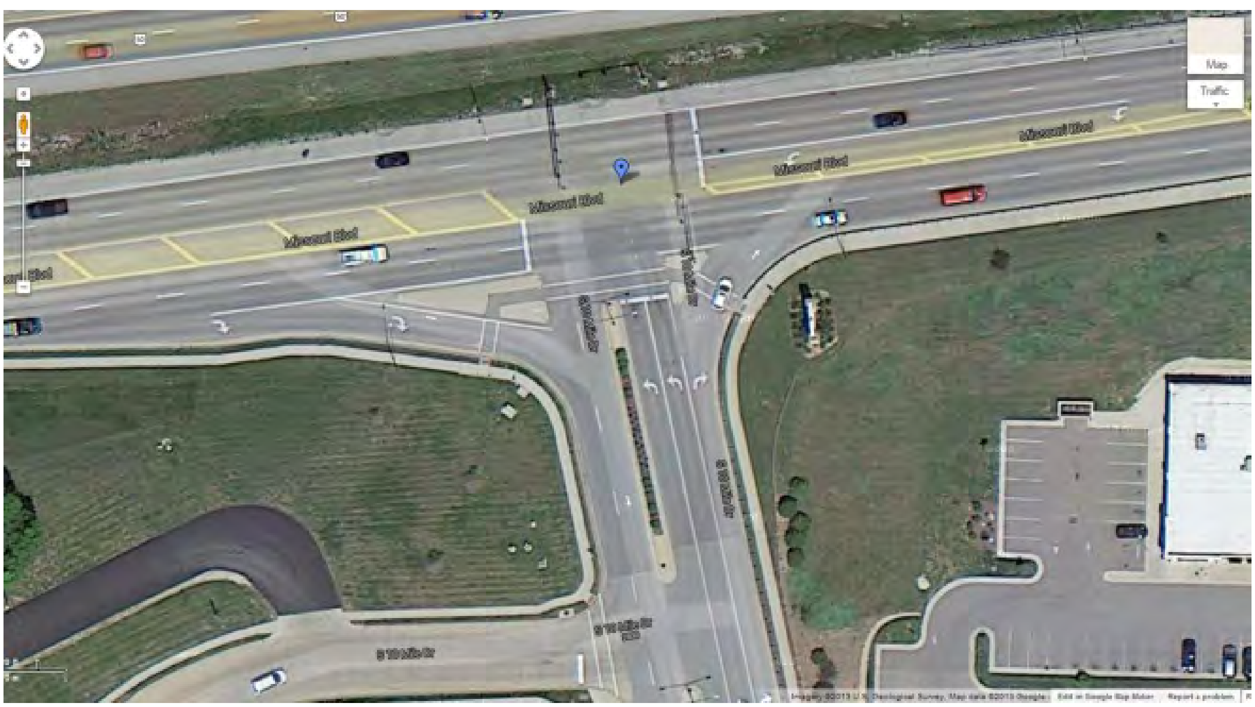

Figure A.5 Site No. 5, Intersection 302396, BU 50 and Stoneridge Blvd. (Kohls entrance), Jefferson City in Cole County (Google 2013)

Figure A.6 Site No. 6, Intersection 121469, MO 291 (NE Cookingham Dr.) and N Stark Ave., Kansas City in Clay County (Google 2013)

Figure A.7 Site No. 7, Intersection 168735, US 40 and E 47th St. S, Kansas City in Jackson County (Google 2013)

Figure A.8 Site No. 8, Intersection 132535, US 69 and Ramp I-35N to US 69 (Exit 13), Pleasant Valley in Clay County (Google 2013)

Figure A.9 Site No. 9, Intersection 123483, MO 291 (NE Cookingham Dr.) and N Flintlock Rd., Liberty in Clay County (Google 2013)

Figure A.10 Site No. 10, Intersection 929297, US 40 and Entrance to Blue Ridge Crossing, Kansas City in Jackson County (Google 2013)

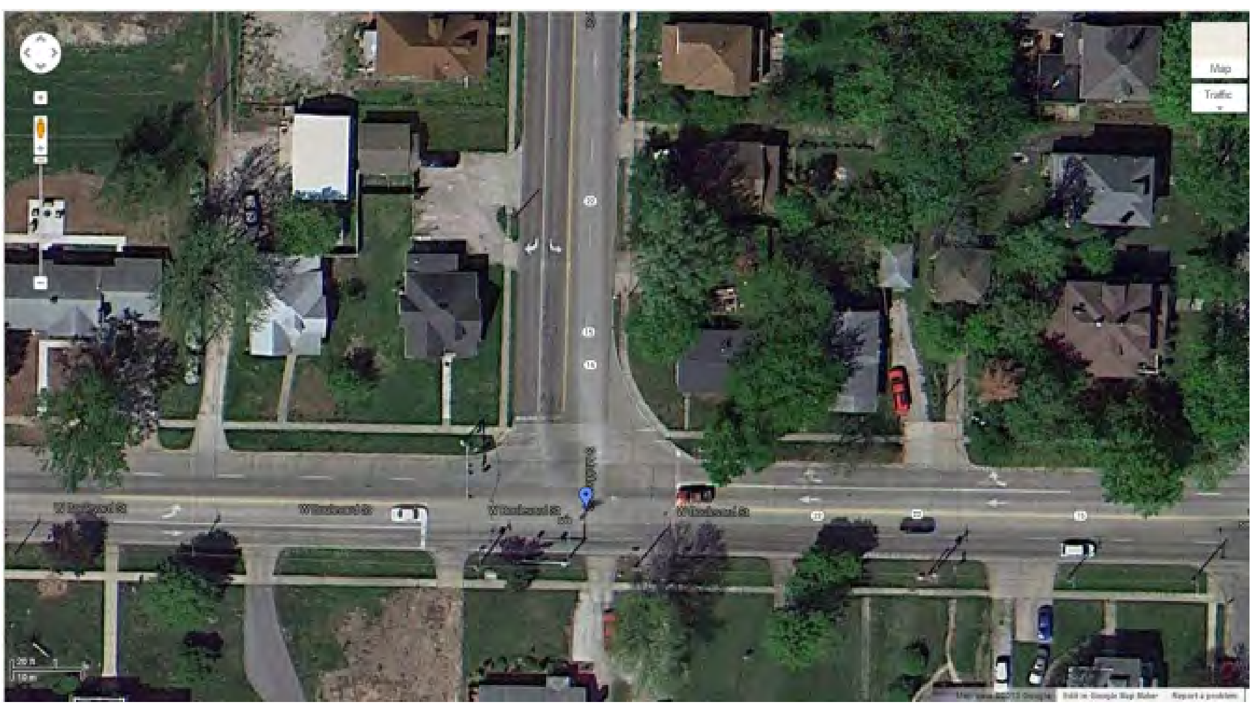

Figure A.11 Site No. 11, Intersection 143089, MO 15 and Boulevard St., Mexico in Audrain County (Google 2013)

Figure A.12 Site No. 12, Intersection 68340, Rt. YY (Mitchell Ave.) and Woodbrine Dr., St. Joseph in Buchanan County (Google 2013)

Figure A.13 Site No. 13, Intersection 280553, Rt. HH and Ramp Rt. HH W to MO 141 S, Town and Country in St. Louis County (Google 2013)

Figure A.14 Site No. 14, Intersection 288254, MO 100 and Woodgate Dr., St. Louis in St. Louis County (Google 2013)

Figure A.15 Site No. 15, Intersection 324301, MO 231 (Telegraph Rd.) and Black Forest Dr., St. Louis in St. Louis County (Google 2013)

Figure A.16 Site No. 16, Intersection 489147, US 61 and Old Orchard Rd., Jackson in Cape Girardeau County (Google 2013)

Figure A.17 Site No. 17, Intersection 573057, US 62 (E Malone Rd.) and Ramp IS 55 S to US 62, Sikeston in Scott County (Google 2013)

Figure A.18 Site No. 18, Intersection 496486, Rt. K and Siemers Dr., Cape Girardeau in Cape Girardeau County (Google 2013)

Figure A.19 Site No. 19, Intersection 574289, US 61 and Smith Ave., Sikeston in Scott County (Google 2013)

Figure A.20 Site No. 20, Intersection 588152, Business 60 and Wal-Mart Entrance, Dexter in Stoddard County (Google 2013)

Figure A.21 Site No. 21, Intersection 219957, MO 94 and Ramp MO 370 W to MO 94, St. Charles in St. Charles County (Google 2013)

Figure A.22 Site No. 22, Intersection 653651, US 50 and Independence Dr., Union in Franklin County (Google 2013)

Figure A.23 Site No. 23, Intersection 928641, Rt. B (Natural Bridge Rd.) and Fee Fee Road, St. Louis in St. Louis County (Google 2013)

Figure A.24 Site No. 24, Intersection 241803, MO 180 and Stop n Save (St. John Crossing), St. John in St. Louis County (Google 2013)

Figure A.25 Site No. 25, Intersection 313246, MO 267 (Lemay Ferry Rd.) and Victory Dr., St. Louis in St. Louis County (Google 2013)

Figure A.26 Site No. 26, Intersection 347423, MO 47 (W. Gravois Ave.) and MO 30 (Commercial Ave.), St. Clair in Franklin County (Google 2013)

Figure A.27 Site No. 27, Intersection 651105, BU 60 (N. Westwood Blvd.) and Valley Plaza Entrance, Poplar Bluff in Butler County (Google 2013)

Figure A.28 Site No. 28, Intersection 543380, LP 49B/BU60/BU71 (N. Rangeline Rd.) and Turkey Creek Rd. (N. Park Ln.), Joplin in Jasper County (Google 2013)

Figure A.29 Site No. 29, Intersection 257667, Rt. D and Page Industrial Blvd., St. Louis in St. Louis County (Google 2013)

Figure A.30 Site No. 30, Intersection 523828, Rt. D (Sunshine St.) and Lone Pine Ave., Springfield in Greene County (Google 2013)

Figure A.31 Site No. 31, Intersection 932947, MO 744 (E. Kearney St.) and N. Cresthaven Ave., Springfield in Greene County (Google 2013)

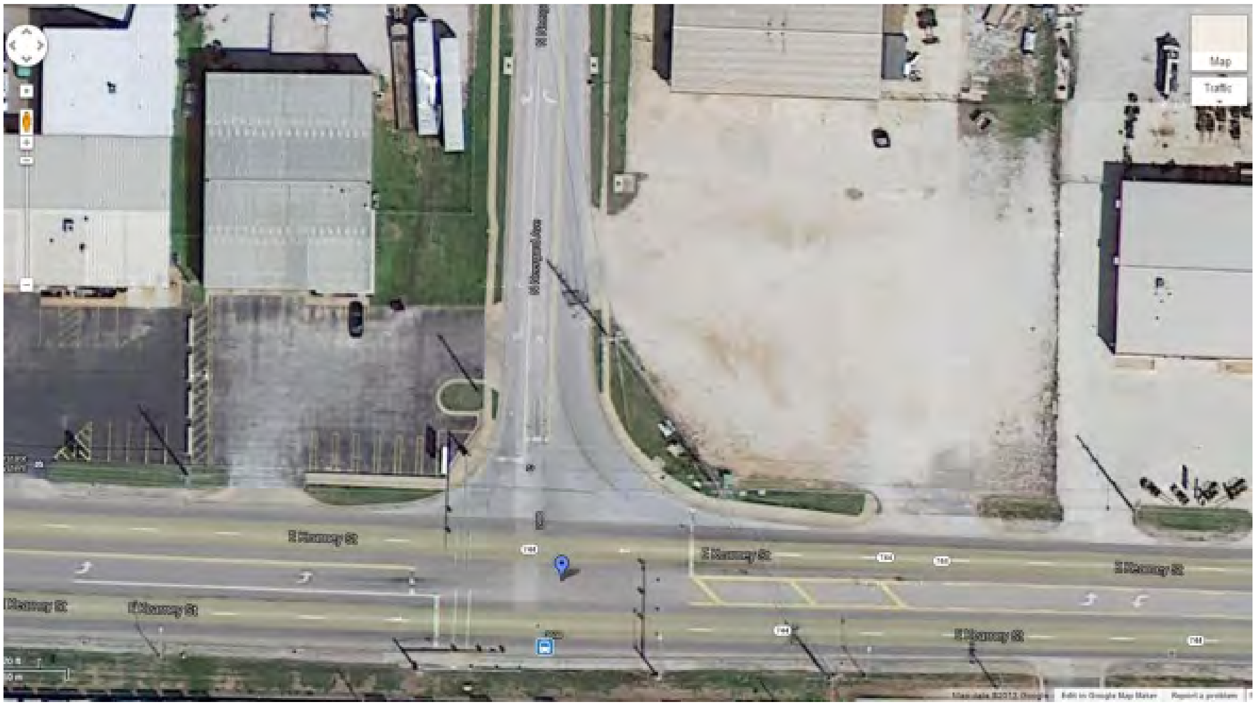

Figure A.32 Site No. 32, Intersection 512492, MO 744 (E. Kearny St.) and N. Neergard Ave., Springfield in Greene County (Google 2013)

Figure A.33 Site No. 33, Intersection 963973, US 60 and Lowe's Ln., Monett in Barry County (Google 2013)

Figure A.34 Site No. 34, Intersection 963880, MO 66 (7th St.) and Wal-Mart (2623 W. 7th St.), Joplin in Japser County (Google 2013)

Figure A.35 Site No. 35, Intersection 963860, MO 571 (S. Grand Ave.) and Wal-Mart Entrance, Carthage in Jasper County (Google 2013)

Four-Legged Signalized Intersections

Figure A.36 Site No. 1, Intersection 458532, MO 32 and MO 19 (Main St.), Salem in Dent County (Google 2013)

Figure A.37 Site No. 2, Intersection 452499, MO 64 (N. Jefferson Ave.) and MO 5 (W. 7th St.), Lebanon in Laclede County (Google 2013)

Figure A.38 Site No. 3, Intersection 458516, MO 32 and Rt. J/HH, Salem in Dent County (Google 2013)

Figure A.39 Site No. 4, Intersection 302287, BU 50 (Missouri Blvd.) and St. Mary's Blvd./W. Stadium Blvd., Jefferson City in Cole County (Google 2013)

Figure A.40 Site No. 5, Intersection 409975, US 63 (N. Bishop Ave.) and 10th St., Rolla in Phelps County (Google 2013)

Figure A.41 Site No. 6, Intersection 262974, US 50 (E. Broadway Blvd.) and Engineer Ave., Sedalia in Pettis County (Google 2013)

Figure A.42 Site No. 7, Intersection 924806, MO 152 and Shoal Creek Pkwy., Kansas City in Clay County (Google 2013)

Figure A.43 Site No. 8, Intersection 178087, MO 7 and Clark Rd./Keystone Dr., Blue Springs in Jackson County (Google 2013)

Figure A.44 Site No. 9, Intersection 165662, US 40 and Sterling Ave., Kansas City in Jackson County (Google 2013)

Figure A.45 Site No. 10, Intersection 175906, MO 7 and US 40, Blue Springs in Jackson County (Google 2013)

Figure A.46 Site No. 11, Intersection 73685, US 63 (N. Missouri St.) and Vine St., Macon in Macon County (Google 2013)

Figure A.47 Site No. 12, Intersection 106134, BU 63 (S. Morley St.) and Rt. EE (E. Rollins St.), Moberly in Randolph County (Google 2013)

Figure A.48 Site No. 13, Intersection 102590, US 24 and BU 63 (N. Morley St.), Moberly in Randolph County (Google 2013)

Figure A.49 Site No. 14, Intersection 219337, MO 47 and Old US 40 (E. Veterans Memorial Pkwy.), Warrenton in Warren County (Google 2013)

Figure A.50 Site No. 15, Intersection 179534, MO 47 and Main St. (Sydnorville Rd.), Troy in Lincoln County (Google 2013)

Figure A.51 Site No. 16, Intersection 64653, US 169 (N. Belt Hwy.) and MO 6/LP 29 (Frederick Ave.), St. Joseph in Buchanan County (Google 2013)

Figure A.52 Site No. 17, Intersection 66131, US 169 (N. Belt Hwy.) and Faraon St., St. Joseph in Buchanan County (Google 2013)

Figure A.53 Site No. 18, Intersection 68315, US 169 (S. Belt Hwy.) and Rt. YY (Mitchell Ave.), St. Joseph in Buchanan County (Google 2013)

Figure A.54 Site No. 19, Intersection 926385, US 59 (S. 6th St.) and Atchison St., St. Joseph in Buchanan County (Google 2013)

Figure A.55 Site No. 20, Intersection 41614, MO 6 (E. 9th St.) and Harris Ave.), Trenton in Grundy County (Google 2013)

Figure A.56 Site No. 21, Intersection 597292, BU 60 (W. Pine St.) and N. 5th St., Poplar Bluff in Butler County (Google 2013)

Figure A.57 Site No. 22, Intersection 439049, US 61 (N. Kingshighway St.) and MO 51 (N. Perryville Blvd.), Perryville in Perry County (Google 2013)

Figure A.58 Site No. 23, Intersection 496355, US 61 (S. Kingshighway St.) and Rt. K (William St.), Cape Girardeau in Cape Girardeau County (Google 2013)

Figure A.59 Site No. 24, Intersection 412022, MO 47 and Ramp US 67 S. to MO 47, Bonne Terre in St. Francois County (Google 2013)

Figure A.60 Site No. 25, Intersection 599957, MO 53 and MO 142/Rt. WW, Poplar Bluff in Butler County (Google 2013)

Figure A.61 Site No. 26, Intersection 258418, MO 115 (Natural Bridge Ave.) and Goodfellow Blvd., St. Louis in St. Louis City (Google 2013)

Figure A.62 Site No. 27, Intersection 368007, MO 185 and Springfield Ave., Sullivan in Franklin County (Google 2013)

Figure A.63 Site No. 28, Intersection 345142, MO 47 (N. Main St.) and Commercial Ave., St. Clair in Franklin County (Google 2013)

Figure A.64 Site No. 29, Intersection 295564, MO 30 (Gravois Ave.) and Holly Hills Blvd., St. Louis in St. Louis City (Google 2013)

Figure A.65 Site No. 30, Intersection 262408, MO 115 (Natural Bridge Ave.) and Marcus Ave., St. Louis in St. Louis City (Google 2013)

Figure A.66 Site No. 31, Intersection 512290, MO 744 and Summit Ave., Springfield in Greene County (Google 2013)

Figure A.67 Site No. 32, Intersection 540602, US 60 and Rt. P/S Main Ave., Republic in Greene County (Google 2013)

Figure A.68 Site No. 33, Intersection 528475, US 60 (W. Sunshine St.) and Ramp US 60 W. to US 60 W/MO 413 S/W Sunshine St., Republic in Greene County (Google 2013)

Figure A.69 Site No. 34, Intersection 345687, MO 18 (Ohio St.) and BU 13 (S. 2nd St.), Clinton in Henry County (Google 2013)

Figure A.70 Site No. 35, Intersection 554723, MO 14 (W. Mt. Vernon St.) and Rt. M (N. Nicholas Rd.), Nixa in Christian (Google 2013)