Development of South Carolina Databases and Calibration Factors for the Highway Safety Manual

Final Report

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16. Abstract This report provides the Highway Safety Manual (HSM) calibration factors for the state of South Carolina. In this report, all facility types analyzed in HSM part C, are calibrated using the crash data of 2013 to 2015. Crash distribution tables are also provided using the observed crashes from 2011 to 2015. Finally, state-specific safety performance functions are also developed and evaluated for use in South Carolina. Two slightly different crash assignment methods are used, and as a result, two sets of results are generated. However, only the results from the SCDOT preferred method of a 250 foot intersection buffer are presented in this report; the other series of results related to a variable buffer by intersection design parameters are presented in the electronic Appendix.		
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EXECUTIVE SUMMARY

The AASHTO Highway Safety Manual (HSM) provides standard methods for predicting the safety performance of existing and future roadways using quantitative information to facilitate improved decision making. The HSM assembles the best-known information and methodologies on measuring, estimating, and evaluating roadways in terms of crash frequency (number of crashes per year) and crash severity (level of injuries due to crashes). The methods can be used across the full spectrum of DOT work activities including: planning, programming, project development, construction, operations, and maintenance.

Prior to the publication of the HSM, safety analysts only had tools to assess the safety of a roadway based on historical crash data but had no prediction capability. The HSM begins to fill this gap, providing transportation professionals with current knowledge, techniques, and methodologies to estimate future crash frequency and severity and to identify and evaluate options to reduce crash frequency and severity. It also improves the capability and use of crash estimation methods to incorporate new and alternate designs or conditions.

The predictive models in the HSM have three basic elements: safety performance functions (SPFs), crash modification factors (CMFs), and calibration factors. The SPFs were developed using the most complete and consistent data available, however the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including crash reporting thresholds and crash reporting procedures. These variations may cause one jurisdiction to have many more reported crashes on a certain facility type than another jurisdiction.

Of all the various steps in the Empirical Bayes analysis that are described in the HSM, the calibration process is one of the most important steps. The HSM prediction models either overestimate or underestimate the safety predictions at a location, when calibration factor is not equal to 1.00. For example, if a calibration factor was found to be 0.75, and if this calibration procedure wasn't performed, the safety at a site might have been overestimated by ~33% ($0.25/0.75 = 0.33$). These predictions, if not accurately calculated, would have a vital impact on safety improvements especially with the benefit cost analysis.

This research will allow the SCDOT safety office to confidently use the HSM with expectations that the resulting predictions are going to be a fair estimate of the effects of safety improvements in South Carolina. The following table provides the three-year (2013-2015) calibration factors for all 18 facility types in the original part C of the HSM with additional factors for basic interstate segments. Two calibration factors shown in red text have coefficients of variation >15%, which is beyond the threshold recommended by the HSM. These two facility types had smaller samples, and the calibration factors are still recommended for use because the coefficients are only slightly above at 15.0% and 17.52%.

Type	Sample Size	Total Length	Average AADT Major	Average AADT Minor	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	Calibration Factor C.V.
Roadway Segments								
R2U	1,841	1,117.73	753	--	447	451	0.99	5.10%
R4D	508	161.16	9,934	--	253	413	0.61	8.17%
R4U	484	126.25	3,921	--	58	189	0.31	14.24%
U2U	667	201.65	2,109	--	261	157	1.66	7.95%
U3T	73	15.73	9,697	--	82	56	1.47	15.01%
U4U	349	76.57	8,602	--	275	367	0.75	8.70%
U4D	352	85.02	19,172	--	321	387	0.83	6.87%
U5T	673	155.59	16,059	--	1,035	1,348	0.77	5.15%
Intersections								
R3ST	7,000	--	892	205	907	2,253	0.40	3.98%
R4ST	2,785	--	995	233	787	1,660	0.47	4.97%
R4SG	97	--	6,104	1,497	131	287	0.46	11.76%
RM3ST	613	--	8,061	357	261	471	0.55	10.91%
RM4ST	284	--	6,438	271	63	244	0.26	17.52%
RM4SG	80	--	11,619	1,375	272	682	0.40	9.42%
U3ST	5,607	--	1,765	287	2,136	1,782	1.20	3.92%
U4ST	2,992	--	1,702	324	1,650	1,719	0.96	5.00%
U3SG	299	--	16,181	3,170	1,255	629	2.00	5.05%
U4SG	538	--	12,870	2,725	3,334	1,362	2.45	4.52%
Interstates								
R4F	138	59.38	35,055	--	785		2.59	5.77%
U4F	105	36.34	49,218	--	902		2.69	6.82%
U6F	126	38.33	73,592	--	1,972		3.66	5.22%

Typically, not all the required data for calculating HSM predicted crashes is available in state DOT databases and must be manually collected for calibration studies. The data collection task in most prior studies is the major time-consuming component (about 85% (Bahar, 2014)). In this project 2,700 roadway segments (684 miles) and 6,824 intersections were selected for data collection. This project is almost 4 times larger than similar prior calibration studies from Oregon, Maryland, North Carolina, and Missouri; yet the overall time commitment is roughly the same. The research team developed a process for the manual data collection, data assembly and re-segmentation in ArcGIS instead of using spreadsheets and found it much faster and easier in comparison. The full details are described. The vast number of samples and comprehensive data also allowed the team to develop state-specific safety performance functions. These functions can also be used for statewide network screening. Ultimately, the calibration factors and state-specific SPFs will aid SCDOT in more effective safety performance and efficient use of limited resources.

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LIST OF ACRONYMS

A

AADT .... *Average annual daily traffic*

AASHTO .... *American Association of State Highway and Transportation Organization*

C

CARS .... *Crash Analysis Reporting System (Florida)*

CMF .... *Crash Modification Factor*

CRT .... *Crash Reporting Threshold*

D

DD .... *Driveway Density*

E

ESRI .... *Environmental Systems Ressearch Institute*

e-TEAMS .... *electronic-Transportation Enterprise Activity System (South Carolina)*

F

FDOT .... *Florida Department of Transportation*

FHWA .... *Federal Highway Administration*

G

GLM .... *Generalized Linear Models*

H

HCM .... *Highway Capacity Manual*

HSIS .... *Highway Safety Information System*

HSM .... *Highway Safety Manual*

I

ITE .... *Institute of Transportation Engineers*

L

LiDAR... *Light Detection And Ranging*

M

MOE... *Measure of Effectiveness*

MW ....*Median Width*

N

NCDOT..*North Carolina Department of Transportation*

NCHRP ....*National Cooperative Highway Research Program*

O

ODOT ....*Oregon Department of Transportation*

P

P_{inr} ....*% of total nighttime crashes on unlit segments involving fatality or injury*

P_{pnr} ....*% of total nighttime crashes on unlit segments involving property damage only*

P_{nr} ....*proportion of total crashes for unlighted roadway segments that occur at night*

PDO..*Property Damage Only*

R

R2U .... *Rural 2-lane 2-way roadway*

R3ST ....*Rural 3-leg minor road stop-controlled intersection*

R4D .... *Rural 4-lane 2-way divided roadway*

R4F.. *Rural 4-lane freeway*

R4SG..*Rural 4-leg signal-controlled intersection*

R4ST ....*Rural 4-leg minor road stop-controlled intersection*

R4U .... *Rural 4-lane 2-way undivided roadway*

RCI...*Roadway Characteristics Inventory (Florida)*

RHR ....*Roadway Hazard Rating*

RIMS..*Roadway Information Management System (South Carolina)*

RM3ST..*Rural 3-leg minor road stop-controlled intersection*
RM4SG ....*Rural 4 lane 4 leg signal controlled intersection*
RM4ST..*Rural 4 lane 4 leg minor road stop controlled intersection*

S

SPF...*Safety Performance Function*
SW...*Shoulder Width*

T

TRB..*Transportaion Research Board*
TWLTL..*Two-Way Left-Turn Lane*

U

U2U..*Urban 2-lane 2-way roadway*
U3SG...*Urban 3-leg signal-controlled intersection*
U3ST ....*Urban 3-leg minor road stop-controlled intersection*
U3T ....*Urban 2-lane+TWLTL roadway*
U4D...*Urban 4-lane divided roadway*
U4F ....*Urban 4-lane Freeway*
U4SG...*Urban 4-leg signal-controlled intersection*
U4ST ....*Urban 4-leg minor road stop-controlled intersection*
U4U...*Urban 4-lane undivided roadway*
U5T ....*Urban 4-lane+TWLTL roadway*
U6F ....*Urban 6-lane freeway*

V

VMT..*Vehicle Miles Travelled*

1. INTRODUCTION

The Highway Safety Manual (HSM) provides several regression models in Part C to predict the number of crashes for different types of roadways and intersections (AASHTO, 2010, p. C1). Crash frequency predictions are based on predictive variables such as traffic volume and geometric design factors (e.g., lane width, shoulder width, curve radius, and driveway density). The individual models were originally generated for various states across the nation (Harwood et al., 2000, 2007; Lord et al., 2008), and it is highly recommended to calibrate these models for local use (AASHTO, 2010, p. A1). It is further recommended that, if states have capabilities to conduct advanced studies and the data are available, local jurisdiction models be developed (AASHTO, 2010, p. A1). Several states have undertaken the HSM calibration process in recent years (Saito et al., 2011; Srinivasan and Carter, 2011; Srinivasan et al., 2011; Xie et al., 2011; Sun et al., 2013; Shin et al., 2014). Large amounts of data collection and data analysis are required for this purpose, which presents numerous challenges for state departments of transportation. The "User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors" compiled by Geni Bahar in 2014 addressed many of the challenges, but still more research remains.

The prediction models in the HSM part C are divided into roadway segment models and intersection models. Models are further categorized by facility type using land use context (either rural or urban environments) as well as several design and operational variables including: number of lanes and median type for roadway segments; and number of approaches, stop or signal controlled, for intersections. The main roadway and intersection types supported in HSM are listed in following tables. These abbreviations will be used in this document frequently hereafter. In Table 1.1, roadway segment types are listed using three characters: the first character describes the rural or urban environment (i.e. R or U), the second character describes the number of lanes (i.e. two, three, four, or five), and the last character describes the median type Divided or Undivided or Two Way Left Turn Lane (D, U, T). Toward the completion of the project, a freeway predication chapter was released. The segment designation for freeways ends in (F) and accounts for the assumption that freeways are divided either with grassy median or barrier. The HSM supplement for freeways is used for freeway calibration factors (AASHTO, 2014). Each component is shown in the table as a separate column.

Table 1.1 Roadway segment types and definitions in HSM (AASHTO, 2010)

Segment Types	**Description**	**Urban/Rural**	**Number of Lanes**	**Divided, Undivided, or Freeway**
R2U	Rural two-lane undivided	Rural	2	Undivided
R4U	Rural four-lane undivided	Rural	4	Undivided
R4D	Rural four-lane divided	Rural	4	Divided
U2U	Urban two-lane undivided	Urban	2	Undivided
U3T	Urban 2+TWLTL* lane	Urban	2+TWLTL*	Undivided
U4U	Urban four-lane undivided	Urban	4	Undivided
U4D	Urban four-lane divided	Urban	4	Divided
U5T	Urban 4+TWLTL*	Urban	4+TWLTL*	Undivided
R4F	Rural four-lane freeway	Rural	4	Freeway
U4F	Urban four-lane freeway	Urban	4	Freeway
U6F	Urban six-lane freeway	Urban	6	Freeway

* TWLTL: Two Way Left Turn Lane

In Table 1.2, intersection types are listed, which again is consisted of three major components: the first component describes the rural or urban environment plus additional data for rural intersections on multilane highways (i.e. R, RM, or U) (please note that the HSM does not distinguish between the intersections on urban two-lane and multilane highways), the second component describes the number of legs of the intersection (i.e. 3 or 4), and the last component defines the signal or stop controlled intersections (i.e. SG or ST) (please note that all stop controlled intersections are minor approach stop controlled).

Table 1.2 Intersection types and definitions in HSM (AASHTO, 2010)

Intersection Types	Description	Urban/Rural	Number of Legs	Stop/Signal
R3ST	Rural two-lane three-leg stop controlled*	Rural	3	Stop Control
R4ST	Rural two-lane four-leg stop controlled*	Rural	4	Stop Control
R4SG	Rural two-lane four-leg signal controlled	Rural	4	Signal Control
RM3ST	Rural multi-lane three-leg stop controlled*	Rural	3	Stop Control
RM4ST	Rural multi-lane four-leg stop controlled*	Rural	4	Stop Control
RM4SG	Rural multi-lane four-leg signal controlled	Rural	4	Signal Control
U3ST	Urban three-leg stop controlled* **	Urban	3	Stop Control
U4ST	Urban four-leg stop controlled* **	Urban	4	Stop Control
U3SG	Urban three-leg signal controlled **	Urban	3	Signal Control
U4SG	Urban four-leg signal controlled **	Urban	4	Signal Control

* All stop controlled intersections are minor approach stop controlled.
** The HSM does not distinguish between urban two-lane and multi-lane intersections, thus the major approach on these intersections might be any of the five urban segment types (i.e. U2U, U3T, U4D, U4U, or U5T).

Regression models for predicting the average crash frequency in the HSM are called Safety Performance Functions (SPFs). SPFs are developed for "base conditions", meaning that they correspond to specific geometric designs or traffic control features (AASHTO, 2010, p. C15). SPFs are functions of a few parameters, mainly traffic volume and length (AASHTO, 2010, p. C9). Adjustments to SPFs for sites with different geometric designs relative to base conditions or traffic control features may be done with Crash Modification Factors (CMF). CMFs are defined as a function of specific geometric design or traffic control features to adjust the SPFs. The final crash frequency is obtained from the following equation (AASHTO, 2010, p. C4):

$$N_{\text{predicted}} = N_{\text{spf}} \times (CMF_1 \times CMF_2 \times \ldots) \times C \quad (1\text{-}1)$$

$N_{\text{predicted}}$: Predicted average crash frequency
N_{spf}: Predicted average crash frequency for base condition
CMF_i: Crash modification factor
C: Calibration factor

The distribution of observed crashes over a large number of sites (i.e. facilities) follows a Negative Binomial (NB) form; therefore, SPFs are obtained using the negative binomial family regression of Generalized Linear Models (GLM) (AASHTO, 2010). SPFs in the HSM are primarily in the following form:

Roadways:

$$\ln(N_{\text{spf}}) = \hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT) + \ln(L)$$
$$N_{\text{spf}} = e^{\hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT) + \ln(L)} = e^{\hat{\beta}_0} \times L \times AADT^{\hat{\beta}_1} \quad (1\text{-}2)$$

ln( ) : Natural logarithm
$AADT$: Average Annual Daily Traffic (AADT)
L : Segment length
$\hat{\beta}_0, \hat{\beta}_1$: Coefficients of regression

Intersections:

$$\ln(N_{\text{spf}}) = \hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT_{Major}) + \hat{\beta}_2 \times \ln(AADT_{Minor})$$
$$N_{\text{spf}} = e^{\hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT_{Major}) + \hat{\beta}_2 \times \ln(AADT_{Minor})}$$
$$= e^{\hat{\beta}_0} \times AADT_{Major}{}^{\hat{\beta}_1} \times AADT_{Minor}{}^{\hat{\beta}_2} \quad (1\text{-}3)$$

$AADT_{Major}$: Major approach AADT
$AADT_{Minor}$: Minor approach AADT
$\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2$: Coefficients of regression

The CMFs, on the other hand, are the functions of other highway design variables (i.e. predictors) that are not included in SPFs but are identified as significant factors in highway safety. The HSM CMFs are listed in following table with their corresponding facility types. For each highway design variable used in CMFs, a base condition is defined, and the CMF function output will be equal to 1.0 for the base condition value.

Table 1.3 CMFs by corresponding facility types in HSM (AASHTO, 2010)

CMF Variable	Facility Type
Lighting	All types except RM4SG
Lane Width	R2U, R4U, R4D
Shoulder Width and Type	R2U, R4U, R4D
Horizontal Curves: Length, Radius and Presence or Absence of Spiral Transitions	R2U
Horizontal Curves: Superelevation Equations	R2U
Grades	R2U
Driveway Density	R2U
Centerline Rumble Strips	R2U
Passing Lanes	R2U
Two-Way Left-Turn Lanes	R2U
Roadside Design	R2U
Automated Speed Enforcement	R2U, R4U, R4D
Intersection Skew Angle	R3ST, R4ST, RM3ST,RM4ST, U3ST,U4ST
Intersection Left-Turn Lanes	R3ST, R4ST, RM4SG, RM3ST, RM4ST, U3ST,U4ST,U3SG,U4SG
Intersection Right-Turn Lanes	R3ST, R4ST, RM4SG, RM3ST, RM4ST, U3ST,U4ST,U3SG,U4SG
Side slopes	R4U
Median Type	R4D
On-Street Parking	U2U,U3T,U4D,U4U,U5T
Roadside Fixed Objects	U2U,U3T,U4D,U4U,U5T
Intersection Left-Turn Signal Phasing	U3SG, U4SG
Right-Turn-on-Red	U3SG, U4SG
Red-Light Cameras	U3SG, U4SG
Number of Bus Stops	U4SG
Presence of School	U4SG
Alcohol Sales Establishments	U4SG

There are different approaches for development of SPFs (Srinivasan and Bauer, 2013). To develop SPFs, the most common approach, which is used in this study, is to include all significant variables in the model (also known as covariate SPFs or full models), and then, substitute the base condition values in the model to obtain the base condition SPF, which is only a function of AADT and length. The advantage of using covariate SPFs is that the entire sample can be included in the model. Depending on the significance of model variables, these models may be used for network screening if the significant variables are available statewide. If some variables are not available for the entire state, default values can be substituted for missing variables; however, this practice may increase variability of the results.

Additionally, the SPFs might be developed by doing a regression analysis on the part of the data that matches the base condition (Srinivasan and Bauer, 2013). The advantage of this method is that because only base data is used for regression the outcome is expected to be more reliable. The problem with this approach is that it requires more data collection to find enough sites matching the base condition.

There is another type of SPFs, referred to as "General AADT Models" (Lord et al., 2008). In this approach, only AADT (intersections) and AADT/length (segments) are used for model development regardless of the other variables. These models can be developed for network level data because the AADT and length is usually available for state-wide. Therefore, these models could be used for network screening purposes, but might be less reliable than covariate models with more significant variables.

There are two major approaches to develop CMFs, before-after studies and cross section analysis (Gross et al., 2010). In before-after studies, specific treatment is applied to target sites and their safety measures are observed before and after the treatment. A group of control sites are also observed for safety measures to evaluate the effect of the treatment on the target sites (Hauer, 1997). The treatment can be improving any geometric design variable such as increasing lane width or shoulder width for roadways and adding exclusive left turn or right turn lanes for intersections. The advantage of before-after analysis is providing reliable CMFs applicable to similar conditions which they are developed. In many cases conducting a before-after study is not feasible. Thus, cross sectional analysis can be used to replace a before-after study. In this method, unlike before-after studies that the same sites are compared before and after the treatment, different sites are selected to represent the before and after conditions. Then regression analysis is performed to evaluate the safety effect of the desired variable.

In this study, in addition to the calibration factors, state-specific base SPFs are developed using covariate SPF development method for all 18 facility types in HSM part C. The base condition defined for the state-specific SPFs matches the base condition in the HSM, which enables the analyst to apply HSM CMFs to state-specific SPFs. Thus, no additional CMFs are developed in this study. One should note that however the regression analysis performed for cross sectional CMFs is very similar to the regression analysis performed for covariate SPFs, these two studies may not necessarily overlap. In other words, one may generate both covariate SPFs and cross sectional CMFs from the same sample and same regression model, but in general, the sample used for SPF development should be a random sample representing the average conditions of the network (AASHTO, 2010), whereas, the sample used for cross sectional CMFs should be a collection of very similar sites that are only different in the variable of interest (Gross et al., 2010).

Calibration factors are implemented to account for time periods and local conditions such as climate, driver population, crash reporting systems, etc. that may vary from state to state and will not be captured in the adjustment factor CMFs provided in Table 1.3. Calibration factors in the HSM are defined based on the following equation (AASHTO, 2010, p. A7):

$$C = \frac{\sum N_o}{\sum N_u} \quad (1\text{-}4)$$

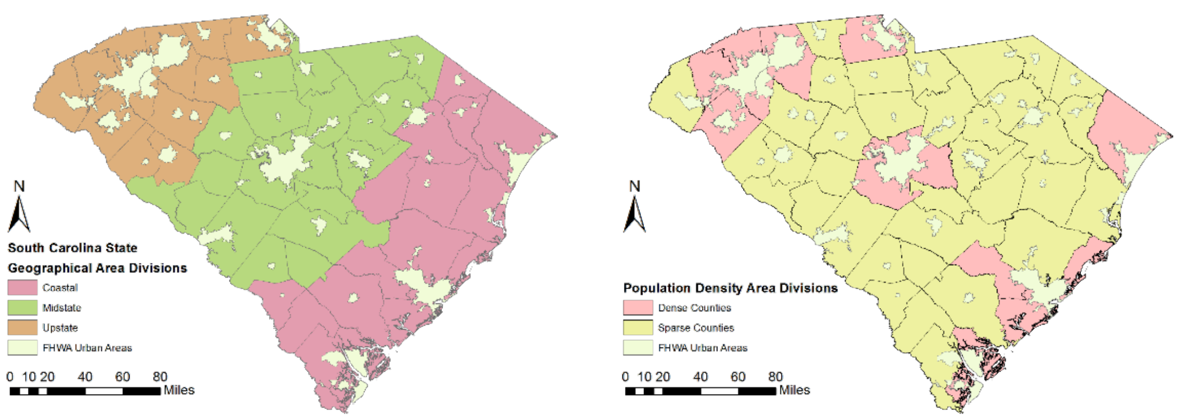
N_o: Observed crash

N_u: Unadjusted predicted crash

$N_u = N_{spf} \times (CMF_1 \times CMF_2 \times CMF_3 \times \dots)$

Based on the HSM, determination of a calibration factor for any of the aforementioned facility types requires a sample of at least 30-50 sites, and there must be at least 100 observed crashes across the selected sites (Note: some sites may have zero crash experience) (AASHTO, 2010, p. A3). These sampling requirements were suggested to limit the standard error of the calculated calibration factor. However, the variability of the observed crashes remains a significant component in truly understanding variability in the calibration calculation, and this method has been questioned in previous literature (Shin et al., 2014, p. 13).

Prior to selecting samples, collecting data, and conducting the calculations to determine calibration factors, it is important to decide how many calibration factors should be defined for the state (Bahar, 2014, p. 166). In other words, in areas where the calibration factor for particular facility types differs in relation to a statewide calibration factor, and this difference is statistically significant, these areas should have their own calibration factor (or their own SPFs). For this research project, two types of divisions for developing calibration factors are considered: geographical areas including upstate, mid-state (piedmont) and coastal, and population density, including dense and sparse counties, shown in Figure 1.1.



a) Geographical area divisions b) Population density area divisions

Figure 1.1 Area divisions for calculating separate calibration factors

Statistical information about the area divisions is provided in Table 1.4. The basis for the geographical areas is assumed to capture flat, low-lying coastal areas, rolling terrain of the middle portion of the state, and the more mountainous areas of the upstate.

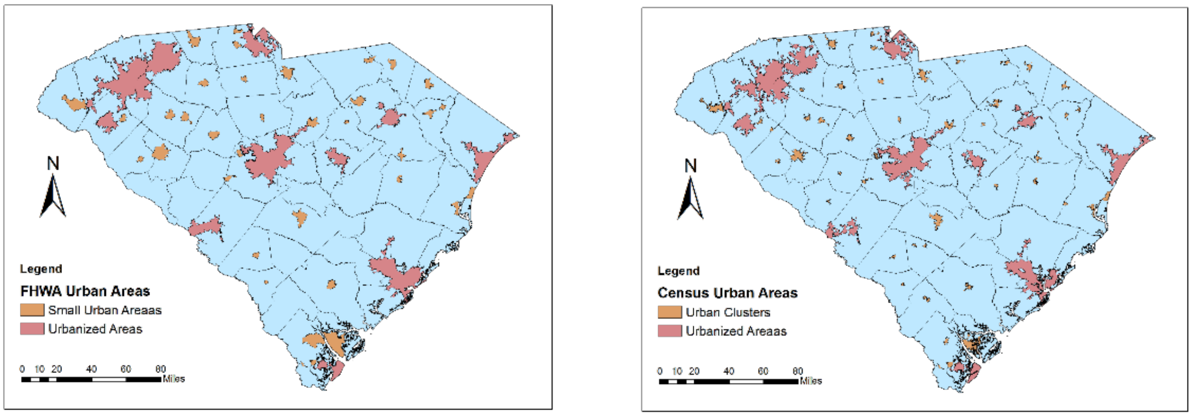
Table 1.1.4 Urban/Rural statistics by area divisions

	Number of Counties	Total Area (Acres)	Urban Area (Acres)	Urban Percentage	Rural Percentage
Upstate	11	4,392,581	613,450	13.97%	86.03%
Midstate	20	8,084,276	461,700	5.71%	94.29%
Coastal	15	7,259,002	461,939	6.36%	93.64%
Dense	11	5,901,452	1,106,139	18.74%	81.26%
Sparse	35	13,834,407	430,950	3.12%	96.88%
Statewide	46	19,735,859	1,537,089	7.79%	92.21%

Urban areas in the HSM are defined based on Federal Highway Administration (FHWA) guidelines (AASHTO, 2010, pp. 12–3). FHWA uses the US Census Bureau urban boundaries with some boundary adjustments for the purpose of transportation planning. According to FHWA, urban areas are places where the population is greater than 5,000 persons (FHWA, 2015a); However, based on US Census Bureau urban areas must encompass at least 2,500 persons (US Census Bureau, 2015). These definitions are compared in Table 1-5. There are two types of urban areas based on population range in both definitions including small urban areas or urban clusters with population less than 50,000 and urbanized areas with population greater than 50,000. The boundaries for both definitions are provided in Figure 1-2. Since the census data and FHWA data are updated every 10 years, the latest updates from 2010 are shown.

Table 1.1.5 FHWA vs Census urban area definitions, source:(FHWA, 2015a)

Census Bureau Area Definition		**FHWA Area Definition**		
	Population Range		Population Range	Allowed Urban Area Boundary Adjustments
Urban Area	2,500+	Urban Area	5,000+	Yes
Urban Clusters	2,500-49,999	Small Urban Area (From Clusters)	5,000-49,999	Yes
Urbanized Area	50,000+	Urbanized Area	50,000+	Yes



a) FHWA urban boundaries b) Census urban boundaries

Figure 1.2 FHWA and Census urban boundaries

The goal of most safety-related researches is to reduce the number and severity of crashes on the roadways. This research aids in accomplishing this goal by providing knowledge and data to undertake better decision making on safety in improvements through the methods of the Highway Safety Manual. The objectives for this research were twofold: 1) provide calibration factors for each SPF in the predictive models to account for jurisdictional variations such as crash reporting, driver populations, topography, and climate; and 2) provide crash distributions specific to South Carolina to increase the reliability of the predictive models.

Most the work associated with this research involved collection and compilation of all the various data necessary to calibrate each of the 18 SPFs in the HSM. While some of these data variables could be found in the SCDOT Roadway Inventory Management System (RIMS), others had to be obtained from other sources, such as:

- Horizontal curvature from linear referencing systems line work,
- Vertical grades from aerial LiDAR (Light Detection and Ranging) data, and
- Lighting and signals from Google Street View, etc.

One purpose of the calibration is to account for variations between the base conditions used for the default SPF development from another state, and the conditions across the analysis state. Many states have found that the base conditions do not necessarily represent the conditions in their state, and thus, calibration is required to obtain usable results from the HSM. For example, few southern states have six-foot shoulders on all rural two-lane roadways. Databases and calibration factors for all roadway segment and intersection combinations had to be developed.

This research produced calibration factors for use across the state of South Carolina. Calibration factors were developed for three distinct areas within the state – coastal areas, midlands, and the upstate. Each of these areas has different terrain, weather patterns, and traffic patterns and these variations were expected to produce varying calibration factors. While some calibration factors were significantly different across various areas of the state and require multiple calibration factors to be used in safety analysis, others were not, and a single statewide calibration factor is recommended for use. Upon completion of this research, SCDOT employees could immediately begin to apply the procedures in the highway safety manual to typical safety improvement projects, planning, and operational assessments with assurances that the costs and benefits would be representative of the state.

Of all the various steps in the prediction methodologies that are described in the HSM, the calibration process is one of the most important steps. Based on research from other states, it is found that a substantial percent of roadway segments deviates from the pre-defined base conditions, requiring the adjustment of predicted crashes to accurately assess the safety of a specific site. The calibration factor, when not equal to 1.00, either overestimates or underestimates the safety predictions at a location. For example, if a calibration factor was found to be 0.75, and if this calibration procedure wasn't performed, the safety at a site might have been overestimated by ~33% (0.25/0.75). These predictions, if not accurately calculated, would have a vital impact on safety improvements especially with the benefit cost analysis. This research will allow SCDOT safety office to confidently use the HSM with expectations that the resulting predictions are going to be a fair estimate of the effects of safety improvements in different areas of South Carolina.

The HSM calibration process can be divided into four major steps: 1) Site selection, 2) Data collection, 3) Calibration results and 4) Crash distributions. After a brief literature review, the remainder of the research report provides an overview for each step and the resulting calibration factors and crash distributions are provided.

2. LITERATURE REVIEW

In this Chapter, a brief history of the development of the HSM is provided. A thorough examination of reference documents for individual HSM SPFs enabled compilation of summary statistics of the samples for each model. Because the data used to develop HSM models range across years 1985 to 2006, and cover almost the entire nation geographically, factors such as economic growth, legislation, vehicle technology, driver population, etc., may play a significant role, although these factors are not usually considered in the models. To provide a measure that can be used to compare different samples, accident rates are calculated for different samples in this review. Accident rates are defined as the number of accidents per million vehicle miles traveled for roadways, and accidents per million entering vehicles for intersections.

2.1 HSM DEVELOPMENT

The idea of HSM development grew out of a conference session in the 78th annual meeting of the Transportation Research Board (TRB) in January 1999 in Washington D.C. The conference session discussed the role of safety in the Highway Capacity Manual (HCM). After significant deliberation, it was determined that the HCM without consideration of safety is complex enough, and another standalone document would be required to quantify the effects of highway design on safety (Harwood et al., 2007, p. 1). Further on December 1999 in Irvine, California, a workshop sponsored by AASHTO and TRB led to NCHRP project 17-18(4) to specify the detailed outlines and strategy plan of the HSM, which was later published in 2004 (Hughes et al., 2004). The Safety Measures of Effectiveness (MOE) for the purpose of the HSM, are identified as the followings (Harwood et al., 2007):

- Crash frequency,
- Crash frequency distribution by crash severity level, and
- Crash frequency distribution by crash type.

These MOEs are the output variables of the predicted methods described in HSM part C.

Most of the data used for HSM SPF development came from the Highway Safety Information System (HSIS). Federal Highway Administration (FHWA) developed HSIS in 1987 with data from five states including Illinois, Maine, Michigan, Minnesota, and Utah (FHWA, 2015b). Later in 1995, they were joined by California, North Carolina, and Washington followed by Ohio in 2002. However, Michigan and Utah ended their participation in 1997 and 2000, respectively. The main criteria for state selection was data availability (FHWA, 2015b). An illustration of active and historic participant states is provided in Figure 2.1. Note the limits of the geographic mix, which potentially limits the model transferability from one area to another requiring at a minimum calibration to local conditions.

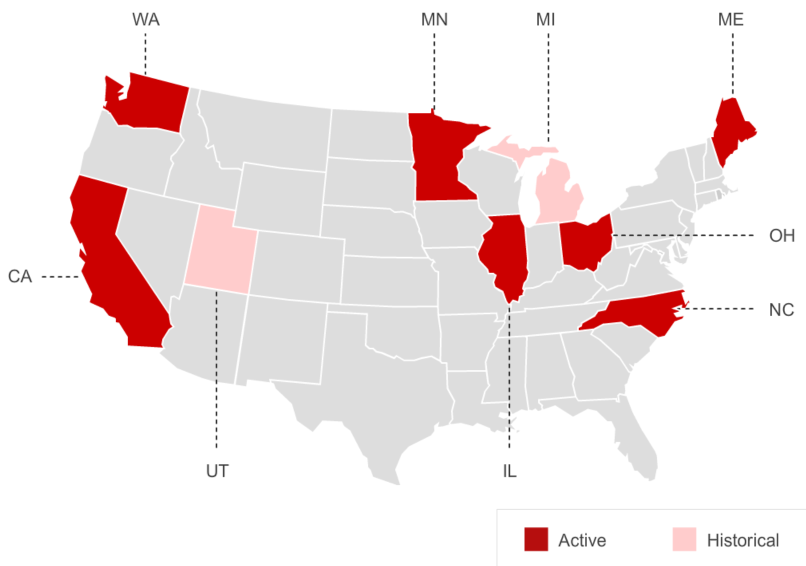


Figure 2.1 HSIS participant states, source: (FHWA, 2015b)

The SPFs in the HSM are categorized in 3 Chapters in the 2010 Edition. An addendum was published late in the research project containing a Freeway Chapter (Freeway analysis is covered separately in this document due to the timing of the release of the addendum.). The first category is two-lane two-way rural highways and intersections, and the respective SPFs can be found in Chapter 10. In this Chapter, there are four SPFs for R2U, R3ST, R4ST and R4SG types (see Table 2.1 and Table 2.2 for each type's description). The second category includes four-lane two-way rural highways and intersections with SPFs presented in Chapter 11. The SPFs in this Chapter include R4U, R4D, RM3ST, RM4ST and RM4SG. The last category, which is found in Chapter 12, deals with urban and suburban arterials and intersections. U2U, U3T, U4U, U4D, U5T and U3ST, U4ST, U3SG, U4SG are the SPF types that are covered in Chapter 12. A total of 18 facility types are covered in the first edition of the HSM and each one is briefly described here.

In Chapter 10 of the HSM, R2U, R3ST and R4ST models were originally developed by (Vogt and Bared, 1998) and R4SG models were originally developed by (Vogt, 1999). In both studies covariate models were developed. The report by (Harwood et al., 2000) summarizes the work done by (Vogt and Bared, 1998) and (Vogt, 1999) and also defines the base conditions for the purposes of the HSM. A summary of the dataset used to develop those models is provided in Table 2.1 and Table 2.2.

Table 2.1 HSM Chapter 10 roadways source data summary

State	Facility Type	Selected Sites	Mileage	Total Observed Crashes	Average AADT (Vehicle/Day)	Accident Rate (Accidents/10^6 Vehicle-Mile)
Minnesota (1985-1989)	R2U	619	700.0	1,694	2,402	0.55
Washington (1993-1995)	R2U	712	530.0	1,706	3,352	0.88

Table 2.2 HSM Chapter 10 intersections source data summary

State	Facility Type	Selected Sites	Total Observed Crashes	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Accident Rate (Accidents/10^6 Entering Vehicles)
Minnesota (1985-1989)	R3ST	382	524	3,687	413	0.18
Minnesota (1985-1989)	R4ST	342	494	2,238	308	0.31
Michigan (1993-1995)	R4SG	31	789	10,491	4,367	0.99
California (1993-1995)		18				

The SPFs in Chapter 11 of the HSM, which are related to R4U and R4D roadways and RM3ST, RM4ST and RM4SG intersections were developed by (Lord et al., 2008). In this report, a survey was conducted among state transportation agencies to determine the data availability and candidate input variables and to discover possible current statistical models that were in use by agencies to predict the safety performance of rural multilane highways. Based on the survey, data from California, Minnesota, Texas and Washington were selected for model development and New York data was selected for validation and recalibration. Both SPFs and CMFs were developed in this report. The study period was from 1991 to 1998.

All three classes of models were developed for each facility type: general AADT models, baseline models and covariate models (Lord et al., 2008). For developing baseline models, only the data matching the base condition was used, which, in this report, was about 20% of all data. The summary of selected sites is presented in Table 2.3 and Table 2.4.

Table 2.3 HSM Chapter 11 roadways source data summary

State	Facility Type	Selected Sites	Mileage	Total Observed Crashes	Average AADT (Vehicle/Day)	Accident Rate (Accidents/ 10^6 Vehicle-Mile)
Washington	R4U	35	6.7	134	17,539	3.14
Washington	R4D	476	195.6	2,282	15,626	2.05
California	R4U	356	150.5	3,893	9,312	7.61
California	R4D	1,087	518.9	18,614	12,281	8.00
Texas (5 years)	R4U	1,522	830.5	4,253	6,614	0.42
Texas (5 years)	R4D	1,733	1,746.0	11,500	10,403	0.35
New York	R4U	159	85.4	2,031	7,478	8.72
New York	R4D	197	138.8	2,800	10,288	5.37

Table 2.4 HSM Chapter 11 intersections source data summary

State	Facility Type	Selected Sites	Total Observed Crashes	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Accident Rate (Accidents/10^6 Entering Vehicles)
Minnesota	RM3ST	171	1,190	13,070	795	1.38
Minnesota	RM4ST	224	3,184	11,379	743	3.21
Minnesota	RM4SG	43	2,024	21,351	5,137	4.87
California	RM3ST	403	13,070	17,339	447	0.45
California	RM4ST	267	11,379	15,058	429	2.11
California	RM4SG	37	21,351	18,478	3,689	6.76
New York	RM4SG	71	472	8,597	911	1.92

In Chapter 12 of the HSM, models for urban roads including U2U, U3T, U4U, U4D and U5T, as well as urban intersections including U3ST, U4ST, U3SG and U4SG are presented. The SPFs and CMFs in this Chapter are based on work by (Harwood et al., 2007). In this report, a survey was conducted among 50 state highway agencies, 100 local highway agencies, 100 MPOs and 28 TRB task force members to identify candidate variables and data availability. A comprehensive literature review was implemented to summarize previous safety prediction methods. Data from Michigan, Minnesota and North Carolina from 1997 to 2003 was used for model development and data from Washington and Florida was used for model validation. Models were developed using all the data and all the predictors, and then base condition values were substituted to obtain the base models. The summary of selected sites is provided in Table 2.5 and Table 2.6.

Table 2.5 HSM Chapter 12 roadways source data summary

State	Facility Type	Selected Sites	Mileage	Total Observed Crashes	Average AADT (Vehicle/Day)	Accident Rate (Accidents/ 10^6 vehicle-Mile)
Michigan (1999-2003)	U2U	590	88.1	4,069	13,246	1.911
Michigan (1999-2003)	U3T	100	14.3	940	14,846	2.431
Michigan (1999-2003)	U4U	440	37.6	2,795	21,259	1.916
Michigan (1999-2003)	U4D	140	29.6	1,531	17,784	1.593
Michigan (1999-2003)	U5T	549	79.8	13,136	29,703	3.036
Minnesota (1998-2002)	U2U	577	77.6	1,539	9,376	1.159
Minnesota (1998-2002)	U3T	380	45.4	1,184	10,806	1.322
Minnesota (1998-2002)	U4U	741	78.0	2,955	13,534	1.534
Minnesota (1998-2002)	U4D	540	80.5	3,154	22,260	0.965
Minnesota (1998-2002)	U5T	198	23.6	974	15,013	1.508

Table 2.6 HSM Chapter 12 intersections source data summary

State	Facility Type	Selected Sites	Total Observed Crashes	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Accident Rate (Accidents/106 Entering Vehicles)
Minnesota (1998-2002)	UM3ST	36	161	16,523	1,157	0.139
Minnesota (1998-2002)	UM3SG	34	602	24,597	5,331	0.324
Minnesota (1998-2002)	UM4ST	48	382	17,868	956	0.232
Minnesota (1998-2002)	UM4SG	64	1,516	21,270	5,502	0.485
North Carolina (1997-2003)	UM3ST	47	896	12,691	2,173	0.502
North Carolina (1997-2003)	UM3SG	42	2,404	21,354	3,908	0.887
North Carolina (1997-2003)	UM4ST	48	1,038	14,074	1,409	0.547
North Carolina (1997-2003)	UM4SG	44	4,522	20,796	9,133	1.344

The final models presented in the HSM are not exactly the models reported by original references. Original models were calibrated by Srinivasan et al. (2008). The reason for this adjustment, according to an email sent to HSM subcommittee members, based on FHWA request (Dixon, 2008) was to make base models more logical since each one was developed using different databases. For this purpose, all HSM models were calibrated using data from California and Washington from 2002 to 2006. Data from Washington was used to calibrate the segment models and data from California was used for intersection models. For comparison, the original models along with the adjusted models and calibration factors are shown in following table.

Table 2.7 HSM one state calibration summary

Facility Type		Model Form	Original Model			Calibration Factor	Adjusted Intercept
			β_0	β_1	β_2		
R2U		$N = e^{\beta_0} \times L \times AADT \times 365 \times 10^{-6}$	-0.4865	N.A.	N.A.	1.1915	-0.3120
R4D		$N = e^{\beta_0} \times L \times AADT^{\beta_1}$	-9.2660	1.0492	N.A.	1.2717	-9.0250
R4U			-10.5045	1.1759	N.A.	2.4588	-9.6530
U2U	Multi Vehicle Crashes	$N = e^{\beta_0} \times L \times AADT^{\beta_1}$	-14.7500	1.6800	N.A.	0.6261	-15.2200
U3T			-11.9200	1.4100	N.A.	0.6202	-12.4000
U4U			-11.5300	1.3300	N.A.	0.9010	-11.6300
U4D			-11.8800	1.3600	N.A.	0.6284	-12.3400
U5T			-9.9300	1.1700	N.A.	1.2630	-9.7000
U2U	Single Vehicle Crashes	$N = e^{\beta_0} \times L \times AADT^{\beta_1}$	-5.0000	0.5600	N.A.	0.6261	-5.4700
U3T			-5.2600	0.5400	N.A.	0.6202	-5.7400
U4U			-7.8900	0.8100	N.A.	0.9010	-7.9900
U4D			-4.5900	0.4700	N.A.	0.6284	-5.0500
U5T			-5.0500	0.5400	N.A.	1.2630	-4.8200
R3ST		$N = e^{\beta_0} \times {AADT_{Major}}^{\beta_1} \times {AADT_{Minor}}^{\beta_2}$	-10.9000	0.7900	0.4900	2.8335	-9.8600
R4ST			-9.3400	0.6000	0.6100	2.1866	-8.5600
R4SG			-5.7300	0.6000	0.2000	1.8147	-5.1300
RM3ST			-13.0982	1.2040	0.2357	1.7718	-12.5260
RM4ST			-10.7137	0.8482	0.4481	2.0265	-10.0080
RM4SG			-7.4234	0.7224	0.3369	1.0390	-7.1820
U3ST			-13.3900	1.1100	0.4100	1.0290	-13.3600
U3SG			-11.6300	1.1100	0.2600	0.6091	-12.1300
U4ST			-8.9700	0.8200	0.2500	1.0684	-8.9000
U4SG			-10.6300	1.0700	0.2300	0.6983	-10.9900

To adjust the models based on the calibration factors, the intercept of the original model was changed. The following equation describes how the new intercept is calculated:

$$\beta_{0_{HSM}} = \beta_{0_{Original}} + \ln(C) \quad (2\text{-}1)$$

C: Calibration factor

As mentioned earlier, considering the wide range of crash data (e.g. 1985-2006) for developing different HSM models, several other factors such as economic change, unemployment increases, seatbelt legislation, cellphone distraction, etc., may affect the direct applicability of regression outcomes. National accident rates are shown in Figure 2.2 for comparison.

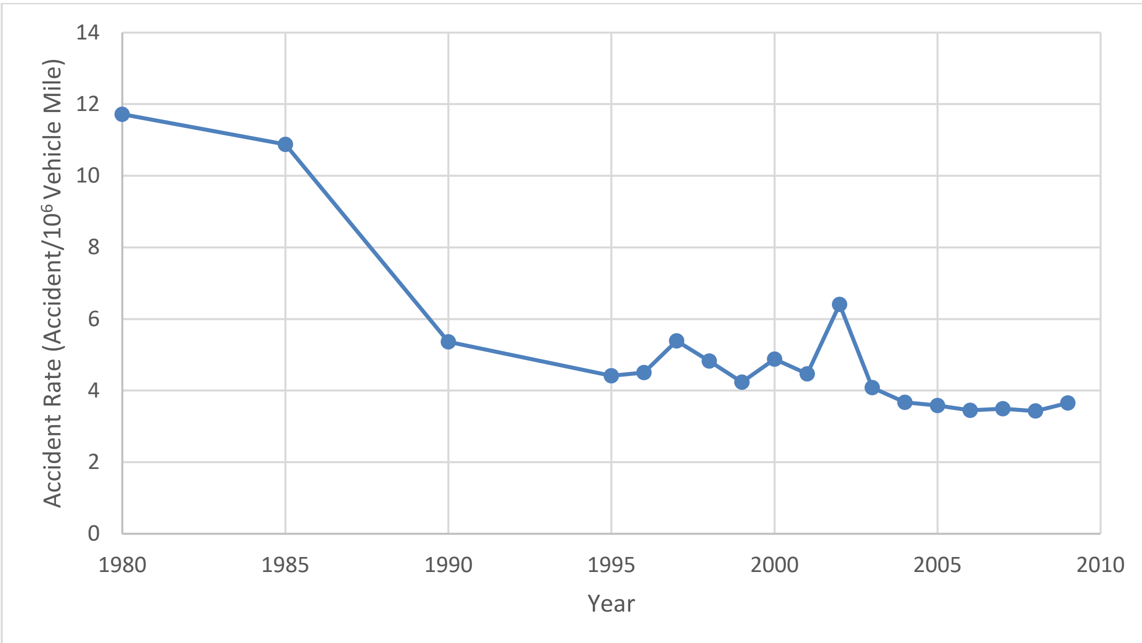


Figure 2.2 National accident rates

Having the detailed perspective of how HSM SPFs are developed, and considering that accident rates are varied in respect to time and location, HSM models must be at least calibrated, if not recalculated for use at state level. This is true even if SPFs are used in the same state where they were originally developed. A brief discussion of HSM calibration projects are provided in the following sections. Where data was available, summary statistics of development samples are presented.

2.2 CALIBRATION STUDIES

After the Highway Safety Manual (HSM) was released in 2010, several different states conducted research studies to develop calibration factors for the HSM part C prediction models. In this section, a summary of the calibration studies and their findings are provided.

Louisiana published two papers for calibration of the HSM in 2006 and 2011 at TRB. The first paper focuses on R2U roadways (Sun et al., 2006). Since the paper was published before the HSM, the calibration process was conducted on the original SPF developed by (Vogt and Bared, 1998), before calibration using Washington data. As a result, the resulting calibration factor (1.63) cannot be compared with other calibration factors and is not further considered. The second paper considers R4U and R4D roadways (Sun et al., 2011) for 2003 to 2007. The summary of this calibration process is shown in the following table. Because the number of sites for each year was slightly different, the average number of sites during the study period is provided. Also, it is mentioned in the report that all segments are assumed not lighted because the data was not available.

Table 2.8 Louisiana State 2003 to 2007 calibration factor summary (Sun et al., 2011)

Facility Type	Selected Sites	Selected Mileage	Observed Crashes	Calibration Factor
R4U	174	66.6	767	0.98
R4D	387	523.3	7,796	1.25

The Utah Department of Transportation (UDOT) published a report on calibrating HSM models for R2U's accompanied by state specific SPFs and development of a hierarchical Bayesian model in March 2011. This research, conducted by Brigham Young University, was prepared and reported in 3 volumes (Schultz et al., 2010; Saito et al., 2011; Schultz et al., 2011). It includes 157 sites with average length of about 1 mile and average AADT of roughly 2,800 vehicles per day (Saito et al., 2011).Crash data from the period 2005 to 2007 were compiled, and all severity levels of crashes were used in analysis (Saito et al., 2011). Crash assignment was completed without geocoding the crashes and authors indicated that strict random sampling techniques were not used. Of all the models, R2U is one of the most data intensive models, so many states use convenience samples to reduce data collection burden (Saito et al., 2011). A summary of the calibration factor calculation is presented in the following.

Table 2.9 Utah State 2005 to 2007 calibration factor summary (Saito et al., 2011)

Facility Type	Selected Sites	Mileage	Observed Crashes	Calibration Factor
R2U	157	152.29	426	1.16

University of Florida published an HSM calibration report in November 2011, which was funded by Florida Department of Transportation (FDOT)(Srinivasan et al., 2011). The summary of the results is shown in Table 2-10. The study period for roadway segments was 2005 to 2008 and for intersections was 2005 to 2009 (Srinivasan et al., 2011, p. 27). Most of the data elements needed for calibration were available in the Florida Roadway Characteristics Inventory (RCI), and therefore most available segments were selected for calibration. For data elements not found in the RCI (e.g., grade, centerline rumble strips, roadside hazard rating, side slope, driveway density and roadside fixed objects) researchers assumed default values (Srinivasan et al., 2011, p. 8). The research team examined the impact of default value assumptions by performing a sensitivity analysis on driveway density, roadside hazard rating, and roadside fixed objects (Srinivasan et al., 2011, p. 13). Only fatal and injury crashes were included in the calibration process, because PDO crashes were not available in the Florida Crash Analysis Reporting System (CARS) for the period of 2005 to 2008 (Srinivasan et al., 2011, p. 10).

Table 2.10 Florida State 2005 to 2008 calibration factors summary (Srinivasan et al., 2011)

a) Roadway types

Facility Type	Selected Sites	Mileage	Total Observed Crashes (KABC)	Average AADT (Vehicle/Day)	Calibration Factor
R4U	4,811	2,121.00	3,787	5,431	1.03
R4D	1,351	546.20	2,306	15,380	0.70
U2U	5,076	628.40	3,696	12,388	1.03
U3T	709	66.30	489	15,600	1.04
U4U	1,251	96.10	1,318	22,926	0.71
U4D	7,506	970.60	11,540	28,403	1.65
U5T	2,868	253.60	4,021	27,897	0.71

b) Intersection types

Facility Type	Selected Sites	Total Observed Crashes (KABC)	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Calibration Factor
R3ST	39	134	6,319	3,668	0.75
R4ST	24	108	5,425	3,072	0.62
R4SG	28	219	7,572	4,330	1.16
RM4SG	25	241	12,502	6,976	0.37
U3SG	45	537	25,520	14,740	1.85
U4SG	121	3684	36,426	22,495	1.88

*KABC stands for KABC crash types in KABCO crash severity scale. K: fatal, A: incapacitating injury, B: non incapacitating injury, C: possible injury and O: no injury.

North Carolina Department of Transportation (NCDOT) published their HSM calibration report in December 2011. The research was performed by University of North Carolina Highway Safety Research Center. For this calibration, data from 2007 to 2009 was used. R2U segments were calibrated prior to the main report by Hummer et al. (2010b) using data from 2004 to 2008. R2U calibration was not the purpose of the report, rather the focus of the research was on curve crash characteristics. Thus, the random sample size used for calibration (i.e. 26) does not meet the minimum sample size requirement of the HSM (i.e. 30 to 50). Also, RM3ST and RM4ST intersections were calibrated by Hummer et al. (2010a) in a study about superstreets. R4U segments were not calibrated due to lack of sample size. The results are shown in the following table.

Table 2.11 North Carolina State 2007 to 2009 calibration factors summary (Srinivasan and Carter, 2011)

a) Roadway types

Facility Type	Selected Sites	Mileage	Total Observed Crashes	Average AADT (Vehicle/Day)	Calibration Factor
R2U	26	N.A.	146	4,335	1.08
R4D	276	49.8	427	18,073	0.97
U2U	501	59.4	866	7,510	1.54
U3T	94	7.6	268	10,047	3.62
U4U	165	15.3	1435	17,727	4.04
U4D	106	15.5	844	20,752	3.87
U5T	90	12.5	642	19,516	1.72

b) Intersection types

Facility Type	Selected Sites	Total Observed Crashes	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Calibration Factor
R3ST	133	189	3,781	813	0.57
R4ST	59	170	3,841	777	0.68
R4SG	19	302	12,414	6,623	1.04
RM3ST	N.A.	N.A.	N.A.	N.A.	1.57
RM4ST	N.A.	N.A.	N.A.	N.A.	1.39
RM4SG	23	455	15,853	5,136	0.49
U3ST	73	254	7,843	2,035	1.72
U3SG	31	397	16,161	6,518	2.47
U4ST	20	101.0	9,849	1,701	1.32
U4SG	122	2,932.0	17,351	8,787	2.79

The Oregon calibration report was published in February 2012. It was funded by Oregon Department of Transportation (ODOT) and conducted by both Oregon State University and Portland State University (Xie et al., 2011). In this report, calibration factors are defined for all the HSM supported facility types (mentioned in Table 1-1 and Table 1-2). For some facility types there was not enough sample size to obtain a reliable calibration factor (e.g. R4D and RM4ST). Observed crashes for 2004 through 2006 were used to develop yearly and 3-year calibration factors. A summary table of the 3-year calibration factors for Oregon is shown in following table. Low calibration factors were attributed to the fact that the crash reporting system in Oregon relies on self-report of Property Damage Only (PDO) crashes with damages less than $1500.

Table 2.12 Oregon State 2004 to 2006 calibration factors summary (Xie et al., 2011)

Facility Type		Selected Sites	Observed Crashes	Unadjusted Predicted Crashes	Calibration Factor
Roadway Segments	R2U	75	394	533	0.74
	R4U	50	364	1003	0.36
	R4D	19	58	75	0.77
	U2U	491	377	601	0.63
	U3T	205	217	262	0.83
	U4U	375	506	784	0.65
	U4D	86	161	113	1.42
	U5T	323	772	1207	0.64
Intersections	R3ST	200	108	342	0.32
	R4ST	200	204	652	0.31
	R4SG	25	142	300	0.47
	RM3ST	100	37	236	0.16
	RM4ST	107	178	447	0.40
	RM4SG	34	157	1053	0.15
	UM3ST	73	103	295	0.35
	UM4ST	48	105	237	0.44
	UM3SG	49	321	427	0.75
	UM4SG	57	690	625	1.10

In August 2012, Illinois published a paper for calibration of R2U roadways based on crashes from 2007 to 2009 (Williamson and Zhou, 2012). In 2013, the results of calibration for U4SG intersections in Illinois was presented at the Midwestern District ITE conference for the study period of 2006 to 2011 (Zhao, J., 2013). Later in January 2015, another paper published the calibration factors for urban segments using crash data from 2005 to 2009 (Jalayer et al., 2015). The challenge in those studies was the change of Crash Report Threshold (CRT) effective from the beginning of 2009. The CRT increased from $500 to $1500 in 2009 resulting in 21% decrease in reported PDO crashes. During the last study (Jalayer et al., 2015) the authors developed an approach to quantify the effect of CRT on calibration factors. The summary results for all 3 studies are shown in the following.

Table 2.13 Illinois State 2005 to 2011 calibration factors summary (Williamson and Zhou, 2012; Zhao, J., 2013; Jalayer et al., 2015)

Facility Type	Selected Sites	Observed Crashes	Calibration Factor
U4SG	N.A.	10,886	2.72
R2U	165	93	1.40
U2U	30	51.5	1.32
U3T	38	370	1.12
U4U	33	315	0.86
U4D	36	420	0.56
U5T	30	121	0.69

Missouri and Maryland also published calibration reports in December 2013 and March 2014. They both did comprehensive studies calibrating almost all HSM facility types. The results are shown in the following tables.

Table 2.14 Missouri State 2009 to 2011 calibration factors summary (Sun et al., 2013)

a) Roadway types

Facility Type	Selected Sites	Mileage	Total Observed Crashes	Average AADT (Vehicle/Day)	Calibration Factor
R2U	196	107.80	302	2910	0.82
R4D	37	96.20	715	12719	0.98
U2U	73	59.13	259	5585	0.84
U4D	66	69.96	567	13979	0.98
U5T	59	37.76	752	15899	0.73

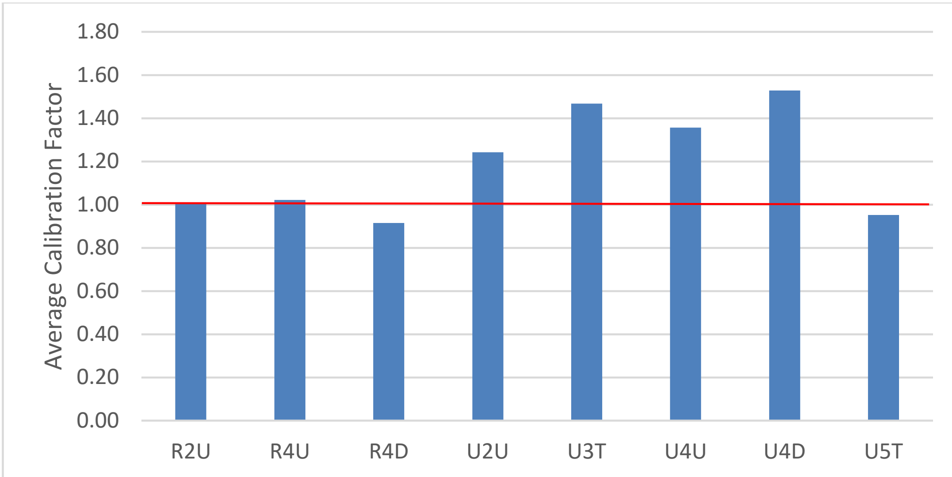
b) Intersection types

Facility Type	Selected Sites	Total Observed Crashes	Average AADT Major (Vehicle/Day)	Average AADT Minor (Vehicle/Day)	Calibration Factor
R3ST	70	25	1,421	72	0.77
R4ST	70	49	1,785	182	0.49
RM3ST	70	46	11,069	342	0.28
RM4ST	70	94	9,831	483	0.39
U3ST	70	52	4,381	303	1.06
U4ST	70	179	4,547	636	1.30
U3SG	35	531	17,551	2,795	3.03
U4SG	35	1,347	16,399	7,801	4.91

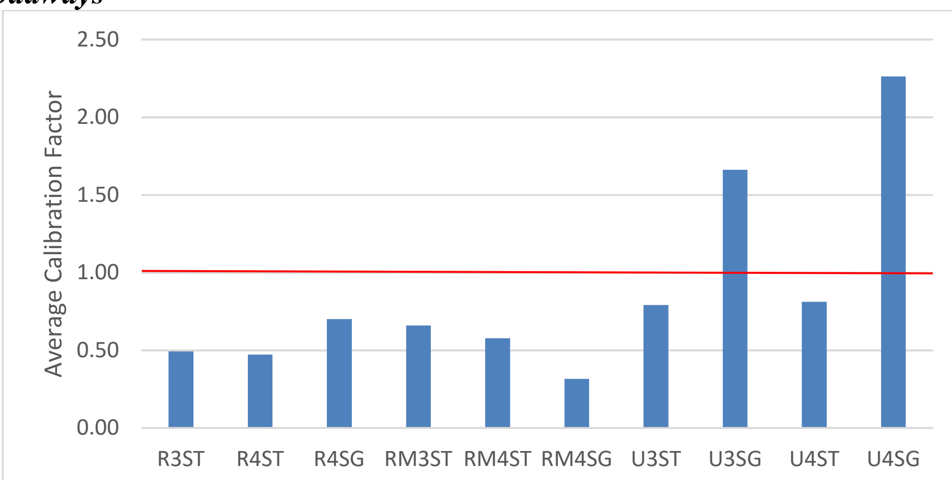
Table 2.15 Maryland State 2008 to 2010 calibration factors summary (Shin et al., 2014)

Facility Type		All Candidates	All Crashes	Selected Sites	Observed Crashes	Unadjusted Predicted Crashes	Calibration Factor
Roadway Segments	R2U	9519	8938	251	458	658	0.696
	R4U	19	43	19	43	19	2.263
	R4D	1410	1818	160	315	540	0.583
	U2U	7215	7859	252	360	528	0.682
	U3T	537	973	138	330	306	1.078
	U4U	741	2491	145	592	674	0.878
	U4D	5328	12105	244	654	791	0.827
	U5T	276	2098	115	1257	1057	1.189
Intersections	R3ST	579	307	162	103	626	0.165
	R4ST	219	290	115	142	706	0.201
	R4SG	69	267	67	262	1000	0.262
	RM3ST	33	26	26	36	201	0.179
	RM4ST	7	10	10	30	82	0.366
	RM4SG	39	35	35	231	1886	0.122
	UM3ST	492	152	152	103	659	0.156
	UM4ST	160	90	90	173	452	0.383
	UM3SG	488	167	167	789	1981	0.398
	UM4SG	960	244	244	1763	3842	0.459

The average calibration factors for the states including North Carolina, South Carolina, Florida, Illinois, Louisiana, Maryland, Oregon, Utah and Missouri are provided in Figure 2.3. More details are provided in section 5. On average, the figure shows urban segments and intersections having higher calibration factors and rural segments and intersections having lower ones. Basically, a calibration factor over one indicates that the crash prediction models are underestimating crashes, and calibration factors under one indicate overestimation by the models.



a) Roadways



b) Intersections

Figure 2.3 Average calibration factors among states

3. METHODS

The methods section is broken into four main sections to include: site selection, data collection and processing, crash assignment, and outlier detection. Each of these processes will be outlined in the following sections.

3.1 SITE SELECTION

The first step in the calibration process is site selection. A randomized sample taken from the entire population is the key to have an unbiased sample. Also, having a large enough sample size is very important to minimize the standard error. To conduct the randomization, a pool of candidate sites for each facility type should be generated. For roadways, SCDOT maintains a roadway database which includes the required information for identifying the type of the roadway (i.e. area type, number of lanes, and median type). For intersections, however, there is no comprehensive database and only the signalized intersection locations are available. Thus, the research team had to extract the intersection locations and types from the roadway layer.

To develop statistically significant calibration factors for each area division, the research team tried to satisfy the HSM sampling requirements within each area, regarding data availability. The site selection process is explained separately for roadways and intersections in the following sections.

3.1.1 Roadway Segment Site Selection

The main database used in this project for initial site selection is the SCDOT Roadway Information Management System (RIMS) (PMG Software Professionals, 2010). RIMS data is available for all state-maintained roadway segments in the state. The RIMS data can be presented as a shapefile in ArcGIS by ESRI (Environmental Systems Research Institute). While the ArcGIS software comes with many standard tools, custom analysis such as that completed for this project requires more specialized custom tools. The research team found creating custom tools, using Python scripts, to be the most efficient and effective way to perform the HSM calibration process. While it took more time and energy at first, it provided a lot of advantages in the end. Thus, ArcGIS scripts were used not only for site selection, but also for data collection, data assembly and predicted crash calculation (around 12,000 lines of Python code).

Among all the route types in RIMS data, US routes, SC routes and secondary routes were selected. This selection was based on the Route_Type field in the RIMS data; see section 7.2 for details. The unused portion of RIMS data consists primarily of interstates and 6-lane highways – neither of which were considered in the first edition of the HSM.

To generate a pool of candidate sites, the roadway type for each road is identified using two fields in the RIMS data: total number of lanes and median type. The median types and how they are used for road type definition are listed in Table 3-1. While a multi-lane bituminous median was an indicator of a two-way left-turn lane (TWLTL), it was not a guarantee. Many samples had to be removed because it was merely a painted median, or median with insufficient width for a TWLTL. A detailed table of the RIMS data dictionary is also provided in the appendix section 7.2. Rural and urban designations were identified by overlaying the RIMS data with the FHWA urban boundaries for the year 2010 (FHWA, 2015a), previously shown in Figure 1-2. Similar boundaries are found by segmenting roads by the RIMS functional classification.

Table 3.1 Median type in RIMS data

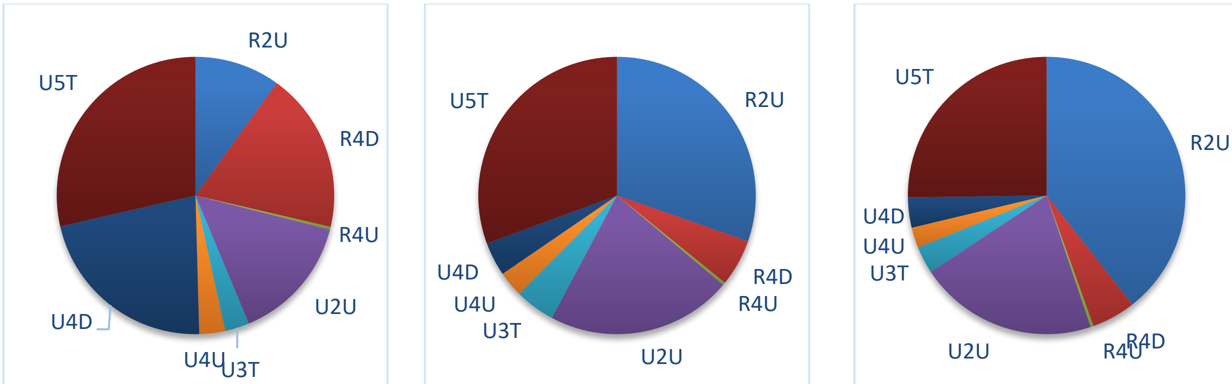
Code	Description	Comments
0	Non-divided	Used for undivided road types
1	Divided - Earth median	Used for divided road types
2	Divided - Concrete median	Used for divided road types
3	Multi-lane - bituminous Median	Used for U3T and U5T
4	Divided - Raised Concrete &	Used for divided road types
5	Divided - Physical Barrier	Used for divided road types
6	Divided - Cable Stay Guardrail	Used for divided road types
8	One-way street	Not used

The following table shows a summary of all the roadway segments in the RIMS data (for more details see section 7.3). The number of observed crashes for each type is provided in following table. The process of crash assignment will be discussed in section 4.3. The 2014 data is used for populating the following tables and figures.

Table 3.2 Summary statistics of all segments by road type (2014 data)

Road Type	Population Size	Mileage	Average AADT (2014)	Tot Observed Crash (2014)
R2U	31,392	6,015.67	3,631	5,826
R4D	1,278	2,320.53	17,651	1,051
R4U	408	84.73	8,448	61
U2U	34,369	3,963.73	8,170	4,156
U3T	2,041	453.25	13,664	897
U4U	989	431.60	15,351	570
U4D	1,161	1,567.70	30,562	755
U5T	2,520	2,839.60	22,076	5,878

In the following figures, the distribution of crashes is shown for different roadway types. For this purpose, the total Vehicle Miles Travelled (VMT) is shown for each road type and is compared with total observed crashes and total fatal/injury crashes. For the area divisions' distributions see section 7.3.



a) VMT ***b) Total observed crashes*** ***c) KABC Crashes***

*KABC stands for KABC crash types in KABCO crash severity scale. K: fatal, A: incapacitating injury, B: non incapacitating injury, C: possible injury and O: no injury.

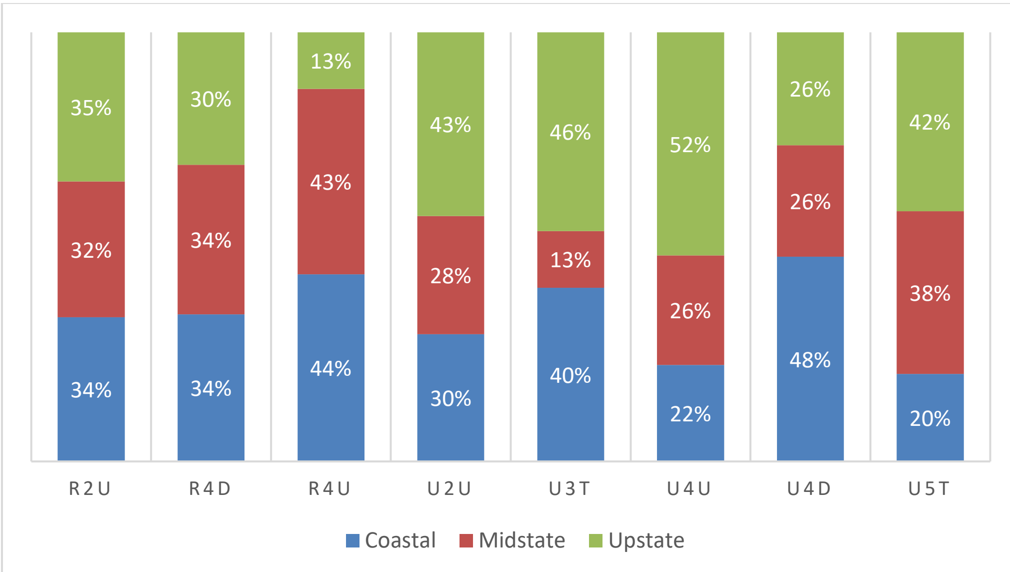
Figure 3.1 VMT and Crash distributions for all RIMS roadway segments by road type

For the site selection process, an algorithm was used to randomly select an equal number of sites from each county to either satisfy the HSM criteria for site selection or select all available sites. The HSM site selection criteria requires at least 30 to 50 sites and 100 observed crashes (AASHTO, 2010). For all roads in each facility type, equal length segments were generated at 1 mile for rural sites and 0.25 miles for urban sites. The sites were given unique numbers and a random number generator was used to select a random sample of 15 sites from the selected counties in each area division. The number of total observed crashes for each site was identified (this process will be described in section 4.3). In each area division, the number of selected sites and total observed crashes were summed to ensure that a sufficient sample was obtained to meet HSM requirements. Given the limited availability of U4U, U3T, and R4U as shown in Figure 3.1, it was expected that these facility types would have limited samples in the selected counties. R4U and U3T did not meet the minimum requirements for sample sizes. Table 3.3 shows summary statistics for the selected roadway segments for 2014.

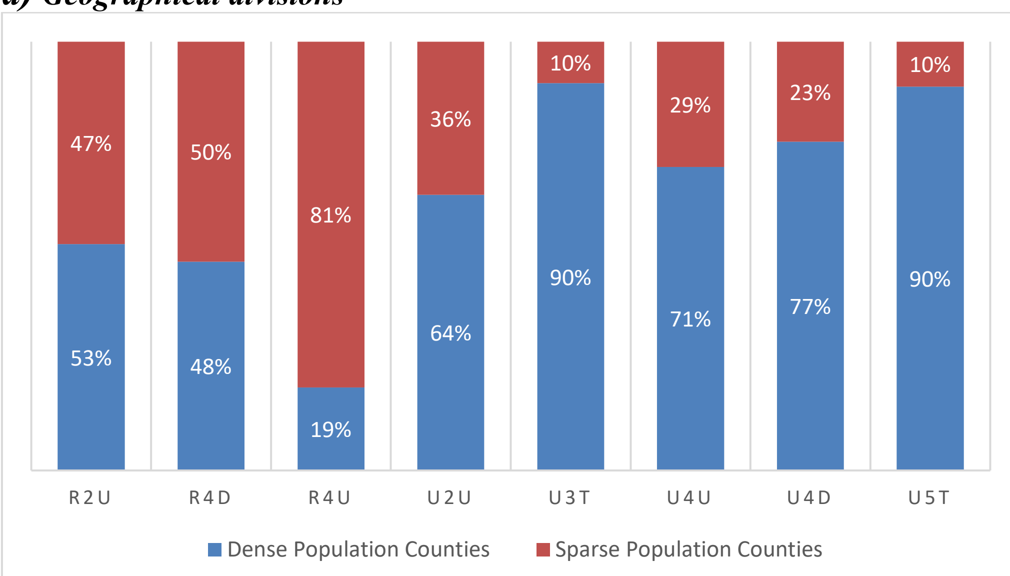
Table 3.3 Summary statistics of selected segments by road type (2014)

Road Type	Sample Size	Mileage	Average AADT (2014)	Tot Observed Crash (2014)
R2U	621	375.80	1,411	175
R4D	172	54.45	11,586	128
R4U	214	46.87	5,380	28
U2U	234	69.57	4,171	121
U3T	37	6.74	10,932	33
U4U	119	26.04	10,572	95
U4D	120	29.01	22,253	140
U5T	229	53.26	17,955	360
All Types	1,746	661.74	10,532	1,080

The distribution of total mileages among different area divisions is provided Figures 3.2 and 3.3. Since only geographical area divisions were considered in initial data selection, site selection is more evenly distributed among geographical divisions compared to population density divisions.



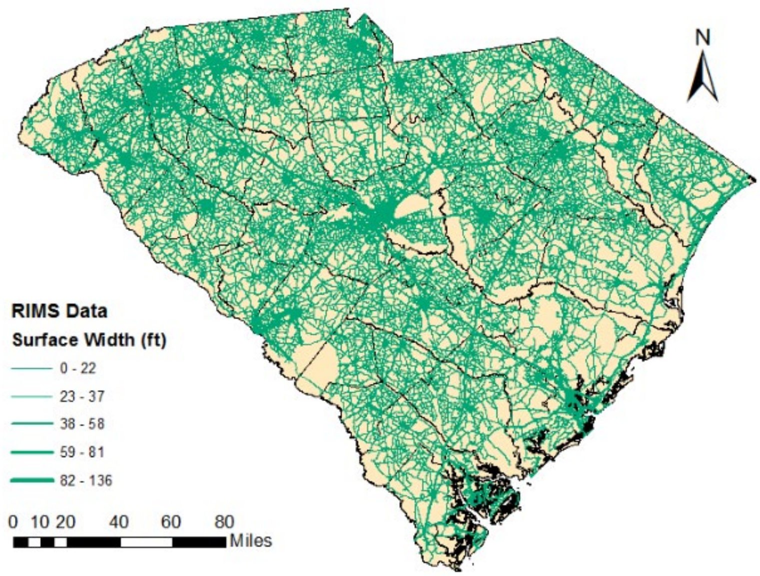
a) Geographical divisions



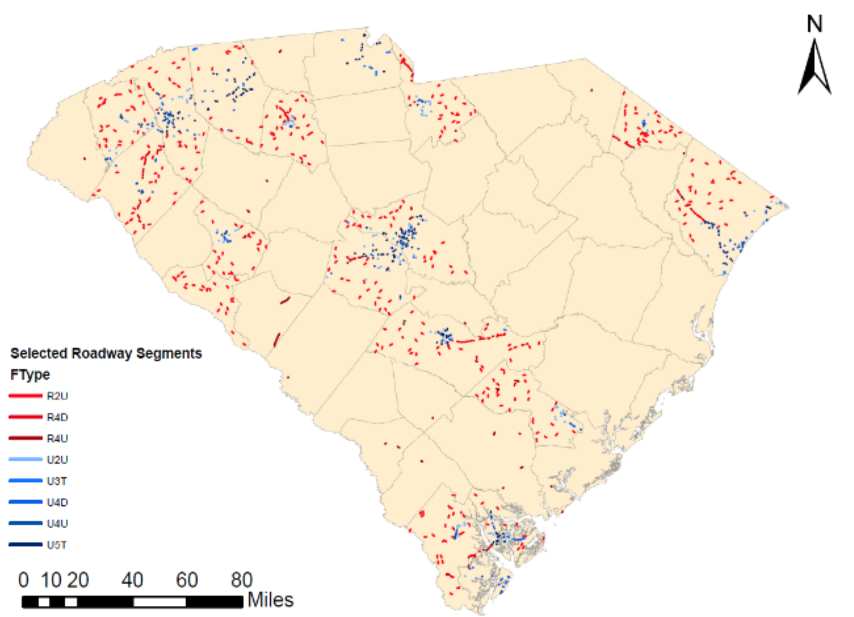
b) Population density divisions

Figure 3.2 Area distribution of selected roadway segments by road type

Figure 3.3 shows all candidate and selected sites geographically.



a) All candidate roadway segments (RIMS)



b) Selected roadway segments

Figure 3.3 All candidate and selected roadway segments

3.1.2 Intersection Site Selection

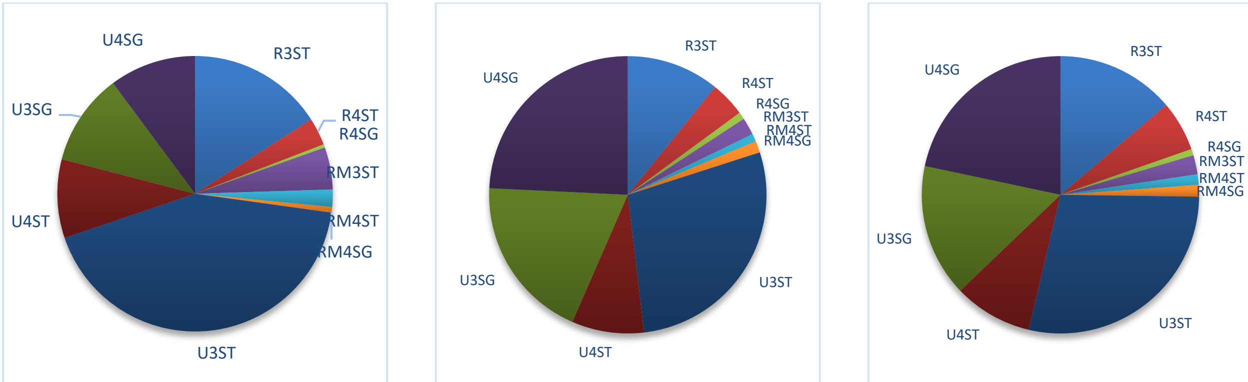
Unlike Roadway Information Management System (RIMS) for the roadways, there is no comprehensive database for all intersections maintained by SCDOT. The research team was given the electronic-Transportation Enterprise Activity System data (e-TEAMS data), which contains the majority of the signalized intersections in the state. To create the pool of candidate intersections, the RIMS data was used. To find intersections from roadways, intersecting points of roadway polylines were considered using the “intersect” tool in ArcGIS. Most of the points obtained by “intersect” are not actual intersections and to extract actual intersections some filters were applied. Some intersecting points were filtered out because they were only connecting two polylines representing the same roadway to account for a change in the attributes. It often happened that an off-center 4 leg intersection was coded as two very close 3 leg intersections; these points were also merged to form a 4-leg intersection. Also, interchanges had to be filtered out because the method was coding them as intersections. The solution for interchanges was found by overlaying the intersection data to bridge database.

To determine the type of intersection, 3 pieces of information is needed for each point: number of legs, rural or urban, stop or signal controlled. Urban/rural info was obtained by overlaying the FHWA urban boundaries, the same procedure as roadways. Signal or stop controlled designation was obtained by overlaying the data to e-TEAMS intersections. The number of legs was obtained by an algorithm to count the number of polylines that are intersecting. This method could find the correct type of most of the intersections in the state.

After obtaining all three attributes, a pool of intersections with their respective type was generated for site the selection process. The automatic identification of the intersection types caused some selected intersections to be incorrectly assigned to a type. Those intersections were excluded during the data collection process. Summary statistics for all RIMS on RIMS intersections (using AADT data from 2014) are provided in the following tables and figures.

Table 3.4 Summary statistics of all RIMS on RIMS intersections by intersection type

Road Type	Population Size	Average AADT Major (2014)	Average AADT Minor (2014)	Tot Observed Crash (2014)
R3ST	18,853	1,741	321	3,746
R4ST	3,468	1,865	393	1,414
R4SG	107	6,751	2,251	294
RM3ST	1,207	9,214	767	695
RM4ST	437	10,540	838	315
RM4SG	103	13,088	2,532	468
U3ST	23,150	3,963	523	9,704
U4ST	5,810	3,311	560	2,915
U3SG	1,119	18,621	4,927	6,639
U4SG	1,248	15,515	4,325	8,382
Other	797	11,757	2,550	NA
All Types	56,299	3,866	666	34,572



a) Total Entering Vehicles ***b) Total observed crashes*** ***c) KABC Crashes***

*KABC stands for KABC crash types in KABCO crash severity scale. K: fatal, A: incapacitating injury, B: non incapacitating injury, C: possible injury and O: no injury.

Figure 3.4 Crash distribution of all intersections by type

Random site selection was completed for intersections to provide enough samples in each area division to satisfy HSM criteria. For some sites that had very low accident experience, as well as low volumes, achieving enough sample to reach 100 observed crashes led to the selection of almost 1000 samples (e.g. R3ST, R4ST, U3ST, U4ST). This occurred because the criteria had to be met in each area division as well as the entire state. This is an example in which HSM site selection criteria led to an unreasonably large sample size. In other calibration studies, for low accident experience intersections such as R3ST and R4ST, either larger samples are generated (Shin et al., 2014; Srinivasan and Carter, 2011; Xie et al., 2011) or this criteria is not met (Sun et al., 2013). The following two tables demonstrate the summary of site selection for intersections by each area division.

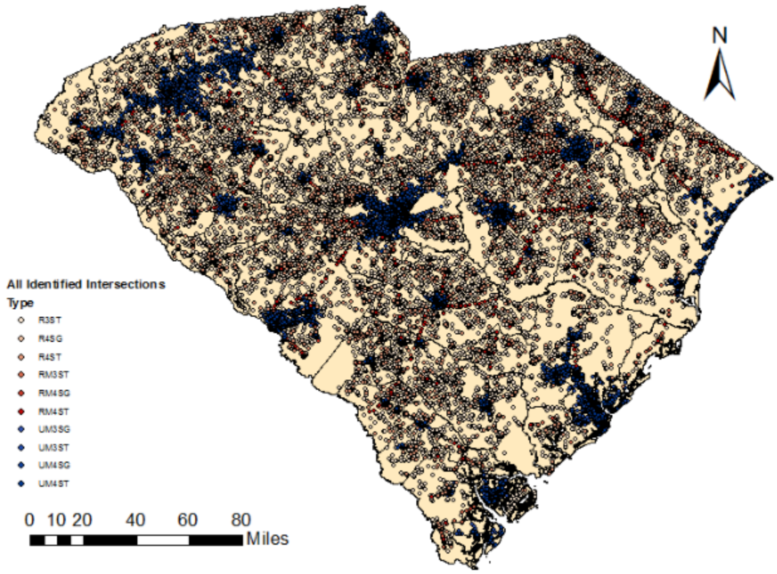
Table 3.5 Summary statistics of selected intersections by geographical division

Road Type	Entire State			Geographical Division								
				Coastal			Midstate			Upstate		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	2,336	1,755	330	40%	1,709	307	32%	1,712	296	28%	1,872	403
R4ST	933	1,893	346	30%	1,744	301	48%	1,859	314	21%	2,195	485
R4SG	33	6,496	2,177	12%	7,675	2,085	48%	6,781	2,346	39%	5,782	1,998
RM3ST	216	9,706	731	38%	10,041	609	43%	9,610	529	19%	9,272	1,415
RM4ST	99	7,735	417	45%	8,503	523	44%	6,709	300	10%	8,793	458
RM4SG	27	12,914	2,050	33%	14,178	2,079	33%	13,344	1,746	33%	11,219	2,324
U3ST	1,885	4,719	577	30%	5,724	507	37%	4,242	487	33%	4,325	743
U4ST	1,007	4,279	619	34%	4,849	748	38%	3,971	472	28%	4,012	665
U3SG	106	18,868	5,712	31%	23,909	8,190	29%	18,832	3,689	40%	14,933	5,258
U4SG	182	15,904	4,230	28%	20,188	4,490	34%	15,726	4,433	38%	12,939	3,865

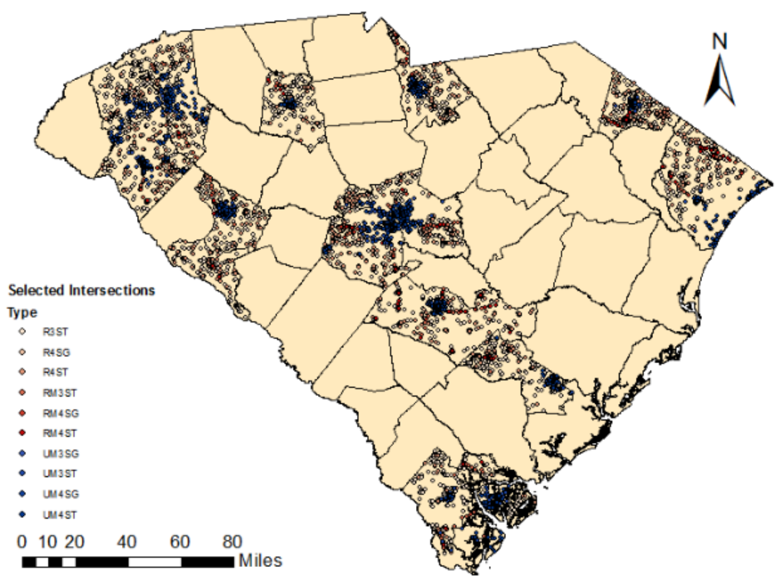
Table 3.6 Summary statistics of selected intersections by population density division

Road Type	Entire State			Population Density Division					
				Dense Population Counties			Sparse Population Counties		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	2,336	1,755	330	52%	2,020	406	48%	1,472	249
R4ST	933	1,893	346	46%	2,474	448	54%	1,394	258
R4SG	33	6,496	2,177	52%	7,139	2,228	48%	5,813	2,123
RM3ST	216	9,706	731	50%	11,157	883	50%	8,254	580
RM4ST	99	7,735	417	42%	9,016	446	58%	6,791	396
RM4SG	27	12,914	2,050	52%	14,520	2,181	48%	11,185	1,909
U3ST	1,885	4,719	577	55%	5,846	682	45%	3,326	449
U4ST	1,007	4,279	619	60%	4,935	703	40%	3,279	490
U3SG	106	18,868	5,712	72%	20,832	6,293	28%	13,893	4,239
U4SG	182	15,904	4,230	63%	18,846	4,809	37%	10,855	3,238

All candidate intersections and selected intersections are shown in Figure 3.5.



a) All identified intersections



b) Selected intersections

Figure 3.5 All identified and selected intersections

3.2 DATA COLLECTION AND PROCESSING

Typically, not all the required data for calculating HSM predicted crashes is available in state DOT databases and must be manually collected for calibration studies. The data collection task in most prior studies is the major time consuming component (about 85% (Bahar, 2014)); however, this varies depending on available state data and simplifying assumptions. Given that there are different types of required data elements for each facility type, and these data elements are obtained from different sources, data elements are usually collected as independent datasets and then overlaid to selected sites (data assembly). After data assembly, homogeneous segments should be created based on collected data (re-segmentation). Furthermore, the domain of applicability should be determined based on the ranges of data (e.g. rural two-lane segments have an AADT range of 0-17,800 in HSM) and outliers should be identified and further studied (data filtering). After these processes are completed, the data can be used for developing calibration factors or state specific SPFs. The process of data collection, data assembly, re-segmentation and data filtering is described in this chapter.

In the case of large amounts of manual data collection, planning the details of the process becomes more and more important to minimize the time and maximize the accuracy. The common approach to manual data collection is to use Excel spreadsheets to record data directly for each site. In small data collections, this approach may work fine and provide simplicity; however, when the project expands there are some downfalls. The major disadvantage is that the spreadsheet does not provide a direct connection to geographical maps and satellite aerial views. A separate application should be engaged to view information and attributes are recorded in Excel using mileposts or other location reference. Collecting attribute data directly in a geographic information system software interface is highly effective and accurate, because the satellite imagery and linear referencing are inherent.

In this project 2,700 roadway segments (684 miles) and 6,824 intersections were selected for data collection. This project is almost 4 times larger than similar prior calibration studies from Oregon, Maryland, North Carolina, and Missouri; yet the overall time commitment is roughly the same (see Figure 3.6). The research team decided to conduct all the manual data collection, data assembly and re-segmentation in ArcGIS instead of using spreadsheets and found it much faster and easier in comparison.

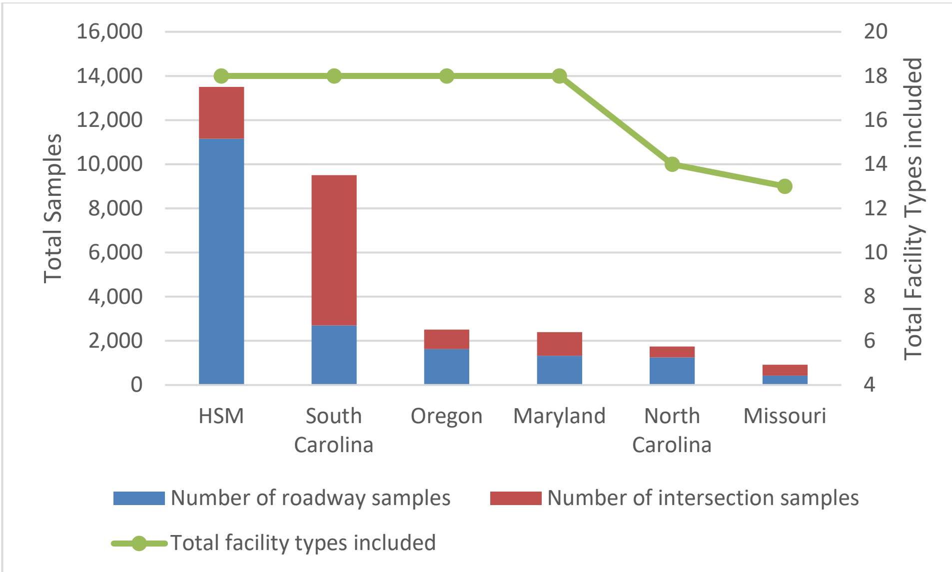


Figure 3.6 Data collection scope among different studies compared with HSM samples

The data collection planning process was very detailed and resulted in a separate GIS database (layer) for each data element (e.g. driveways, roadside fixed objects, shoulder width, etc.). These datasets were collected for every site in the selected sample. For instance, on street parking, was a polyline shapefile with only two fields including parking type (angle or parallel) and area type (commercial, industrial or residential) that was collected along all urban roadways. Roadside fixed objects were point data with known distance from the centerline. Data collection was also specific for the type of roadway. For instance, driveways are not significant elements for rural two-lane roads and therefore were not prompted for collection.

After collecting all the data elements, the data layers were overlaid with selected sites and each piece of information was assigned to a corresponding site. With this process the research team did not need to collect site ID and milepost for each data element because geospatial analysis was used for data assembly. A process called dynamic segmentation automatically generates homogeneous segments. The research team prepared more than 12,000 lines of Python scripts to automate all the processes (including predicted crash calculation). There are several advantages for this method including time efficiency, easy quality control, fewer errors and elimination of unnecessary fields of data collection (i.e. site ID and milepost). The separate processes for roadways and intersections are described in more detail in the following sections.

3.2.1 Roadway Data Collection

To calculate the predicted crashes for selected segments using the HSM method, AADT data is needed to estimate crash frequency given Safety Performance Function (SPF). In addition, Crash Modification Factors (CMFs) must be used to adjust for any "non-base" site characteristics. For example, if the base lane width is 12' and the site lane width is 11', the CMF adjustment creates an increase in the crash frequency. There are certain data elements needed to calculate SPFs and

CMFs which are listed in Table 3.7 along with their corresponding road types and data collection source. All roadway data elements can be divided into 3 categories:

1) Data elements required for all roadway segments to identify the roadway type and define the buffer area to assign crashes to the segment. The roadway buffer size is defined as the width of the area on either side of the roadway polyline that corresponds to the total surface width plus the total median width of the roadway. Please note that observed crashes are counted for all roadway segments to determine the state-specific crash distributions for each roadway type. Data elements, such as urban/rural, number of lanes, and median type, are used to identify the roadway type (e.g. R2U, R4D, etc.); and total surface width and total median width for determining the roadway buffer size for capturing crashes associated with the segment. These data elements must be readily available in a database, because manual data collection for all roadways is not feasible.
2) Data elements required for all selected roadway segments in the sample to calculate the SPFs. For SPF calculation, AADT and length are required. These two data elements are also available in the SCDOT RIMS database.
3) Specific sets of data elements are required for each roadway type to determine needed adjustments using CMFs such as lighting, driveways, roadway hazard rating, etc. Much of the data in this category was not available in any existing SCDOT databases, so the research team had to manually collect data for segments using various Google mapping products, aerial LiDAR (Light Detection and Ranging) data, and estimation of line features from shapefile polylines using CAD software.

Table 3.7 Roadway data elements description

Data Element	Associated Roadway Types	Data Collection Source
Category 1 Data Elements – Required for Roadway Type Identification and Crash Assignment		
Rural/Urban	All Roadways	FHWA Urban Boundaries
Number of Lanes	All Roadways	RIMS Data
Median Type	All Roadways	RIMS Data
Total Surface Width	All Roadways	RIMS Data
Median Width	All Roadways	RIMS Data
Category 2 Data Elements – Required for SPF Estimate		
AADT	Selected Roadways	RIMS Data
Length	Selected Roadways	RIMS Data
Category 3 Data Elements – Required for CMF Adjustments to SPF		
Presence of Lighting	Selected Roadways	Google Street View
Lane Width	Selected R2U, RM4U & RM4D	RIMS data
Shoulder Width	Selected R2U, RM4U & RM4D	RIMS data
Shoulder Type	Selected R2U, RM4U & RM4D	Google Earth
Length of Horizontal Curve	Selected R2U	Estimated in CAD from polylines
Radius of Horizontal Curve	Selected R2U	Estimated in CAD from polylines
Spiral Transition Presence	Selected R2U	Assumed not present
Super Elevation Variance	Selected R2U	Assumed < 1%
Grades	Selected R2U	Aerial LiDAR data
Driveway Density	Selected R2U, U2U, U4D, U4U & U5T	Google Earth
Presence of Centerline Rumble Strips	Selected R2U	Assumed not present
Passing Lanes	Selected R2U	Assumed not present
Two Way Left Turn Lanes (TWLTL)	Selected R2U	RIMS data
Roadside Hazard Rating (RHR)	Selected R2U	Google Earth
Automated Speed Enforcement	Selected R2U	Assumed not present
Side Slopes	Selected RM4U & RM4D	Assumed 1:7 or flatter
Driveway Type	Selected U2U, U4D, U4U & U5T	Google Earth
Roadside Fixed Objects	Selected U2U, U4D, U4U & U5T	Google Earth
On Street Parking	Selected U2U, U4D, U4U & U5T	Google Earth

For the first category, rural and urban classification data was obtained by overlaying RIMS data with FHWA urban areas. The RIMS data also contains information for defining rural and urban definitions, which was very similar to FHWA. In the RIMS data, the functional class field ("FUNC_CLASS", shown in Table 3.8) with values less than 10 correspond to rural roads and greater than 10 corresponds to urban roads.

Table 3.8 RIMS data functional class field for rural and urban definition

FUNC_CLASS Code	Description
1	Rural - Principal Arterial - Interstate
2	Rural - Principal Arterial - Other
3	Rural - Minor Arterial
4	Rural - Major Collector
5	Rural - Minor Collector
9	Rural - Local
11	Urban - Principal Arterial - Interstate
12	Urban - Principal Arterial - Other Freeways
13	Urban - Principal Arterial - Other
14	Urban - Minor Arterial
15	Urban - Collector
18	Urban - Local

For comparison, both the FHWA and SCDOT RIMS definitions are shown in Figure 3.7. The research team did not have information about how RIMS defines the urban roads but compared to Census urban definitions, provided earlier in Figure 1.2, RIMS is more closely correlated with Census data than FHWA data.

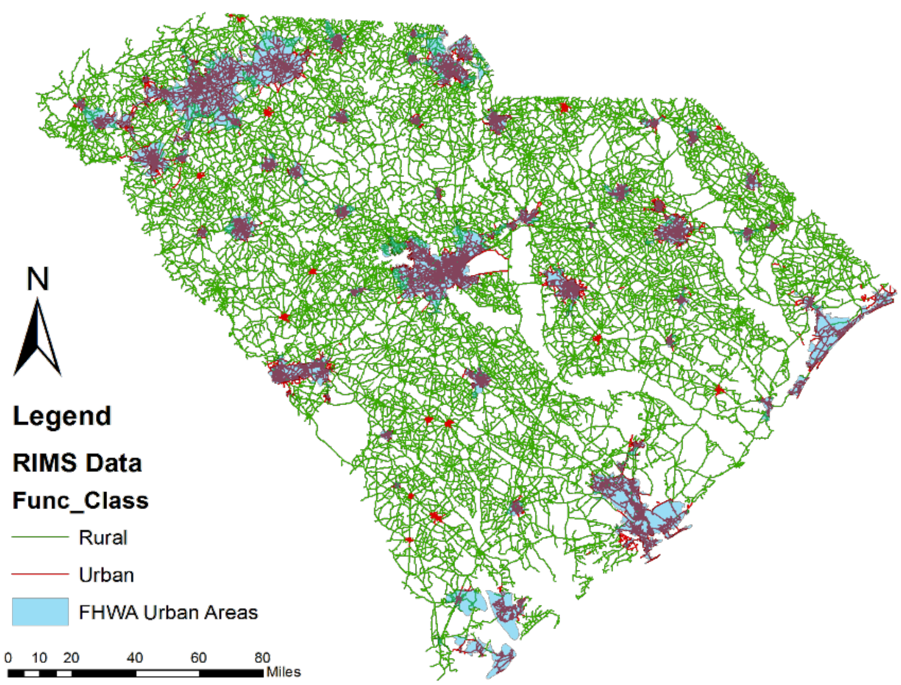


Figure 3.7 FHWA and SCDOT RIMS data urban area definition comparison

Other data elements used for classifying roadway type and developing buffers for assigning crashes are obtained directly from RIMS data fields. The number of lanes is obtained from

"TOTALLANES" field, median type is obtained from "Median_ID", which was previously discussed in section 3.1. Total surface width is obtained from "SurWid_Tot" and median width is obtained from the "Median_Wid" field.

In the second category, AADT and segment length which are required for SPF calculations, are also obtained from RIMS data. Length is obtained from the roadway centerline shape files and AADT is obtained from the AADT tables, which were provided along with the RIMS data. Original RIMS data is in an ArcGIS shapefile format and has AADT for 2010; additional AADT tables were obtained in five separate text files for the years 2011 to 2015. For matching the corresponding sites from RIMS data to the AADT tables, 'maplrs' in the AADT table was matched with 'Route_LRS" in RIMS along with beginning and ending mile posts.

Milepost segmentations in the AADT tables were not necessarily the same as in the RIMS data segmentation. While importing the new AADT data, the RIMS data was resegmented. Also, AADT tables were not comprehensive, and some roadways in RIMS did not have corresponding AADT data. In addition, some roads in the AADT tables were not in RIMS data. AADT tables on average covered about 89% of RIMS data. There were some suspect entries in the AADT tables, where obvious high-volume roads were associated with very low AADTs. In the case of suspect or missing data, an overall growth factor was used which obtained from all 4 years of AADT tables (2011 to 2014, 3137 / 3114 = 1.007). Due to the jump in AADT data from 2014 to 2015, a growth factor of 1.01 was used for 2015. Detailed information is provided in Table 3.9, where AADT is weighted by mileage.

Table 3.9 AADT tables and RIMS data

	Given Datasets			Re-segmented Datasets		
	Total Records	Total Mileage	Average Weighted AADT	Total Records	Total Mileage	Average Weighted AADT
RIMS 2010	75,195	41,440	3,140	75,195	41,440	3,140
AADT Table 2011	45,140	41,448	3,114	75,600	41,440	3,194
AADT Table 2012	45,153	41,432	3,125	75,823	41,440	3,232
AADT Table 2013	45,054	41,414	3,133	75,989	41,440	3,271
AADT Table 2014	45,103	41,391	3,137	76,611	41,440	3,316
AADT Table 2015	44,922	41,358	3,254	77,241	41,440	3,431

The third category includes data elements needed for the CMF adjustment to SPFs for non-base conditions at each specific site in the sample. Among those, some were available in RIMS data such as lane width ("Lane_Width" field), shoulder width ("Sh_Wid_li", "Sh_Wid_lo", "Sh_Wid_ri", "Sh_Wid_ro" fields, with the last two letters showing r/l which indicates right and left, and i/o indicates outside and inside), grades (“Avg_Slope” field), and presence of TWLTL (“Median_ID” field). For some data elements default values were assumed, because either their values were known for entire state or it was not feasible to collect data for them including automatic speed enforcement, superelevation variance, spiral curves, passing lanes and side slopes. Automatic speed enforcement was assumed to be not present since SCDOT did not have any automatic speed enforcement in the state. There was no database available for superelevation and side slopes and the research team could not find a feasible method to collect these data comprehensively, so default values were assumed (to have corresponding CMF = 1). Spiral curve transitions were also assumed to be non-existent because they are typically not utilized in the roadway types considered in this study. Passing lanes were also rarely present in state and assumed not present as a default.

The last category of data elements collected for roadway segments provide the detailed design characteristics for the sections. Many of the data elements in the third category were collected manually from visual inspection using Google Earth or Google Street View because they were not available in RIMS. Lighting was collected as a point shapefile along all roadway types by adding a point in the lighting layer when street lighting was spotted reviewing the corridors in Google Street View. Each light point was assumed to light 200 feet of roadway length in the CMF calculations. 2,052 light poles were identified and estimated to light 21% of the roadway segments. Driveways were also collected as point shapefiles and included 8,593 driveways with the predominant type being minor residential driveways. Shoulder type and Roadway Hazard Rating (RHR) were also collected as point layers. The average RHR was 3.2 and more than 50% of shoulder types were turf. Fixed objects and on street parking were collected as line shapefiles. The research team drew lines where fixed objects were present, as well as measured and coded the roadway offset and the number of fixed objects for each fixed object line. On-street parking was also collected as a linear feature and attributed with the type of the parking (parallel or angular) and area type (commercial or residential). Average slope for each segment was obtained by overlaying the roadway segments to LiDAR data (Light Detection And Ranging) and horizontal curvature was obtained by using the polylines obtained from the map shapefiles. Some samples of collected data is provided in Figure 3.8.

Figure 3.8 Collected data along roadway segments

3.2.2 Intersection Data Collection

Unlike roadway segments, which have a shapefile and attribute table (RIMS) containing most of the data for the segments, there is only a stand-alone database for signalized intersections (e-TEAMS data) that does not include any data for non-signalized intersections. This database does contain location information through latitude/longitude coordinates and contains 4,012 signalized intersections from across the state. Another intersection shapefile was generated by the research team, which was described previously in section 3.2, included 56,299 intersections. The research team developed scripts to automatically identify the type of intersection, but not all intersections were assigned the correct type by this algorithm. Based on the selected samples, where intersection type was verified during the data collection process, 88% of 7,775 initially selected samples had correctly assigned intersection type. Incorrect intersections were removed from database during data collection.

As with roadway segments, all required intersection data elements for HSM analysis can be divided into 3 main categories:

1) The first category is required information to identify the intersection type and buffer size for assigning crashes to the intersection. To identify the intersection type, the number of legs, rural or urban designation, and stop or signal controlled information is required. To identify the buffer size of the intersection for crash assignment, the curb line limits of the intersection had to be estimated. In the RIMS data, the actual width of the road was

available (“SurWid_Tot” + “Median_Wid”). To determine the direct intersection buffer, both the major and minor approach total widths were recorded and used to find the total buffer size – this is discussed in more detail in section 4.3.

2) The second category of data elements needed to calculate the SPF crash frequency includes AADT information for both the major and minor approaches. This information is only required for selected intersections.
3) The last category is data elements for CMF calculation which differ by intersection types; however, some elements are common in all types such as: number of approaches with left turn lanes and right turn lanes.

A complete list of intersections data elements for HSM analysis with their source and associated intersection type is shown in Table 3.10.

Table 3.10 Intersections data elements description

Data Element	Associated Intersections	Data Collection Source
Category 1 Data Elements – Required for Intersection Type Identification and Crash Assignment		
Number of Legs	All Intersections	RIMS Data
Rural/Urban	All Intersections	FHWA Urban Boundaries
Stop/Signal Control	All Intersections	e-TEAMS Data
Curbline limits	All Intersections	RIMS Data
Category 2 Data Elements – Required for SPF Estimate		
AADT Major	Selected Intersections	RIMS Data
AADT Minor	Selected Intersections	RIMS Data
Category 3 Data Elements – Required for CMF Adjustments to SPF		
Left Turn Lanes	Selected Intersections	Google Earth
Right Turn Lanes	Selected Intersections	Google Earth
Presence of Lighting	Selected Intersections	Google Street View
Skew Angle	Selected R3ST, R4ST, RM3ST & RM4ST	Google Earth
Left Turn Signal Phasing	Selected U3SG & U4SG	Google Street View
Right Turn on Red Prohibited	Selected U3SG & U4SG	Google Street View
Red Light Cameras	Selected U3SG & U4SG	Assumed not present
Bus Stops	Selected U4SG	Google Earth
Schools	Selected U4SG	Google Earth
Alcohol Sales Establishments	Selected U4SG	Google Earth

For intersections, all the collected data was pinned to a single point location. Therefore, all required data fields were created in the selected intersections shapefile and no separate shapefile was needed. The first and second category of data elements were automatically imported from RIMS data, while the third category was collected using Google imagery. Among 6,824 selected intersections, 13% were lighted, 10% had at least one approach with left turn lane and 3% had at least one approach with right turn lane. Skew angles were measured from the images displayed on the computer monitor and was recorded as "SKEW1" for 3-leg intersections or "SKEW1" and "SKEW2 for 4 leg intersections. About 27% of the rural stop-controlled intersections had skew angles more than 10 degrees. Signal related attributes (left turn phasing and right turn prohibited on red) were obtained using Google Street View. Red light cameras are prohibited through state legislation and thus were assumed not present for all intersections. Pedestrian crash prediction fields (bus stops, alcohol sales establishments, and schools) were also collected manually from Google Street View.

3.3 CRASH ASSIGNMENT

Aside from the physical characteristics of the roadway and traffic volumes, another major component used to calculate the calibration factors is the observed crashes. Observed crashes should be assigned to individual sites – either roadway segments or intersections. The underlying assumption is that roadway crashes and intersection crashes are independent; and separate HSM models are developed to predict crashes for each one. This assumption has been questioned in the literature (Brown et al., 2012), and in addition, there is not a well-established method to split the crashes between intersections and roadways (Abdel-Aty et al., 2009). The method chosen to define the intersection crashes not only modifies the intersection's calibration factors, but also affects the roadways as well. Therefore, the first step to find observed crashes for each site is to decide which crashes are intersection related.

The HSM defines intersection related crashes as crashes that occurred because of the presence of an intersection (AASHTO, 2010, pp. 10–8). The HSM also mentions that all crashes that occur within the curbline limits of an intersection ("A buffer") should be considered as intersection related. Furthermore, crashes that occur on intersection legs, within 250 feet of the center of the intersection ("B buffer"), might be intersection related or roadway related, based on their characteristics as shown in Figure 3.9 (AASHTO, 2010, p. G-8,). HSM recommends to use the investigator police officer's opinion, if available, in crash report; otherwise, rear-end or signal malfunction crashes might be assigned as intersection related, while single vehicle or driveway crashes should be assigned to roadways (AASHTO, 2010, p. A18).

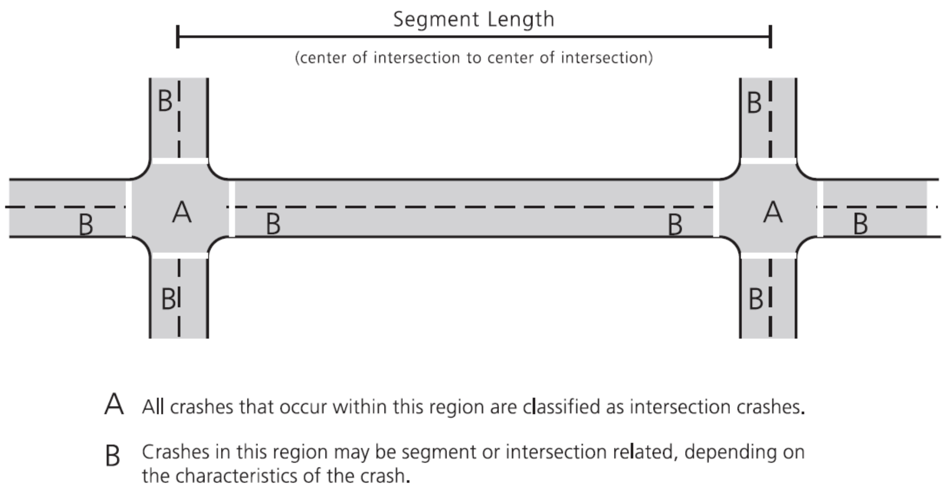


Figure 3.9 HSM intersection related crashes, source:(AASHTO, 2010)

Several pieces of prior literature question the 250 foot distance, and whether or not it is appropriate for identifying intersection related crashes (Harwood et al., 2000). One study revealed that intersection related crashes may occur up to 500 feet away from an intersection depending on the roadway volumes and queue lengths (Abdel-Aty et al., 2009). Relying solely on the police officer's report for intersection relatedness has not worked out in practice, mainly because different officers have differing subjective views. In most states that do have an intersection related field in their crash report, police officers are asked to report a crash as intersection related, not based on HSM definition, but based on the distance from the intersection (Abdel-Aty et al., 2009). Police officers are basically reporting the crash location instead of the fact that presence of the intersection caused the crash or not (Vogt, 1999, p. 40). This information is used to identify intersection related crashes in many studies: "*Michigan's HSIS accident file has a variable called Highway Area Type that indicates whether a crash occurred in the vicinity of an intersection. This perhaps could have been used to establish intersection-relatedness*" (Vogt, 1999). These issues make it difficult to identify actual intersection related crashes and usually best estimates are used instead.

In this study, the HSM crash assignment method is used to assign the crashes to individual roadway segments and intersections. Table 3.11 shows a summary of assigned crashes.

Table 3.11 Crash distribution between intersections and roadways

Years	All Geocoded Crashes		Intersection Crashes		Roadway Crashes		Not Matched to any site	
	All	KABC	All	KABC	All	KABC	All	KABC
2013	117,596	24.28%	32.41%	25.93%	29.60%	26.53%	37.99%	21.13%
2014	114,004	26.76%	39.29%	25.76%	31.53%	26.97%	29.19%	27.87%
2015	130,426	26.40%	40.00%	25.88%	32.09%	26.32%	27.92%	27.23%

The SCDOT crash database includes junction type field ("JCT"), which implies whether the crash has happened in the vicinity of an intersection. However, JCT code was found to be incorrectly used to identify crashes occurring at driveways entering roadway segments. These should not be coded as intersection crashes, and thus the research team did not utilize the JCT in this analysis. The "JCT" codes, definitions and distributions for 2014 crash data are provided in Table 3.12.

Table 3.12 JCT distribution for 2014 crash data

Junction types	JCT codes	% of total crashes
Crossover	1	1.37%
Driveway	2	8.88%
Five or more points	3	0.27%
Four way intersection	4	16.37%
Railway grade crossing	5	0.14%
Shared use path or trails	7	0.16%
T-intersection	8	12.25%
Traffic circle	9	0.29%
Y intersection	12	1.49%
Non junction	13	58.41%
Unknown	99	0.35%
Total Crashes:	128,763	

Additionally, latitude/longitude coordinates are recorded for each crash, which may be used to geocode the crashes in ArcGIS. Having both the crash coordinates and intersection locations enabled the research team to check the actual distance of the crash with the intersection location. During the geocoding process, inaccurate coordinates caused some crashes to fall outside of the state. Figure 3.10 shows the geocoded 2014 crash data.

Figure 3.10 Geocoded 2014 crash data

All out of state crashes were filtered and the amount of data loss is shown in following table by year:

Table 3.13 Out of state crash data due to false coordinates

Crash Year	All Crashes	In State Crashes	Data loss (%)
2011	117,923	93,148	21.00%
2012	121,094	99,792	17.60%
2013	123,933	103,931	16.14%
2014	128,764	114,012	11.46%
2015	140,023	130,429	11.29%

Additionally, using the geometric dimensions of each intersection, obtained from RIMS data, enabled the research team to identify the curbline limits of each intersection ("A buffer"). Intersection curbline limits or "A buffer" radius is calculated based on the following formula:

$$R_A = 1.2 \times \sqrt{\left({(S_{Major} + M_{Major})}/{2} \right)^2 + \left({(S_{Minor} + M_{Minor})}/{2} \right)^2} \quad (3\text{-}1)$$

R_A: Radius of A buffer

S: Total surface width

M: Median width

$Major$: Major approach

$Minor$: Minor approach

The HSM crash assignment method is completed by examining all individual crashes and assigning each one to either an intersection or roadway (or none), instead of checking each intersection or roadway and counting crashes within their buffers. The major advantage of the approach taken here is that crashes will not be counted twice in case of close sites. The algorithm is shown as a flowchart in Figure 3.11. Please note that crashes intersecting "B buffer" of two intersections (and not in "A buffer" of any of them) are assigned to the intersection with the higher volume. The typical example for this is the case when a minor 3 leg stop controlled intersection was close to a major signal-controlled intersection. Crashes not close to any intersection were assigned to roadways if they intersect the roadway buffer. Roadway buffers were defined based on the total surface width of the roadway.

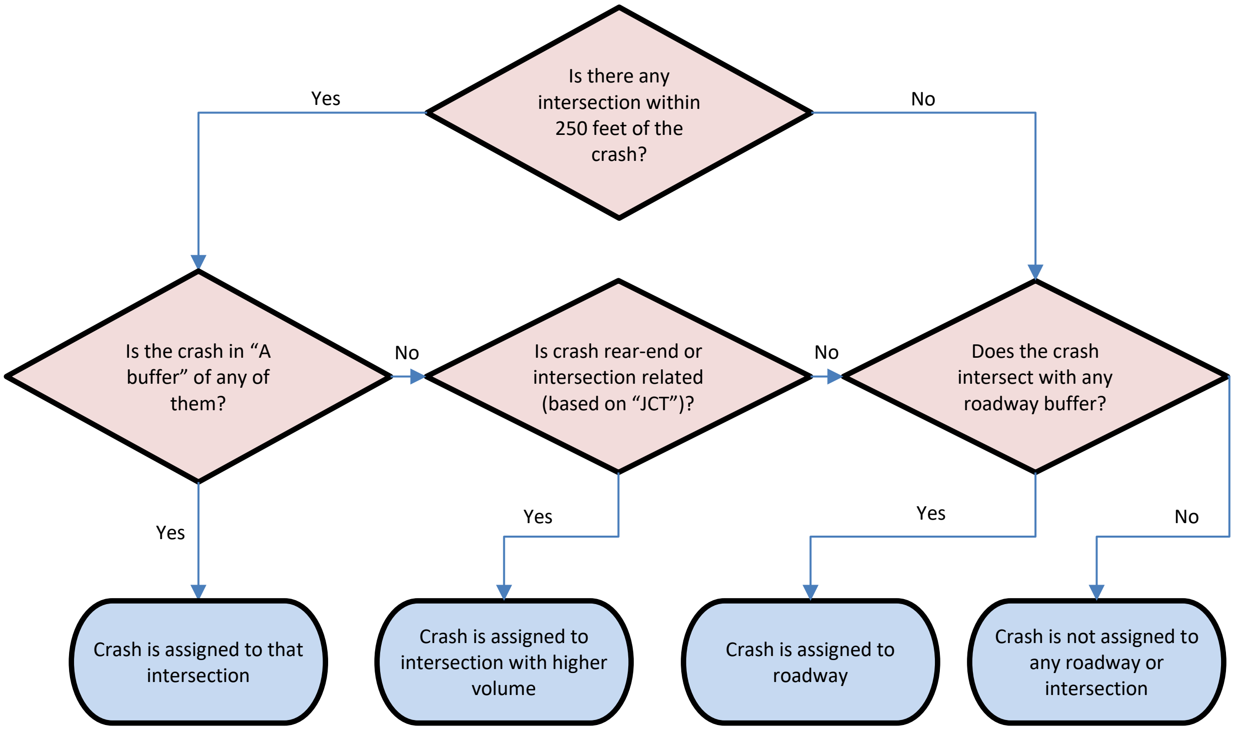


Figure 3.11 Crash assignment flowchart

Based on the algorithm, some crashes may not be assigned to either roadways or intersections. It is important to note that the roadway and intersection database that were used to assign crashes to, are all based on the RIMS database and the RIMS database does not include all the roadways in the state. Thus, some of the unassigned crashes might be intersection or roadway related but the corresponding site is not in the RIMS database. Other explanations for unassigned crashes can be crashes with incorrect coordinates. Unassigned crashes can be identified by using the crash assignment fields in the SC_Crash_20XX.rar files in the electronic appendix. The fields "RCrash" (Roadway Crash) and "ICrash" (Intersection Crash) are binary fields to indicate if the crash was assigned as a roadway crash or an intersection crash. Crashes with ICrash=0 AND RCrash=0 are crashes that were not assigned.

3.4 OUTLIER DETECTION

After collecting all the data elements, datasets should be examined for outliers. Outliers should be evaluated in different aspects, for example, outliers with respect to predictor's (X) values (i.e. AADT or segment length) or with respect to predictions (Y) values (observations i.e. total observed crashes) or influential points etc.

At the very first step, predictor vs predictor plots (e.g. AADT Major vs AADT minor for intersections) are prepared for all sites to define the domain of applicability for each type. Plotting the data rather than using just the range of X values helps to see how the observations are distributed in the domain and helps to prevents "hidden extrapolation" in future applications. Predictor vs predictor plots accompanied with boxplots for each axis are prepared for all facility types and out of range observations are identified. For example, the predictor vs predictor plot for R3ST is shown in Figure 3.12. In this plot, the range of AADT values for corresponding HSM SPF are also included for comparison.

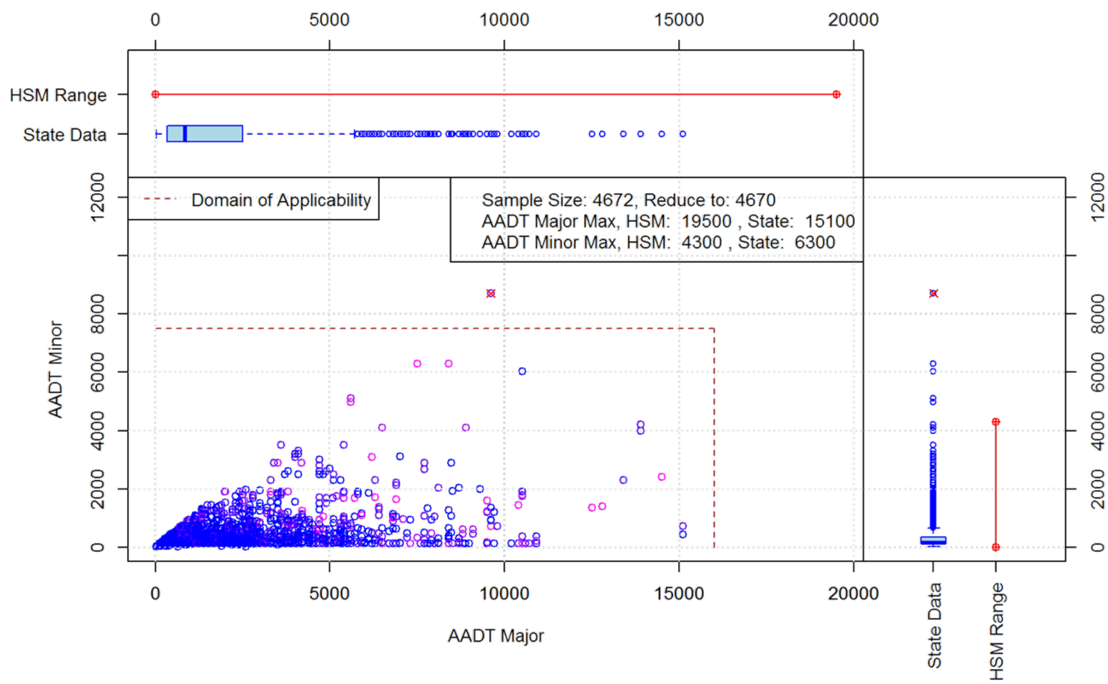


Figure 3.12 Sample domain of applicability identification

In this plot the domain of applicability for state data is determined. The sites that are relatively separated from the rest of data are trimmed. After identifying the domain of applicability, Cook`s distance and Jackknife residuals are used to find the outliers with respect to observations (Y). Also, leverage plots for predictors (i.e. traffic volumes) are used to identify outliers with respect to predictors (X). A sample plot of outliers for R3ST is shown in Figure 3.13.

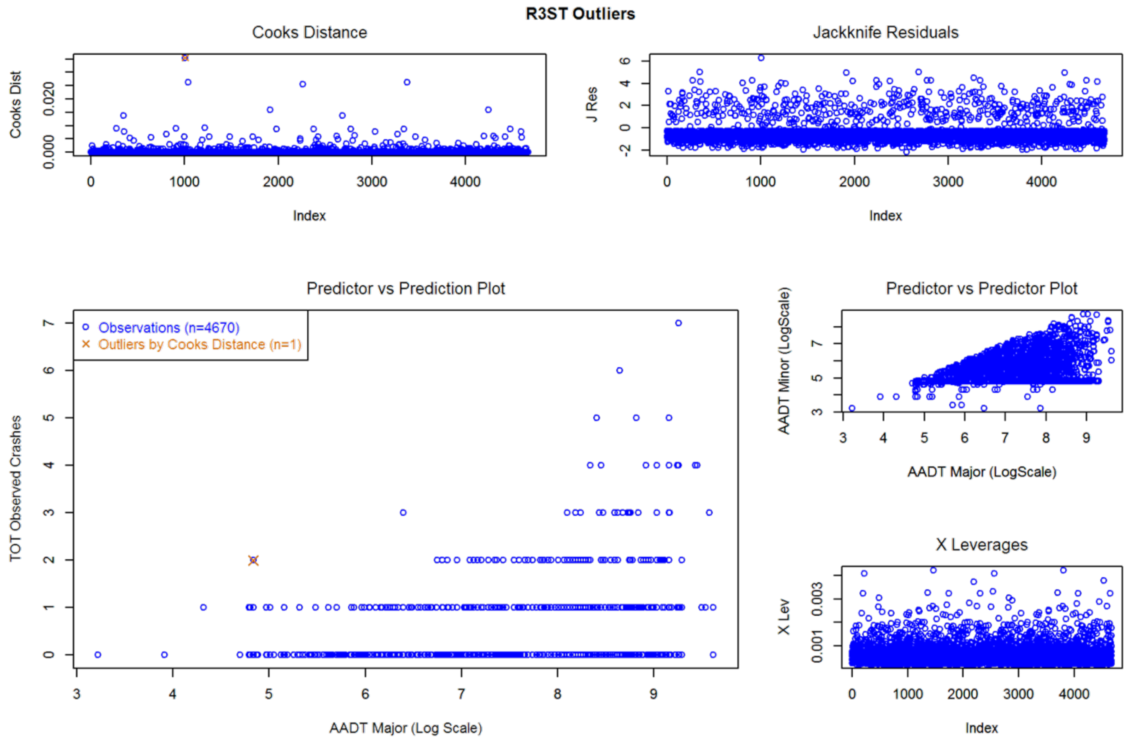


Figure 3.13 Sample outliers identification

Marked sites are further studied to find out why they are outlying with respect to other observations and several common reasons were identified. The most common case, especially in rural sites, happens when the rural site is very close to urban areas. Since the average range of AADT for urban sites is greater than the rural sites, the rural sites that are very close to urban boundaries tend to be outlying in terms of having high volumes compared with other rural sites. Another example was data entry errors, having several years of data, it is easy to identify a site that has AADT of 3,000 for three of those years and 30,000 for one. This is an obvious key entry error. The research team corrected the latter when identified.

4. RESULTS

4.1 CALIBRATION FACTORS

Unadjusted predicted crashes can be obtained from the following equation:

$$N_u = N_{spf} \times (CMF_1 \times CMF_2 \times \ldots) \tag{4-1}$$

N_u: Unadjusted predicted average crash frequency
N_{spf}: Predicted average crash frequency for base condition
CMF_i: Crash modification factor

Calibration factors are calculated based on observed crashes and unadjusted predicted crashes, also mentioned in equation (1-4), with the following equation:

$$C = \frac{\sum Observed\ Crash}{\sum Unadjusted\ Predicted\ Crash} = \frac{\sum N_o}{\sum N_u} \tag{4-2}$$

N_o: Observed crash frequency
N_u: Unadjusted predicted crash frequency
C: Calibration factor

It is important to estimate the standard error of calibration factors to have interval estimates of calibration factors. In HSM calibration guide (Bahar, 2014) a method is proposed to estimate the standard error of calibration factors. This method assumes that $\sum N_u$, the denominator of equation (5-2), is not a random variable:

$$Var(C) = \frac{Var(\sum N_o)}{(\sum N_u)^2} = \frac{\sum var(N_o)}{(\sum N_u)^2} = \frac{\sum(N_o + kN_o{}^2)}{(\sum N_u)^2} \tag{4-3}$$

k: Overdispersion factor in negative binomial distribution ($\sigma^2 = \mu + k\mu^2$)
var: Variance

By assuming $N_o \cong N_p = CN_u$, and replacing N_o by CN_u, and also using average values instead of summations, $var(C)$ is calculated as a function of sample size as following (Bahar, 2014):

$$Var(C) = \frac{\sum(N_o + kN_o{}^2)}{(\sum N_u)^2} = \frac{\sum(CN_u + kC^2 N_u{}^2)}{(\sum N_u)^2} = \frac{C}{n\overline{N_u}} + \frac{\bar{k}C^2}{n} \tag{4-4}$$

It is recommended to limit the coefficient of variation of calibration factors ($c.v(C) = var(C)/C^2$) between 0.10 to 0.15 (Bahar, 2014). Simplifying assumptions that were made to develop equations (4-3) and (4-4), will cause bias in estimation of the variance of calibration factors. Other statistical methods can be used to estimate the $var(C)$ to avoid these simplifying assumptions. The best method identified by this research team is a bootstrapping method. In this method a random resampling with replacement is used to find the summary statistics of the desired function (i.e. calibration factor) (Efron and Tibshirani, 1994). Standard error of calibration factors is calculated based on bootstrapping method, which the authors believe gives more accurate results. Table 4.1 shows the statewide calibration factors along with the summary of predictor values and observed crashes.

Table 4.1 Statewide calibration factors summary for 2013-2015

Type	Sample Size	Total Length	Average AADT Major	Average AADT Minor	Total Observed Crashes	Calibration Factor	Calibration Factor C.V.
R2U	1,841	1,117.73	753	0	447	0.99	5.10%
R4D	508	161.16	9,934	0	253	0.61	8.17%
R4U	484	126.25	3,921	0	58	0.31	14.24%
U2U	667	201.65	2,109	0	261	1.66	7.95%
U3T	73	15.73	9,697	0	82	1.47	15.01%
U4U	349	76.57	8,602	0	275	0.75	8.70%
U4D	352	85.02	19,172	0	321	0.83	6.87%
U5T	673	155.59	16,059	0	1,035	0.77	5.15%
R3ST	7,000	0.00	892	205	907	0.40	3.98%
R4ST	2,785	0.00	995	233	787	0.47	4.97%
R4SG	97	0.00	6,104	1,497	131	0.46	11.76%
RM3ST	613	0.00	8,061	357	261	0.55	10.91%
RM4ST	284	0.00	6,438	271	63	0.26	17.52%
RM4SG	80	0.00	11,619	1,375	272	0.40	9.42%
U3ST	5,607	0.00	1,765	287	2,136	1.20	3.92%
U4ST	2,992	0.00	1,702	324	1,650	0.96	5.00%
U3SG	299	0.00	16,181	3,170	1,255	2.00	5.05%
U4SG	538	0.00	12,870	2,725	3,334	2.45	4.52%

Please note that the sample size provided in the above table represent the number of observations in the analysis which is the multiplication of location of sites and years of crash data. Basically, the number of locations for each year is the above sample size divided by 3 years of crash data.

Calibration factors are calculated for each area division as well, including geographical area divisions and population density are divisions (see Figure 1-1 for details). For each type a figure is prepared to compare the statewide calibration factor with local area's calibration factor. Figure 4.1 shows the results for R3ST. In this figure, calibration factors are plotted with their 95% confidence intervals. Standard error of calibration factors is obtained by bootstrapping. Additionally, the sample size and number of observed crashes are shown, as well as the coefficient of variation. Also, minimum values for sample size (i.e. 50) and number of observed crashes (i.e. 100), as well as maximum value for coefficient of variation (i.e. 0.15) is used for color coding the results. In R3ST case, all the criteria are met for all the area divisions and therefore all the results are shown in green in Figure 4.1.

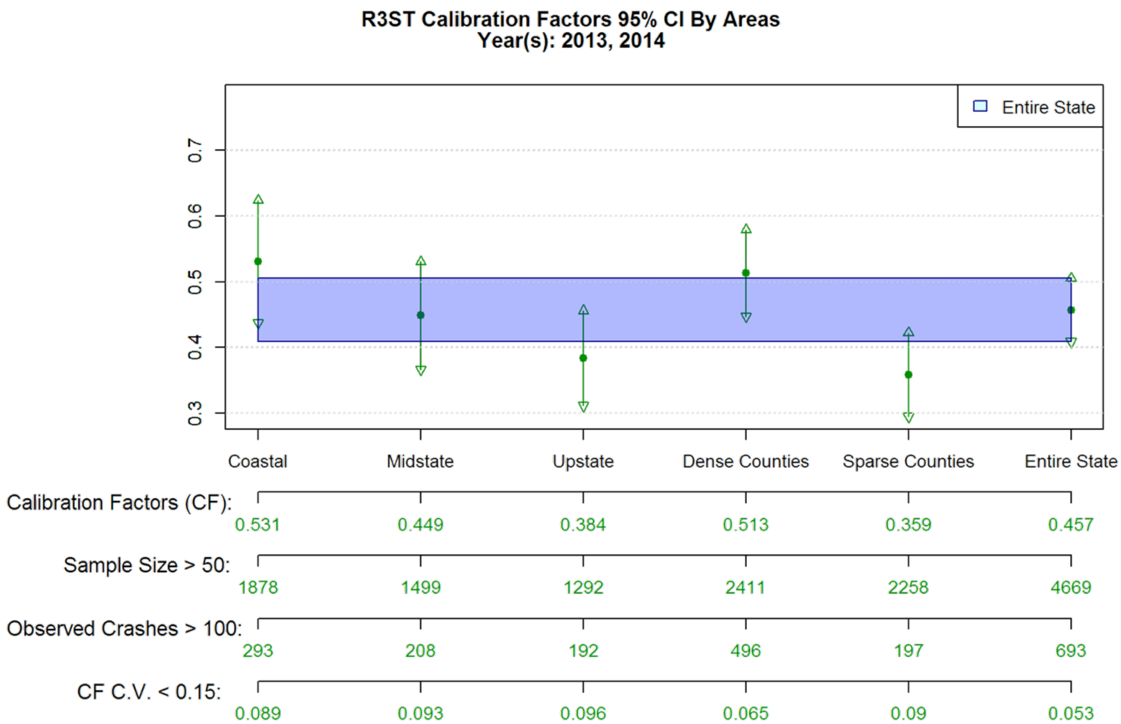


Figure 4.1 Sample calibration results by area type

To evaluate the accuracy of the calibration factors, the research team recommends considering the sample size and coefficient of variation together as a more accurate measure than considering the sample size and number of observed crashes, as recommended by the HSM. However, coefficient of variation is very likely to exceed the maximum limit (i.e. 0.15) in low sample sizes, considering the coefficient of variation alone is not enough. In extreme cases, where the variability in the data is very low, a low coefficient of variation may be obtained for a low sample size.

4.2 STATE SPECIFIC SAFETY PERFORMANCE FUNCTIONS

State-specific SPFs are developed for all 18 facility types in HSM part C using covariate SPF method. The functional form considered in this study is the same functional form that is used in HSM. First, a negative binomial regression is performed by including volume, length and other geometric design variables as predictors and total observed crashes as prediction. These models are called initial models. In Initial models, all the geometric design variables were centered to their base value. Centering the variables to their base value helps to avoid any future adjustment to the model's intercept after substituting the base values to find the base SPFs. For segment models, length is defined as an offset variable. The format of the initial SPFs is shown in the following.

Roadways:

$$\ln(N_{\text{spf}}) = \hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT) + \ln(L) + \sum_{i=1}^{n} \hat{\beta}_i (X_i - X_{b_i})$$

$$N_{\text{spf}} = e^{\hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT) + \ln(L) + \sum_{i=1}^{n} \hat{\beta}_i (X_i - X_{b_i})}$$

$$= e^{\hat{\beta}_0} \times L \times AADT^{\hat{\beta}_1} \times \prod_{i=1}^{n} (X_i - X_{b_i})^{\hat{\beta}_i} \qquad (4\text{-}5)$$

ln( ) : Natural logarithm
$AADT$: Average Annual Daily Traffic (AADT)
L : Segment length
$\hat{\beta}_0, \hat{\beta}_1$: Coefficients of regression
n: Number of geometric design variables included in the model
X_i: Geometric design variable I (e.g. Lighting, LTL, RTL, etc.)
X_{b_i}: Base condition value for X_i (based on HSM)
$\hat{\beta}_i$: Coefficient of regression for X_i

Intersections:

$$\ln(N_{\text{spf}}) = \hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT_{Major}) + \hat{\beta}_2 \times \ln(AADT_{Minor}) + \sum_{i=1}^{n} \hat{\beta}_i (X_i - X_{b_i})$$

$$N_{\text{spf}} = e^{\hat{\beta}_0 + \hat{\beta}_1 \times \ln(AADT_{Major}) + \hat{\beta}_2 \times \ln(AADT_{Minor}) + \sum_{i=1}^{n} \hat{\beta}_i (X_i - X_{b_i})} \qquad (4\text{-}6)$$

$$= e^{\hat{\beta}_0} \times AADT_{Major}^{\hat{\beta}_1} \times AADT_{Minor}^{\hat{\beta}_2} \times \prod_{i=1}^{n} (X_i - X_{b_i})^{\hat{\beta}_i}$$

$AADT_{Major}$: Major approach AADT
$AADT_{Minor}$: Minor approach AADT

Please note that in the HSM for R2U, it is assumed that there is a linear relationship between volume and crash frequency while in other road types the above functional form is used. In this study, the above functional form is used for all roadway types including R2Us.

In initial models, some of the coefficients corresponding to some geometric design variables were found to be not statistically significant mainly because there was not enough variation in the dataset. For example, when most of the selected intersections had no left turn lane, the regression coefficient of the left turn lane in the initial model is likely to be not significant. As mentioned earlier in the introduction, random site selection used in this study represents the average condition of the geometric design variables and this average condition may not lead to statistically significant coefficients for all the geometric design variables. To study the effect of each individual geometric design factor, a separate dataset should be prepared where all other attributes remain relatively constant and only the variable of interest changes.

Table 4.2 Initial SPFs for roadways and intersections 2013-2015

Intersection SPFs

Facility Type	Variable	Estimate	p-value
R3ST	***Intercept***	-10.4261	0.0000
R3ST	***AADT_Major***	0.7286	0.0000
R3ST	***AADT_Minor***	0.5275	0.0000
R3ST	LIGHTING	-0.0933	0.6751
R3ST	LTL	-0.0148	0.9658
R3ST	***RTL***	0.7601	0.0199
R3ST	SKEW1	-0.0056	0.0578
R4ST	***Intercept***	-10.9170	0.0000
R4ST	***AADT_Major***	0.6321	0.0000
R4ST	***AADT_Minor***	0.8056	0.0000
R4ST	***LIGHTING***	-0.7120	0.0005
R4ST	LTL	0.0597	0.7532
R4ST	RTL	-0.0302	0.9626
R4ST	SKEW1	0.0067	0.3202
R4ST	***SKEW2***	0.0149	0.0234
R4SG	***Intercept***	-13.2898	0.0001
R4SG	***AADT_Major***	0.9212	0.0127
R4SG	***AADT_Minor***	0.6796	0.0000
R4SG	LIGHTING	0.2105	0.3388
R4SG	LTL	0.0262	0.7126
R4SG	***RTL***	0.3146	0.0113
RM3ST	***Intercept***	-16.4489	0.0000
RM3ST	***AADT_Major***	1.2232	0.0000
RM3ST	***AADT_Minor***	0.6791	0.0000
RM3ST	***LIGHTING***	-0.7577	0.0434
RM3ST	LTL	0.0129	0.9568
RM3ST	RTL	0.0314	0.9001
RM3ST	SKEW1	-0.0152	0.0647
RM4ST	***Intercept***	-20.0500	0.0000
RM4ST	***AADT_Major***	1.5925	0.0001
RM4ST	***AADT_Minor***	0.6985	0.0065
RM4ST	LIGHTING	-0.5583	0.2254
RM4ST	LTL	0.1676	0.4562
RM4ST	RTL	-0.1532	0.7895
RM4ST	SKEW1	0.0077	0.7256
RM4ST	SKEW2	-0.0051	0.8053
RM4SG	***Intercept***	-12.3672	0.0000
RM4SG	***AADT_Major***	1.2949	0.0000
RM4SG	AADT_Minor	0.1741	0.1026
U3ST	***Intercept***	-9.7143	0.0000

Roadway SPFs

Facility Type	Variable	Estimate	p-value
R2U	***Intercept***	-5.6847	0.0000
R2U	***AADT***	0.6672	0.0000
R2U	Lane_Width	-0.0204	0.5811
R2U	Shuold_Wid	-0.0258	0.2516
R2U	RHR	0.0307	0.5382
R2U	DrwDens	0.0019	0.6811
R2U	HorCur	0.0758	0.3390
R2U	Grade	0.5191	0.5117
R4D	***Intercept***	-3.5674	0.0092
R4D	LIGHTING	0.9785	0.1711
R4D	***AADT***	0.4002	0.0066
R4D	Lane_Width	0.1806	0.0586
R4D	***Shuold_Wid***	-0.0733	0.0038
R4D	***Median_Wid***	-0.0111	0.0383
R4U	***Intercept***	-12.3235	0.0001
R4U	LIGHTING	-0.2643	0.5982
R4U	***AADT***	1.3389	0.0002
R4U	Lane_Width	-0.1846	0.2217
R4U	Shuold_Wid	0.0549	0.1358
R4U	Grade	0.3347	0.6829
U2U	***Intercept***	-4.3148	0.0000
U2U	LIGHTING	0.9581	0.0762
U2U	***AADT***	0.5619	0.0000
U2U	DrwDens	0.0019	0.6102
U2U	FODensity	-0.0031	0.4778
U3T	***Intercept***	-22.4244	0.0000
U3T	LIGHTING	-0.2109	0.5988
U3T	***AADT***	2.4839	0.0000
U3T	DrwDens	0.0149	0.0688
U3T	FODensity	0.0006	0.8606
U4U	***Intercept***	-10.5993	0.0000
U4U	***LIGHTING***	-0.4891	0.0147
U4U	***AADT***	1.2403	0.0000
U4U	***DrwDens***	0.0103	0.0028
U4U	FODensity	0.0020	0.2225
U4D	***Intercept***	-7.9389	0.0000
U4D	LIGHTING	-0.4478	0.2612

U3ST	***AADT_Major***	0.8745	0.0000
U3ST	***AADT_Minor***	0.2289	0.0000
U3ST	LIGHTING	0.0537	0.7241
U3ST	LTL	-0.1043	0.5017
U3ST	RTL	0.2970	0.3057
U4ST	***Intercept***	-9.8119	0.0000
U4ST	***AADT_Major***	0.8476	0.0000
U4ST	***AADT_Minor***	0.3574	0.0000
U4ST	LIGHTING	-0.1437	0.2881
U4ST	LTL	0.0493	0.6118
U4ST	RTL	0.4489	0.2054
U3SG	***Intercept***	-11.7916	0.0000
U3SG	***AADT_Major***	1.2623	0.0000
U3SG	***AADT_Minor***	0.0991	0.0373
U3SG	***LIGHTING***	-0.3491	0.0010
U3SG	LTL	0.0522	0.5129
U3SG	RTL	0.1456	0.0648
U3SG	***LTP1***	-0.1868	0.0420
U3SG	***LTP2***	0.3261	0.0078
U3SG	No_RTOR	-0.1071	0.5410
U4SG	***Intercept***	-10.4160	0.0000
U4SG	***AADT_Major***	1.0770	0.0000
U4SG	***AADT_Minor***	0.2076	0.0000
U4SG	***LIGHTING***	-0.2643	0.0025
U4SG	***LTL***	0.0784	0.0046
U4SG	RTL	0.0035	0.9266
U4SG	***LTP1***	-0.7024	0.0020
U4SG	***LTP2***	0.5821	0.0140
U4SG	No_RTOR	-0.0195	0.8601
U4SG	LTP3	-0.3906	0.1775
U4SG	***LTP4***	0.9053	0.0026
U4D	***AADT***	0.9519	0.0000
U4D	DrwDens	-0.0010	0.8438
U4D	***Median_Wid***	-0.0136	0.0046
U4D	FODensity	0.0022	0.1388
U5T	***Intercept***	-6.9311	0.0000
U5T	***LIGHTING***	-0.3523	0.0208
U5T	***AADT***	0.8927	0.0000
U5T	***DrwDens***	0.0066	0.0192
U5T	FODensity	0.0002	0.9237

Variables that found to be 95% significant are shown as italic and bold

After developing the initial models, variables that were not significant or had the wrong sign in the initial models are removed and the same regression process is performed with remaining variables to develop the covariate SPFs. Then covariate SPFs are used to define the base SPFs. For this purpose, the base values of the geometric design variables are substituted in the covariate SPFs to form the base SPFs. Because the geometric design variables are centered to their base values in the initial models, substituting the base values does not change the intercept or the coefficient of the traffic volume and it is equivalent to removing them from the model. The following table shows the Covariate SPFs.

Table 4.3 Covariate SPFs for roadways and intersections 2013-2015

Intersection SPFs

Facility Type	Variable	Estimate	p-value
R3ST	Intercept	-10.4683	0.0000
R3ST	AADT_Major	0.7386	0.0000
R3ST	AADT_Minor	0.5129	0.0000
R4ST	Intercept	-10.8348	0.0000
R4ST	AADT_Major	0.6430	0.0000
R4ST	AADT_Minor	0.8154	0.0000
R4ST	LIGHTING	-0.8492	0.0000
R4SG	Intercept	-12.2852	0.0001
R4SG	AADT_Major	0.9193	0.0078
R4SG	AADT_Minor	0.5974	0.0000
RM3ST	Intercept	-16.0644	0.0000
RM3ST	AADT_Major	1.1737	0.0000
RM3ST	AADT_Minor	0.6698	0.0000
RM3ST	LIGHTING	-0.7815	0.0316
RM4ST	Intercept	-21.3096	0.0000
RM4ST	AADT_Major	1.6801	0.0000
RM4ST	AADT_Minor	0.7950	0.0005
RM4SG	Intercept	-12.3672	0.0000
RM4SG	AADT_Major	1.2949	0.0000
RM4SG	AADT_Minor	0.1741	0.1026
U3ST	Intercept	-9.6784	0.0000
U3ST	AADT_Major	0.8669	0.0000
U3ST	AADT_Minor	0.2337	0.0000
U4ST	Intercept	-9.9180	0.0000
U4ST	AADT_Major	0.8605	0.0000
U4ST	AADT_Minor	0.3566	0.0000
U3SG	Intercept	-13.0444	0.0000
U3SG	AADT_Major	1.3504	0.0000
U3SG	AADT_Minor	0.1673	0.0001
U3SG	LIGHTING	-0.3404	0.0008
U4SG	Intercept	-11.6370	0.0000
U4SG	AADT_Major	1.1562	0.0000
U4SG	AADT_Minor	0.2729	0.0000

Roadway SPFs

Facility Type	Variable	Estimate	p-value
R2U	Intercept	-5.4065	0.0000
R2U	AADT	0.6441	0.0000
R4D	Intercept	-3.5177	0.0087
R4D	AADT	0.3984	0.0057
R4D	Shuold_Wid	-0.0668	0.0081
R4D	Median_Wid	-0.0110	0.0395
R4U	Intercept	-12.7287	0.0000
R4U	AADT	1.3841	0.0000
U2U	Intercept	-4.2232	0.0000
U2U	AADT	0.5612	0.0000
U3T	Intercept	-25.0381	0.0000
U3T	AADT	2.7995	0.0000
U4U	Intercept	-10.6102	0.0000
U4U	LIGHTING	-0.5127	0.0101
U4U	AADT	1.2514	0.0000
U4U	DrwDens	0.0122	0.0001
U4D	Intercept	-8.2188	0.0000
U4D	AADT	0.9790	0.0000
U4D	Median_Wid	-0.0116	0.0075
U5T	Intercept	-6.9451	0.0000
U5T	LIGHTING	-0.3467	0.0192
U5T	AADT	0.8943	0.0000
U5T	DrwDens	0.0066	0.0193

It should be noted that having these variables in the model enables us to use all our dataset in contrast to base SPF method which only part of the data that matches the base condition is used for regression. The following South Carolina specific SPFs can be used for prediction of total crashes and will enable network screening on most road and intersection types.

South Carolina Specific SPFs for Intersections:

R3ST:

$$N_{spf(tot)} = e^{-10.4683} \times \left(AADT_{major}\right)^{0.7386} \times (AADT_{minor})^{0.5129} \quad (4\text{-}7)$$

R4ST:

$$N_{spf(tot)} = e^{-10.8348} \times \left(AADT_{major}\right)^{0.7386} \times (AADT_{minor})^{0.5129} \times e^{-0.8492 \times Light} \quad (4\text{-}8)$$

where, Light = 0 if not present, 1 if present

R4SG:

$$N_{spf(tot)} = e^{-12.2852} \times \left(AADT_{major}\right)^{0.9193} \times (AADT_{minor})^{0.5974} \quad (4\text{-}9)$$

RM3ST:

$$N_{spf(tot)} = e^{-16.0644} \times \left(AADT_{major}\right)^{1.1737} \times (AADT_{minor})^{0.6698} \times e^{-0.7815 \times Light} \quad (4\text{-}10)$$

where, Light = 0 if not present, 1 if present

RM4ST:

$$N_{spf(tot)} = e^{-21.3096} \times \left(AADT_{major}\right)^{1.6801} \times (AADT_{minor})^{0.7950} \quad (4\text{-}11)$$

RM4SG:

$$N_{spf(tot)} = e^{-12.3672} \times \left(AADT_{major}\right)^{1.2949} \times (AADT_{minor})^{0.1741} \quad (4\text{-}12)$$

U3ST:

$$N_{spf(tot)} = e^{-9.6784} \times \left(AADT_{major}\right)^{0.8669} \times (AADT_{minor})^{0.2337} \quad (4\text{-}13)$$

U4ST:

$$N_{spf(tot)} = e^{-9.9180} \times \left(AADT_{major}\right)^{0.8605} \times (AADT_{minor})^{0.3566} \quad (4\text{-}14)$$

U3SG:

$$N_{spf(tot)} = e^{-13.0444} \times \left(AADT_{major}\right)^{1.3504} \times (AADT_{minor})^{0.1673} \times e^{-0.3404 \times Light} \quad (4\text{-}15)$$

U4SG:

$$N_{spf(tot)} = e^{-11.6370} \times \left(AADT_{major}\right)^{1.1562} \times (AADT_{minor})^{0.2729} \quad (4\text{-}16)$$

South Carolina Specific SPFs for Segments:

R2U:

$$N_{spf(tot)} = e^{-5.4065} \times (AADT)^{0.6641} \quad (4\text{-}17)$$

R4D:

$$N_{spf(tot)} = e^{-3.5177} \times \left(AADT_{major}\right)^{0.3984} \times e^{-0.0668 \times SW} \times e^{-0.0110 \times MW} \quad (4\text{-}18)$$

where, SW = shoulder width (ft) and MW = median width (ft)

R4U:

$$N_{spf(tot)} = e^{-12.7287} \times (AADT)^{1.3841} \quad (4\text{-}19)$$

U2U:

$$N_{spf(tot)} = e^{-4.2232} \times (AADT)^{0.5612} \quad (4\text{-}20)$$

U3T:

$$N_{spf(tot)} = e^{-25.0381} \times (AADT)^{2.7995} \quad (4\text{-}21)$$

U4U:

$$N_{spf(tot)} = e^{-10.6102} \times \left(AADT_{major}\right)^{1.2514} \times e^{-0.5127 \times Light} \times e^{0.0122 \times DD} \quad (4\text{-}22)$$

where, Light = 0 if not present, 1 if present; and DD = driveway density per mile

U4D:

$$N_{spf(tot)} = e^{-8.2188} \times \left(AADT_{major}\right)^{0.9790} \times e^{-0.0116 \times MW} \quad (4\text{-}23)$$

where, MW = median width (ft)

U5T:

$$N_{spf(tot)} = e^{-6.9451} \times \left(AADT_{major}\right)^{0.8943} \times e^{-0.3467 \times Light} \times e^{0.0066 \times DD} \quad (4\text{-}24)$$

where, Light = 0 if not present, 1 if present; and DD = driveway density per mile

In the final step, base SPFs are developed from the covariate SPFs. Base SPFs can be used instead of the HSM SPFs for safety applications. The coefficients of the base SPFs are the same as covariate SPFs. For each facility type, the state specific covariate SPF is compared with the calibrated HSM SPF and plotted against the data. The following figure shows the state specific SPF for U2U. Note that the overdispersion parameter (k) is listed in the index box with State Specific SPF. The k value is needed to develop the weight function for calculating N_{pred} using Empirical Bayes procedures. The data and SPF plots for all intersection and segment types are available in the appendix. The detailed equations and method for applying the EB method can be found in the HSM Vol. 2 on page A-19 (see equations (A-4) and (A-5)).

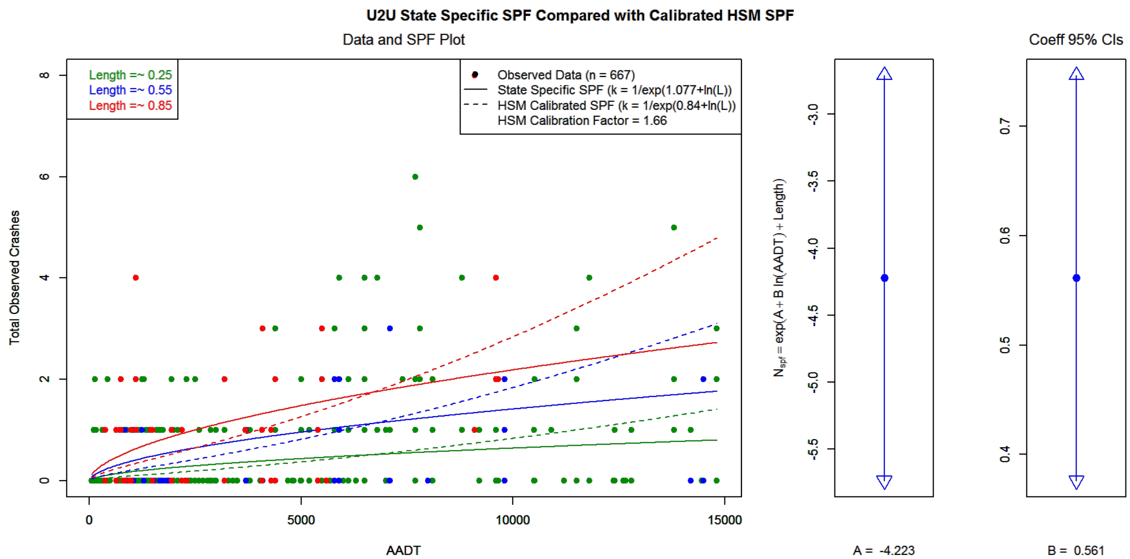


Figure 4.2 Sample state specific SPF for U2U

Also, the performance of the state specific SPFs is measured by Cumulative Residual (CURE) plots. The following figure shows the CURE plot for U2U segments.

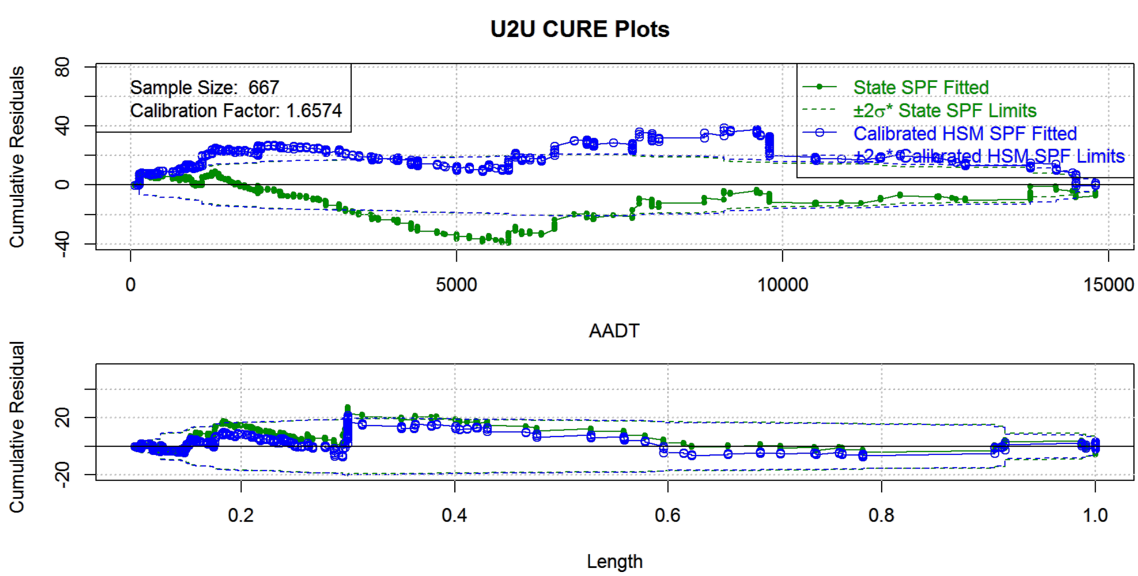


Figure 4.3 Sample CURE plot for state specific SPF for U2U

In addition to CURE plots, distribution of the observed crashes is compared with the distribution of the predicted crashes for both HSM calibrated SPFs and state specific SPFs.

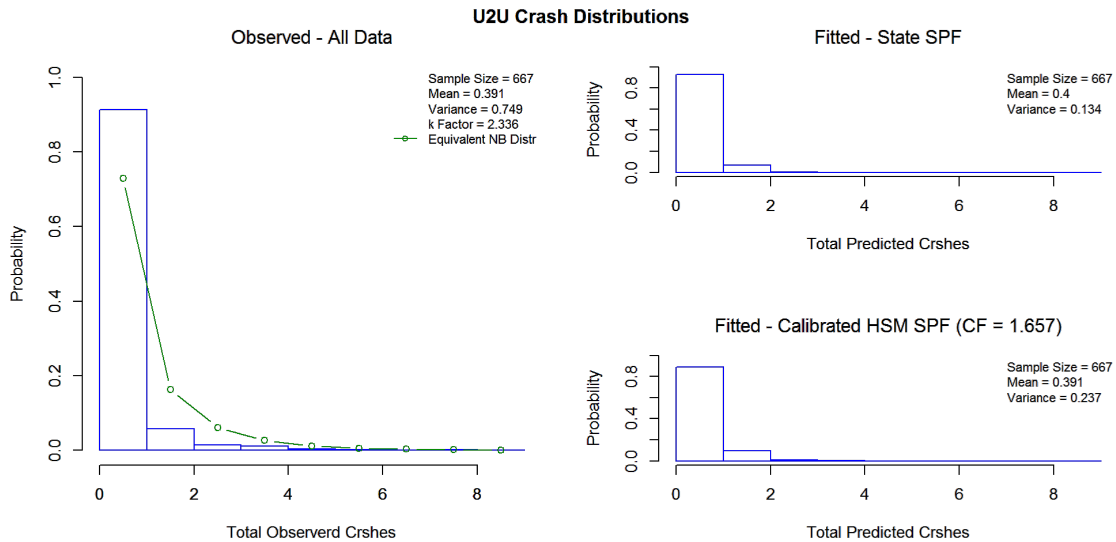


Figure 4.4 Sample Crash distribution plot for U2U

The above figure can be used to compare the distribution of observed crashes and predicted crash and it provides the mean and variance for each distribution.

4.3 FREEWAY CALIBRATION FACTORS

Using the HSM supplement (AASHTO, 2014), calibration factors are calculated for 3 basic freeway segments, R4F, U4F and U6F. Other freeway facility types such as freeways with 8 or 10 lanes, ramps, speed change lanes, collector-distributor roads and ramp terminals which are presented in the HSM supplement are not calibrated mainly because ramp volume data was not available in state level. The same process which described in the previous chapters is used to develop the freeway calibration factors. The following table shows a summary of the total R4F, U4F and U6F segments in the state.

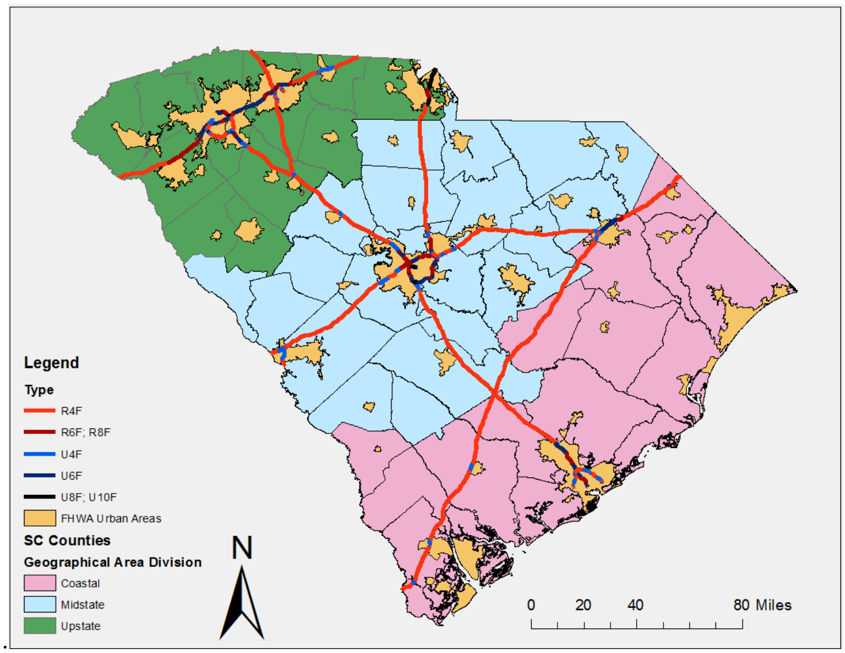
Table 4.4 Summary statistics of state-wide freeway segments by road type (2015 data)

Road Type	Population Size	Mileage	Average AADT	Tot Observed Crash
R4F	470	637.6	38,124	4234
U4F	150	76.5	49,231	742
U6F	186	80.1	77,404	2505

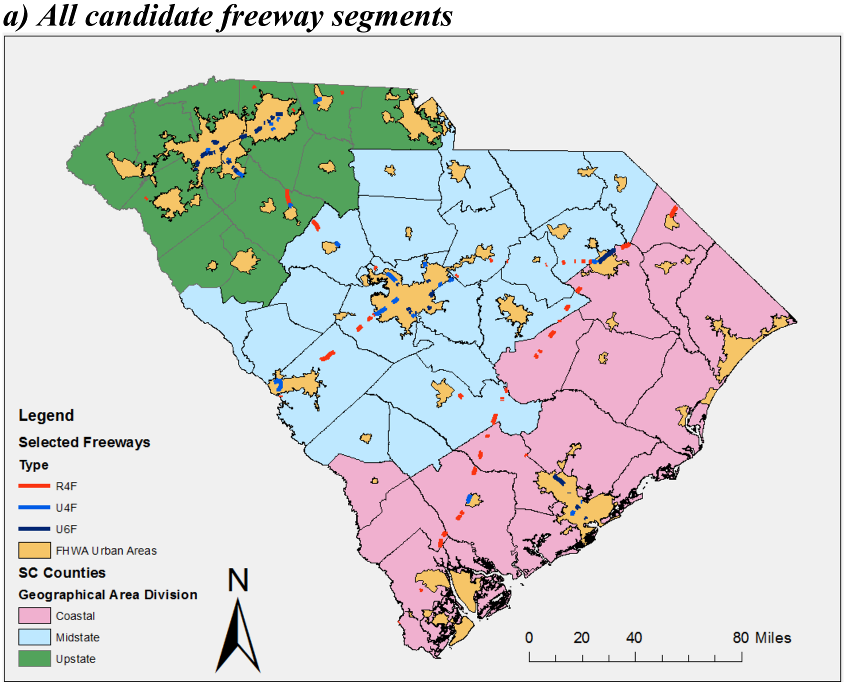
To avoid the issue of not having the ramp volumes, selected segments are chosen to be about 0.5 mile away from ramp exits and entrances where possible. Table 4.5 shows a summary of the selected freeway segments. A graphical representation is found in Figure 4.5.

Table 4.5 Summary statistics of selected freeway segments (2015 data)

Road Type	Sample Size	Mileage	Average AADT	Tot Observed Crash	KABC Crashes (% of Tot)
R4F	46	19	34,456	333	28%
U4F	35	12	48,388	457	19%
U6F	43	13	74,481	807	19%



a) All candidate freeway segments



b) Selected freeway segments

Figure 4.5 All candidate and selected freeway segments

Table 4.6 shows the data elements required for the calibration process and it summarizes how each data element is collected.

Table 4.6 Freeway data elements description

Data Element	Associated Roadway Types	Data Collection Source
Category 1 Data Elements – Required for Roadway Type Identification and Crash Assignment		
Rural/Urban	All Roadways	FHWA Urban Boundaries
Number of Lanes	All Roadways	RIMS Data
Median Type	All Roadways	RIMS Data
Total Surface Width	All Roadways	RIMS Data
Median Width	All Roadways	RIMS Data
Category 2 Data Elements – Required for SPF Estimate		
AADT	Selected Roadways	RIMS Data
Length	Selected Roadways	RIMS Data
Category 3 Data Elements – Required for CMF Adjustments to SPF		
Length and radii of horizontal curves	Selected Roadways	Estimated from polylines
Lane width	Selected Roadways	RIMS data
Inside and outside shoulder width (paved)	Selected Roadways	RIMS data
Median width	Selected Roadways	RIMS data
Length of rumble strips on inside and outside shoulders	Selected Roadways	Assumed present
Length of (and offset to) median barrier	Selected Roadways	Google Earth
Length of (and offset to) outside barrier	Selected Roadways	Google Earth
Clear zone width	Selected Roadways	Google Earth
AADT volume of (and distance to) nearest upstream entrance ramp	Selected Roadways	Assumed not present
AADT volume of (and distance to) nearest downstream exit ramp	Selected Roadways	Assumed not present
Presence of speed-change lane	Selected Roadways	Assumed not present
Presence and length of Type B weaving sections	Selected Roadways	Google Earth
Proportion of AADT that occurs during hours where lane volume exceeds 1,000 veh/h/ln	Selected Roadways	SCDOT Website
Average annual daily traffic (AADT) volume	Selected Roadways	RIMS data

After collecting all the data elements, the calibration factors were calculated and shown in Table 4.7.

Table 4.7 Statewide calibration factors summary for 2013-2015

Type	Sample Size	Total Length	Average AADT	Total Observed Crashes	Calibration Factor	Calibration Factor C.V.
R4F	138	59.38	35,055	785	2.59	5.77%
U4F	105	36.34	49,218	902	2.69	6.82%
U6F	126	38.33	73,592	1,972	3.66	5.22%

4.4 CRASH DISTRIBUTION

To obtain the crash distribution, it is desired to use all crashes instead of just crashes occurring in the selected sites to increase the sample size and obtain more accurate results. The crash distributions are provided for each intersection and roadway types in the HSM, and therefore only corresponding crashes for those types are used. To identify corresponding crashes, first, all associated roadways and intersections should be identified. The shapefiles, mentioned in section 3, as the pool of candidate sites, are used for this purpose. In this chapter, to avoid repeating, the term "identified sites" refers to corresponding intersections or roadways analyzed in HSM chapter 10 to 12 (also mentioned in Table 1-1 and Table 1-2). The 250' buffer crash assignment process requested by SCDOT and introduced in section 3.3 is used to assign crashes to identified sites. During this process, some crashes failed to be assigned to any identified site. The first reason that crashes might not be assigned to any site is inaccurate latitude or longitude coordinates. As mentioned earlier, while geocoding crashes some fell outside of the state and filtered out form the crash database. The amount of data loss due to false coordinates was shown previously in Table 3.13, and again is provided in following table 4.8. Over the observation period of 2011-2014, more accurate methods were used by police officers to record the GPS coordinates, and thus less data loss is reduced from 2011(21%), to 2014(11%).

Table 4.8 Out of state crash data due to false coordinates

Crash Year	All Crashes	In State Crashes	Data loss (%)
2011	117,923	93,148	21.00%
2012	121,094	99,792	17.60%
2013	123,933	103,931	16.14%
2014	128,764	114,012	11.46%

Furthermore, while assigning the geocoded crashes to identified sites, not all of them were found related. Those crashes are basically falling outside of the any identified site's buffer. Some of those were parking lot or interstate crashes; while some could not be assigned because the corresponding roadway or intersection is not among the identified sites. These crashes were also filtered out of the crash database. Table 4.9 and Figure 4.6 shows the data loss due to crash assignment.

Table 4.9 Crash assignment summary

Crash Year	All Crashes	In State Crashes	Assigned Crashes	Data loss (%)
2011	117,923	93,148	60,437	48.7%
2012	121,094	99,792	65,649	45.8%
2013	123,933	103,931	87,345	29.5%
2014	128,764	114,012	95,843	25.6%

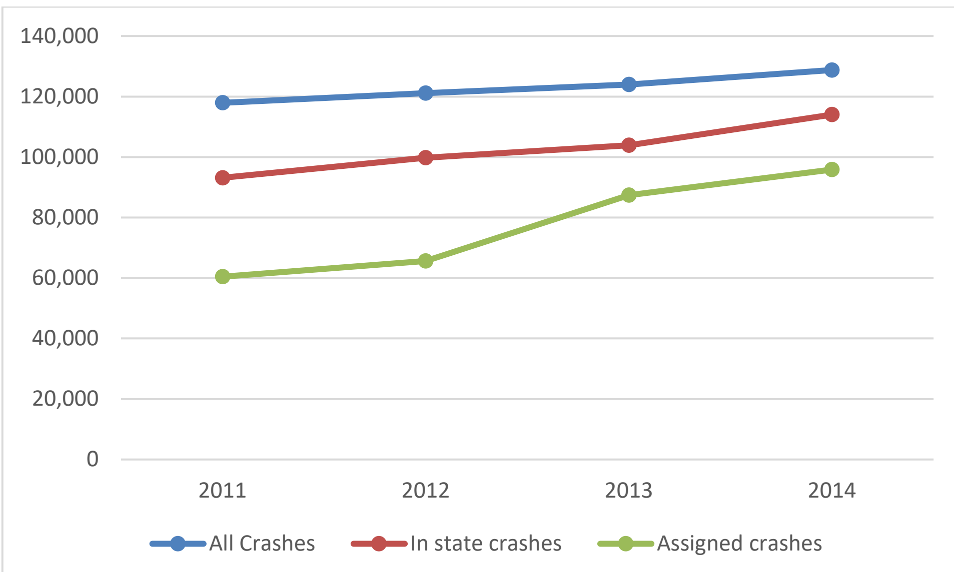


Figure 4.6 Crash data loss by years

The clear jump in the number of assigned crashes in 2013 and 2014 data, compared to 2011 and 2012, shows the more accurate data collection process by South Carolina Highway Patrol and other police agencies in the state. Based on this difference, the authors decided to also provide the 2-year calibration factors for 2013 to 2014, and later added 2015 to provide a 3-year calibration factor.

To find the state specific crash distributions, crash characteristics are exported from crash data. Crash data in South Carolina for each year is reported in 3 different text files: location file, unit file and occupant file, all relating with accident numbers. Each accident has only one record in location file but might have multiple records in unit or occupant file depending on number of units involved and number of occupants. The number of vehicles involved in the crash is determined by examining the number of vehicles in unit file. For single vehicle crash classifications, first harmful event, "FHE", in location file along with most harmful event, "MHE", and sequence of events, “SOE”, in unit file is used. For multiple vehicle classifications, manner of collision, “MAC”, in location file and manner of collision in unit file, “MAN”, is used. Night time crashes are defined as crashes occurring between 6 pm and 6 am based on the crash time in location file “TIM”. Also, crash severity level is defined based on “SEV” in occupant file. More details can be found in “crash code” and “crash type” scripts in the electric appendix of this document. All crash distribution results are based on 2013 and 2014 crash data and are presented in the appendix. The template for these tables is taken from Oregon state’s report (Xie et al., 2011).

5. CONCLUSIONS AND DISCUSSION

The goal of most any safety-related research is to reduce the number and severity of crashes on our roadways. This research aids SCDOT in accomplishing this goal by providing knowledge and data to undertake better decision making on safety improvements through the Highway Safety Manual. The objectives for this research were twofold: 1) provide calibration factors for each SPF in the predictive model chapters to account for jurisdictional variations in crash reporting, driver populations, topography, and climate; 2) provide state-specific safety performance functions; and 3) provide crash distributions specific to South Carolina to increase the reliability of the predictive models.

This research compiled all the required databases for development of calibration factors for use across the state of South Carolina. Calibration factors were developed for three distinct areas within the state – coastal areas, midlands, and the upstate. Each of these areas has different terrain, weather patterns, and traffic patterns and these variations were expected to produce varying calibration factors. In some cases, the variations were significant across the three area boundaries, but the trends were not consistent from area to area across road types, which generated significant questions about the validity of the boundary designations. Further, sample sizes within the geographic divisions were often difficult to obtain and therefore many of the geographic area calibration factors were not found to be statistically significant. The population density divisions also had issues related to sample size – particularly with the sparse density areas.

Based on these factors, the research team is recommending that SCDOT currently use the statewide calibration factors as compiled in Table 5.1. All but two of the calibration factors are significant within coefficient of variation of 15% which is suggested by the Highway Safety Manual. In fact, most are within 10% coefficient of variation. Regardless of the variability, the calibration factors for U3T and RM4ST are the best available and indicate significant differences between the observed crashes in South Carolina and the predicted crashes using uncalibrated HSM models.

Of all the various steps in the Empirical Bayes analysis that are described in the HSM, the calibration process is one of the most important steps. The calibration factor, when not equal to 1.00, either overestimates or underestimates the safety predictions at a location. For example, if a calibration factor was found to be 0.74, and if this calibration procedure wasn't performed, the safety at a selected site might be overestimated by ~26%. These predictions, if not accurately calculated, would have a vital impact on safety improvements especially when considering the benefit cost analysis.

Table 5.1 Final Recommended Calibration Factors (2013-2015)

Type	Sample Size	Total Length	Average AADT Major	Average AADT Minor	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	Calibration Factor C.V.
Roadway Segments								
R2U	1,841	1,117.73	753	--	447	451	0.99	5.10%
R4D	508	161.16	9,934	--	253	413	0.61	8.17%
R4U	484	126.25	3,921	--	58	189	0.31	14.24%
U2U	667	201.65	2,109	--	261	157	1.66	7.95%
U3T	73	15.73	9,697	--	82	56	1.47	15.01%
U4U	349	76.57	8,602	--	275	367	0.75	8.70%
U4D	352	85.02	19,172	--	321	387	0.83	6.87%
U5T	673	155.59	16,059	--	1,035	1,348	0.77	5.15%
Intersections								
R3ST	7,000	--	892	205	907	2,253	0.40	3.98%
R4ST	2,785	--	995	233	787	1,660	0.47	4.97%
R4SG	97	--	6,104	1,497	131	287	0.46	11.76%
RM3ST	613	--	8,061	357	261	471	0.55	10.91%
RM4ST	284	--	6,438	271	63	244	0.26	17.52%
RM4SG	80	--	11,619	1,375	272	682	0.40	9.42%
U3ST	5,607	--	1,765	287	2,136	1,782	1.20	3.92%
U4ST	2,992	--	1,702	324	1,650	1,719	0.96	5.00%
U3SG	299	--	16,181	3,170	1,255	629	2.00	5.05%
U4SG	538	--	12,870	2,725	3,334	1,362	2.45	4.52%
Interstates								
R4F	138	59.38	35,055	--	785		2.59	5.77%
U4F	105	36.34	49,218	--	902		2.69	6.82%
U6F	126	38.33	73,592	--	1,972		3.66	5.22%

Regarding state-specific safety performance functions, the research team developed functions for all applicable roadway types in the first version of the highway safety manual. The model forms can be found in section 4.2 of the report. Most models perform relatively well and, in many cases, quite a bit better than the calibrated models over the full range of AADT (as shown in the resulting CURE plots). The models themselves are limited in predictive capability at the site level because they have few significant variables – AADT being among significance in all models. Further, the models predict only total crashes and not by severity level. Nonetheless, these models and their limited variable formats allow them to provide a valued function as network screening models. The research team recommends incorporating these models into your regular screening processes because all variables (except driveway density and lighting) are available in existing roadway databases resident at SCDOT. Moving from a historic screening approach to a predictive one, based on Empirical Bayes, would move SCDOT light-years ahead of most states.

One thing to note about the state-specific safety performance functions is that while they have limited significant variables within the model form, it does not mean that the additional variables in the HSM are not important in South Carolina. It simply means that no significance was found in the selected sample. This can happen for multiple reasons: 1) the standard design parameters have been followed closely over the years which generates little variance in an element (such as most primary roads in South Carolina are designed with a standard 12-foot lane, so there are few variances), or 2) the sampling did not capture significant numbers to allow for significance. Either way, South Carolina should continue to collect all safety data parameters that are pertinent to business decisions and support the most rigorous safety analysis

The research team also provided specific statewide crash distributions for use with the calibrated HSM models and state-specific models. For the most part, these distributions are very useful for common safety analysis tasks; however, there are some limitations imposed by the available databases and data domains. As an example, SCDOT does not have a statewide intersection database, so traffic control at each intersection (stop vs. signalized control) is unknown. We can use information from the collision reports to infer the traffic control most often reported at the location, but that does constitute a best practice. Further, the research team could not discern if bituminous medians were two-way left-turn lanes, dedicated turning lanes, or simply painted medians. Therefore, the population of U3T and U5T mileage is only estimated. There were also limitations with assigning the crashes to the appropriate segments and intersections. These have been well documented in prior studies but include crashes that fall outside of the state boundary and or are not within the roadway centerline buffers set to account for number of lanes, lane width, and median width. Ultimately, roughly 25% of the crash data is lost in the assignment process – however this is not uncommon from state to state.

Finally, use of the interstate model chapters were limited to basic freeway segments with no interchange influence areas or ramps. A ramp database should be developed for inclusion in RIMS to house traffic data for all ramps as well as to enable crash assignment to ramps. As it currently stands, all ramp crashes are coded to the mainline and may contribute somewhat to the high calibration factors for interstate sections. However, the research team intentionally avoided interchange influence areas to limit this phenomenon. To enable full use of the freeway prediction chapters, the interstate and ramp data needs to be more fully developed.

The products resulting from this research will allow the SCDOT safety office to confidently use the HSM with expectations that the resulting predictions are going to be a fair estimate of the effects of safety improvements in different areas of South Carolina. While better data will always produce better results, the calibration factors, safety performance functions and crash distributions provided herein are derived from the best possible data from South Carolina and currently represent the best opportunity for improving safety decisions.

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7. APPENDIX

7.1 SIMILAR CALIBRATION STUDIES

Table 7.1 Calibration factors summary

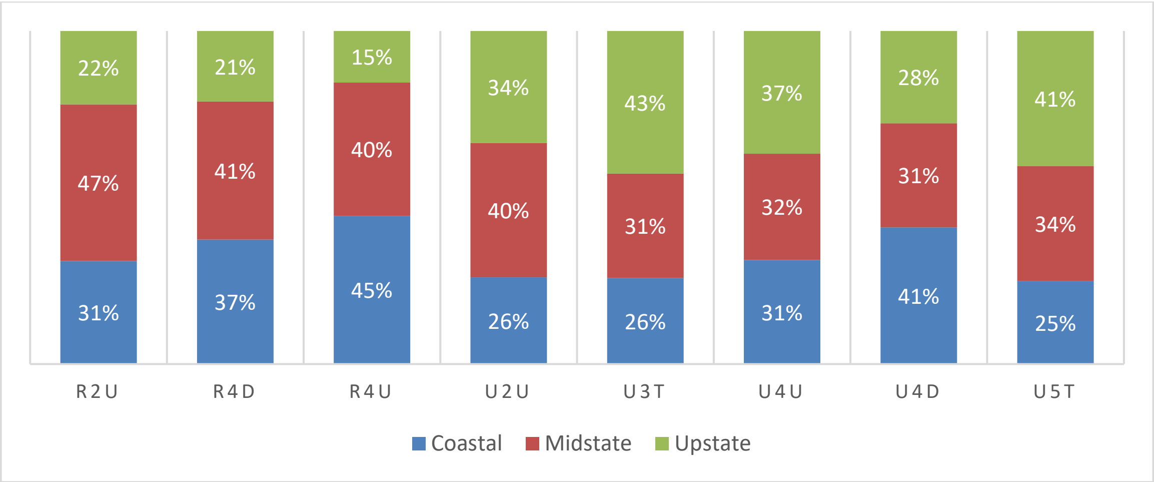
Facility Types	South Carolina	North Carolina	Florida	Illinois	Louisiana	Maryland	Oregon	Utah	Missouri
	2013-2014	2007-2009	2005-2009	2005-2011	2003-2007	2008-2010	2004-2006	2005-2007	2009-2011
R2U	1.179	1.08		1.40		0.70	0.74	1.16	0.82
R4U	1.041		1.03		0.98	2.26	0.36		
R4D	0.336	0.97	0.70		1.25	0.58	0.77		0.98
U2U	1.861	1.54	1.03	1.32		0.68	0.63		0.84
U3T	2.097	3.62	1.04	1.12		1.08	0.83		
U4U	1.226	4.04	0.71	0.86		0.88	0.65		
U4D	1.607	3.87	1.65	0.56		0.83	1.42		0.98
U5T	1.049	1.72	0.71	0.69		1.19	0.64		0.73
R3ST	0.458	0.57	0.75			0.16	0.32		0.77
R4ST	0.593	0.68	0.62			0.20	0.31		0.49
R4SG	0.536	1.04	1.16			0.26	0.47		
RM3ST	0.656	1.57				0.18			0.28
RM4ST	0.744	1.39				0.37	0.16		0.39
RM4SG	0.434	0.49	0.37			0.12	0.15		
U3ST	1.215	1.72				0.16	0.35		1.06
U3SG	1.102	2.47	1.85			0.40	0.75		3.03
U4ST	2.208	1.32				0.38	0.44		1.30
U4SG	2.846	2.79	1.88	2.72		0.46	1.10		4.91

7.2 RIMS DATA DICTIONARY

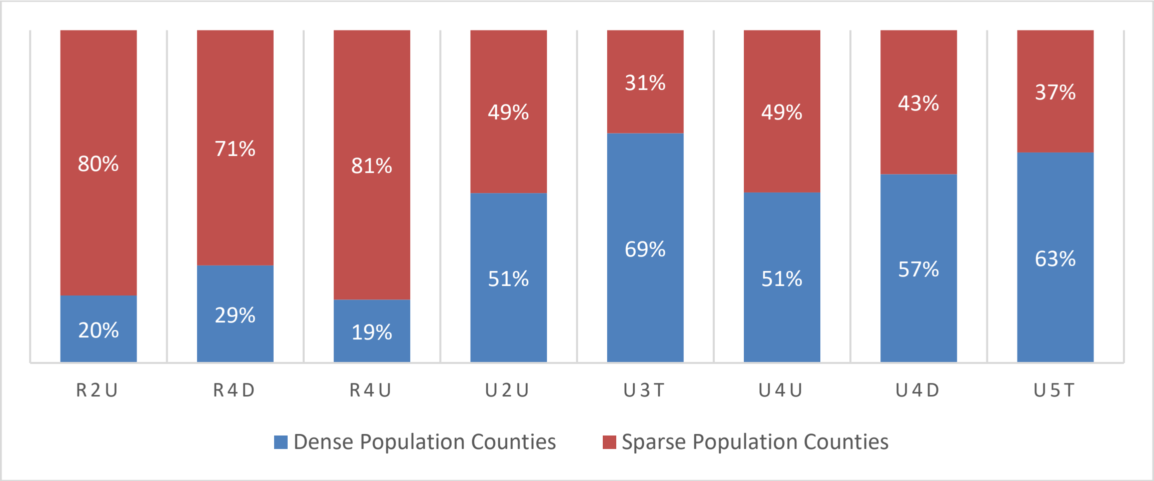
Table 7.2 Roadway Information Management System (RIMS) data dictionary

Column Heading	Description	Codes	
Route_Type	Route Type	1	Interstate
		2	US Route
		4	SC Route
		5	Ramp
		6	Ramp Spur
		7	Secondary road
		9	Local road
		10	State Park
		11	State Institution
		12	National Park
		13	Forest Service road
Median_ID	Median Type	0	Non-divided
		1	Divided - Earth median
		2	Divided - Concrete median
		3	Multi-lane - bituminous Median
		4	Divided - Raised Concrete &
		5	Divided - Physical Barrier
		6	Divided - Cable Stay Guardrail
		8	One-way street
Median_Wid	Median	Varies	
TotalLanes	Total	Varies	
SurWid_Tot	Total	Varies	

7.3 SITE SELECTION SUMMARY TABLES

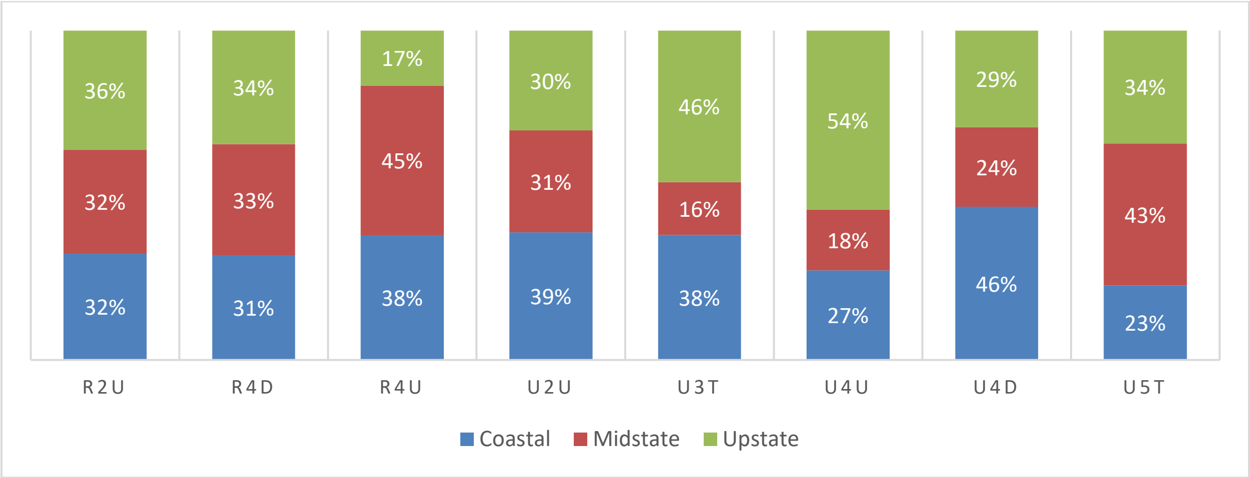


a) Geographical divisions

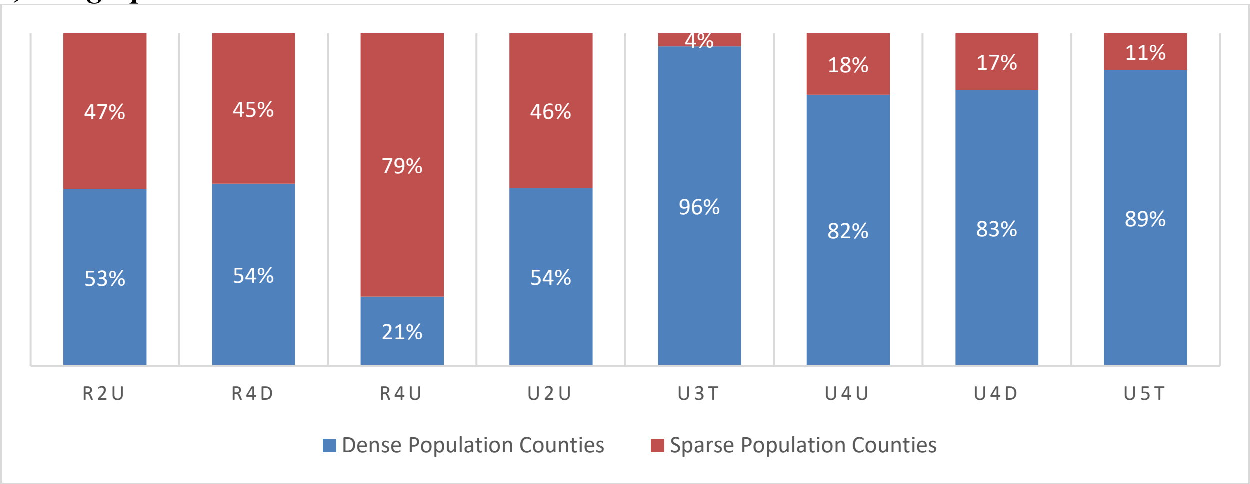


b) Population density divisions

Figure 7.1 All roadway segments by area divisions



a) Geographical divisions



b) Population density divisions

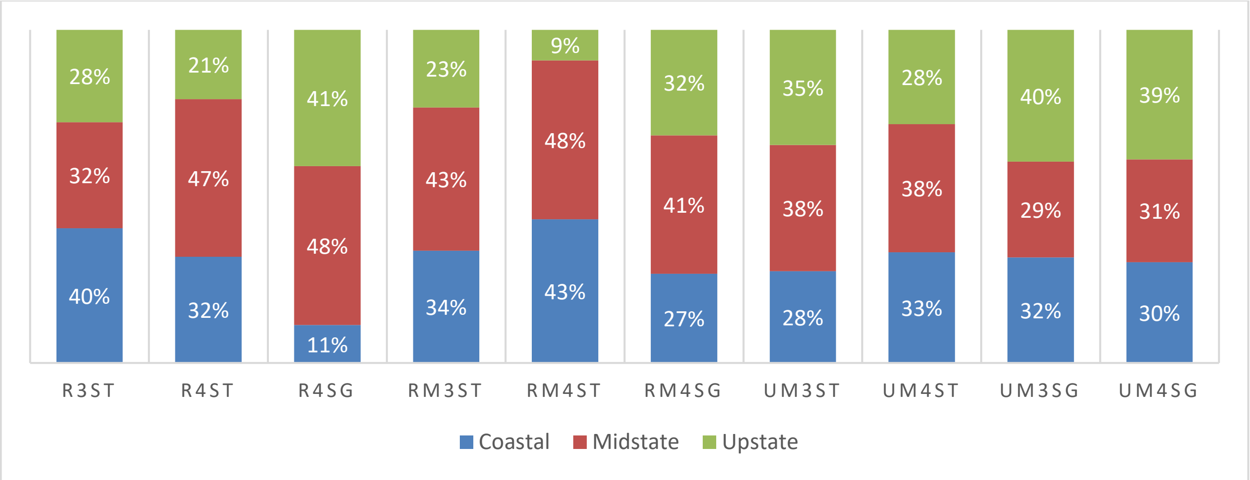
Figure 7.2 Selected roadway segments by area divisions

Table 7.3 All roadway segments by area divisions

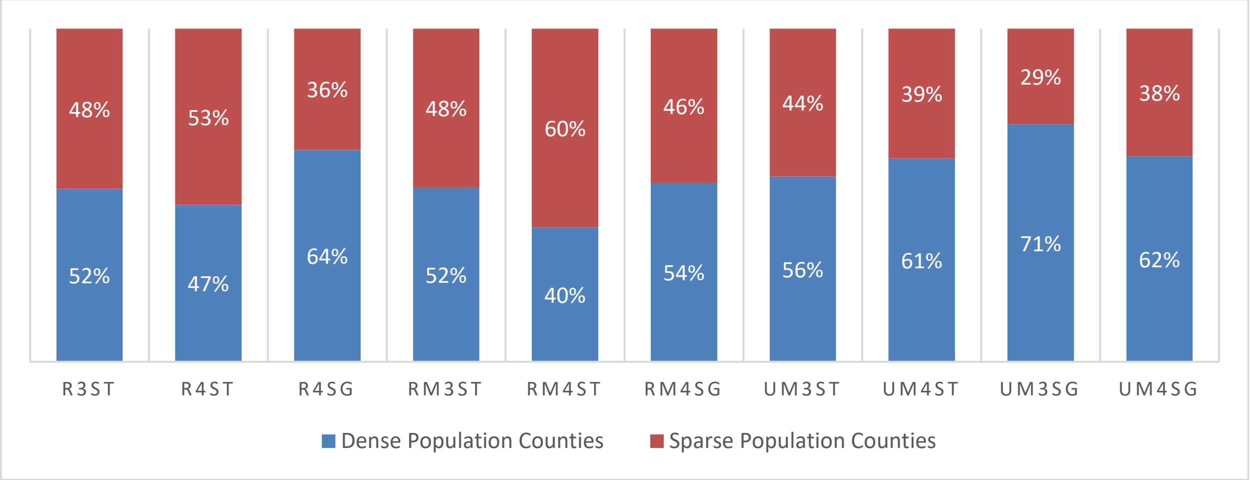
Road Type	Entire State			Geographical Division						Population Density Division			
				Coastal		Midstate		Upstate		Dense Population Counties		Sparse Population Counties	
	Sample Size	Mileage	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT
R2U	30120	26,282	897	31%	926	47%	780	22%	1,123	20%	1,275	80%	806
R4D	1296	1,169	16,593	37%	15,299	41%	16,711	21%	18,621	29%	19,089	71%	15,629
R4U	376	73	4,354	45%	5,407	40%	3,383	15%	4,674	19%	5,901	81%	4,095
U2U	35719	11,088	1,650	26%	1,565	40%	1,317	34%	2,227	51%	2,163	49%	1,164
U3T	2100	287	7,991	26%	9,838	31%	7,597	43%	7,223	69%	8,706	31%	6,269
U4U	1017	236	9,356	31%	10,837	32%	8,807	37%	8,766	51%	10,978	49%	7,344
U4D	1597	754	24,746	41%	32,771	31%	18,615	28%	22,621	57%	30,152	43%	16,360
U5T	2621	938	17,245	25%	21,096	34%	16,362	41%	15,465	63%	19,135	37%	13,574

Table 7.4 Selected roadway segments by area divisions

Road Type	Entire State			Geographical Division						Population Density Division			
				Coastal		Midstate		Upstate		Dense Population Counties		Sparse Population Counties	
	Sample Size	Mileage	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT	Mileage (% of Total)	Average AADT
R2U	621	376	1,394	32%	2,303	32%	1,821	36%	1,724	53%	2,283	47%	1,538
R4D	172	54	11,434	31%	16,043	33%	11,867	34%	7,564	54%	13,579	45%	9,595
R4U	72	19	5,665	38%	5,832	45%	5,040	17%	7,390	21%	5,900	79%	5,639
U2U	234	70	4,129	39%	1,940	31%	2,148	30%	3,549	54%	3,025	46%	1,990
U3T	15	3	14,667	38%	13,344	16%	13,216	46%	12,222	96%	13,080	4%	8,278
U4U	119	26	10,449	27%	10,131	18%	12,406	54%	10,629	82%	11,442	18%	8,838
U4D	120	29	21,933	46%	27,090	24%	17,536	29%	17,432	83%	22,791	17%	14,756
U5T	229	53	17,805	23%	24,036	43%	18,051	34%	15,959	89%	19,718	11%	12,097

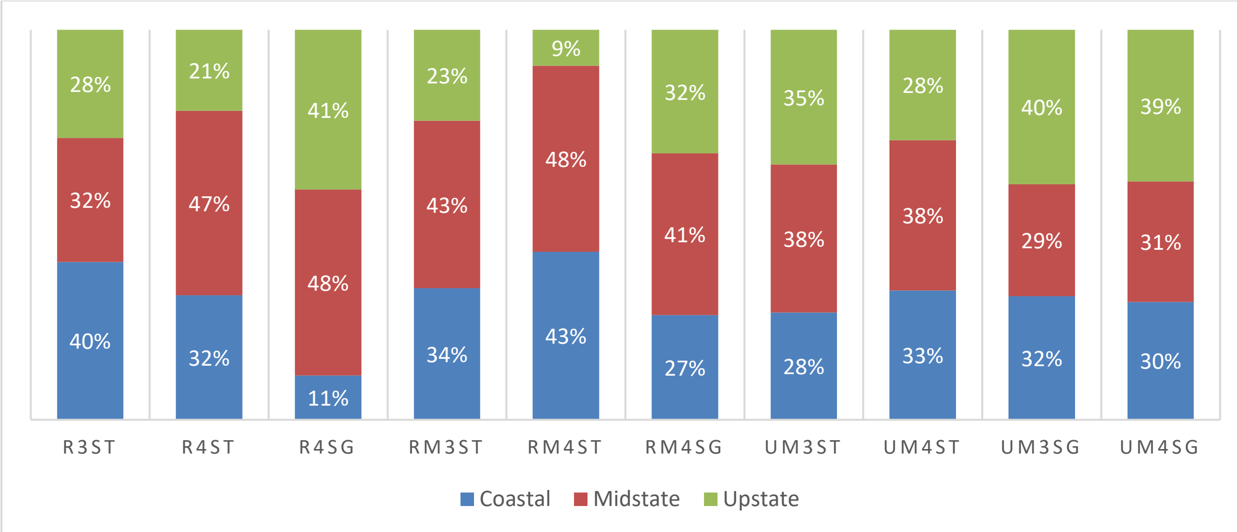


a) Geographical divisions

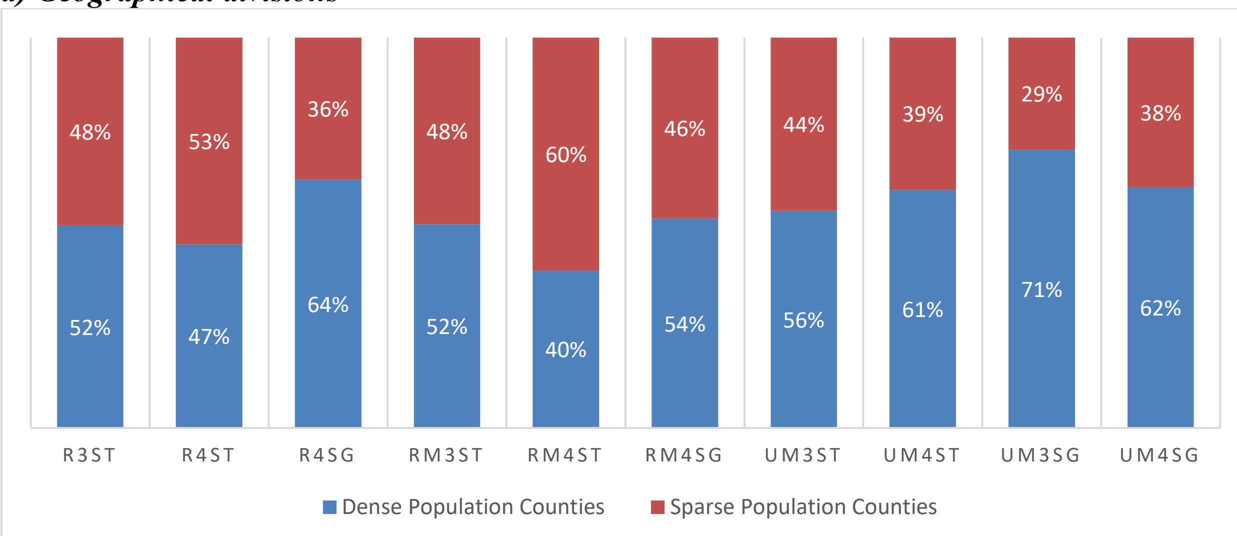


b) Population density divisions

Figure 7.3 All intersections by area division



a) Geographical divisions



b) Population density divisions

Figure 7.4 Selected intersections by area divisions

Table 7.5 Selected sites by counties

Name	County ID	Geo Division	Pop Division	Selected Intersections	Selected Segments	Pop Density	Urban Percentage
Abbeville	1	Upstate	Sparse	0.0%	0.0%	527	2.0%
Aiken	2	Midstate	Sparse	0.0%	0.1%	1635	10.9%
Allendale	3	Coastal	Sparse	0.0%	0.2%	257	0.9%
Anderson	4	Upstate	Dense	6.5%	6.8%	2709	19.6%
Bamberg	5	Midstate	Sparse	0.0%	0.0%	420	0.0%
Barnwell	6	Midstate	Sparse	0.0%	0.0%	427	1.7%
Beaufort	7	Coastal	Dense	4.9%	5.6%	2003	28.2%
Berkeley	8	Coastal	Sparse	0.0%	0.0%	1699	7.2%
Calhoun	9	Midstate	Sparse	0.0%	0.1%	413	0.0%
Charleston	10	Coastal	Dense	0.0%	0.1%	2955	20.3%
Cherokee	11	Upstate	Sparse	0.0%	0.2%	1515	8.9%
Chester	12	Midstate	Sparse	0.0%	0.0%	598	1.5%
Chesterfield	13	Midstate	Sparse	0.0%	0.0%	617	1.6%
Clarendon	14	Coastal	Sparse	0.0%	0.0%	532	0.0%
Colleton	15	Coastal	Sparse	0.0%	0.5%	359	1.8%
Darlington	16	Midstate	Sparse	0.0%	0.0%	1290	7.8%
Dillon	17	Coastal	Sparse	8.3%	5.8%	827	4.8%
Dorchester	18	Coastal	Dense	7.4%	5.7%	2718	9.5%
Edgefield	19	Midstate	Sparse	0.0%	1.2%	562	0.9%
Fairfield	20	Midstate	Sparse	0.0%	0.0%	350	1.0%
Florence	21	Coastal	Sparse	0.0%	0.0%	1853	10.9%
Georgetown	22	Coastal	Sparse	0.0%	0.0%	629	5.2%
Greenville	23	Upstate	Dense	6.3%	6.8%	6422	39.0%
Greenwood	24	Upstate	Sparse	5.9%	4.6%	1621	12.5%
Hampton	25	Coastal	Sparse	0.0%	0.0%	390	0.0%
Horry	26	Coastal	Dense	8.3%	9.0%	2484	15.2%
Jasper	27	Coastal	Sparse	5.7%	5.6%	410	10.1%
Kershaw	28	Midstate	Sparse	0.0%	0.0%	909	5.8%

Lancaster	29	Midstate	Sparse	7.7%	5.7%	1560	9.0%
Laurens	30	Upstate	Sparse	0.0%	0.2%	985	6.1%
Lee	31	Midstate	Sparse	0.0%	0.0%	480	1.0%
Lexington	32	Midstate	Dense	8.3%	6.3%	3889	29.4%
Marion	33	Coastal	Sparse	0.0%	0.0%	217	4.6%
Marlboro	34	Midstate	Sparse	0.0%	0.1%	711	3.9%
McCormick	35	Midstate	Sparse	3.9%	3.7%	765	0.0%
Newberry	36	Midstate	Sparse	0.0%	0.0%	624	3.3%
Oconee	37	Upstate	Sparse	0.0%	0.0%	1199	9.4%
Orangeburg	38	Midstate	Sparse	10.0%	8.0%	868	3.7%
Pickens	39	Upstate	Dense	4.8%	5.6%	2519	15.4%
Richland	40	Midstate	Dense	7.2%	6.6%	5569	27.3%
Saluda	41	Midstate	Sparse	0.0%	0.0%	468	0.3%
Spartanburg	42	Upstate	Dense	0.0%	4.3%	3823	33.8%
Sumter	43	Midstate	Sparse	0.0%	0.0%	1706	11.2%
Union	44	Upstate	Sparse	4.9%	6.1%	585	3.3%
Williamsburg	45	Coastal	Sparse	0.0%	0.0%	380	1.0%
York	46	Upstate	Dense	0.0%	0.9%	3703	27.3%

Table 7.6 All intersections by geographical area division

Road Type	Entire State			Geographical Division								
				Coastal			Midstate			Upstate		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	18,947	1,612	299	30%	1,629	290	50%	1,514	275	20%	1,834	374
R4ST	3,875	1,711	373	31%	1,660	354	52%	1,593	340	17%	2,170	514
R4SG	99	6,144	1,932	19%	6,879	2,153	47%	5,570	1,866	33%	6,538	1,900
RM3ST	1,041	8,589	733	36%	9,116	629	44%	8,024	685	20%	8,903	1,027
RM4ST	453	9,926	699	38%	9,765	842	51%	9,465	573	11%	12,504	786
RM4SG	89	10,791	2,030	40%	11,114	2,011	35%	9,732	2,007	25%	11,753	2,091
UM3ST	23,510	4,105	542	30%	4,332	487	46%	3,806	475	24%	4,403	743
UM4ST	5,423	3,547	596	35%	3,417	537	45%	3,370	531	20%	4,178	846
UM3SG	1,172	18,485	4,875	26%	23,813	5,932	34%	18,167	4,364	40%	15,199	4,607
UM4SG	1,271	15,630	4,350	26%	19,284	4,753	36%	15,057	4,133	38%	13,617	4,274

Table 7.7 All intersections by population density area division

Road Type	Entire State			Population Density Division					
				Dense Population Counties			Sparse Population Counties		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	18,947	1,612	299	18%	2,174	420	82%	1,493	274
R4ST	3,875	1,711	373	16%	2,481	507	84%	1,561	347
R4SG	99	6,144	1,932	27%	7,259	1,883	73%	5,726	1,951
RM3ST	1,041	8,589	733	22%	11,223	976	78%	7,854	665
RM4ST	453	9,926	699	19%	11,879	893	81%	9,469	653
RM4SG	89	10,791	2,030	29%	13,657	2,124	71%	9,608	1,990
UM3ST	23,510	4,105	542	44%	4,952	651	56%	3,437	455
UM4ST	5,423	3,547	596	44%	3,923	630	56%	3,247	569
UM3SG	1,172	18,485	4,875	69%	20,400	5,529	31%	14,285	3,440
UM4SG	1,271	15,630	4,350	57%	17,794	4,978	43%	12,775	3,521

Table 7.8 Selected intersections by geographical area division

Road Type	Entire State			Geographical Division								
				Coastal			Midstate			Upstate		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	2,336	1,755	330	40%	1,837	324	32%	1,980	340	28%	2,156	478
R4ST	933	1,893	346	32%	1,823	314	47%	2,062	337	21%	2,343	522
R4SG	33	6,496	2,177	11%	10,260	2,343	48%	7,710	3,216	41%	5,556	2,396
RM3ST	216	9,706	731	34%	10,415	642	43%	10,951	608	23%	8,149	1,155
RM4ST	99	7,735	417	43%	8,556	500	48%	6,998	329	9%	8,880	550
RM4SG	27	12,914	2,050	27%	14,309	2,248	41%	18,071	2,591	32%	11,983	2,021
UM3ST	1,885	4,719	577	28%	6,704	524	38%	3,770	438	35%	4,336	706
UM4ST	1,007	4,279	619	33%	5,108	784	38%	3,819	451	28%	3,948	635
UM3SG	106	18,868	5,712	32%	23,638	8,001	29%	18,334	3,859	40%	15,298	5,361
UM4SG	182	15,904	4,230	30%	20,649	4,772	31%	15,418	4,291	39%	13,355	4,038

Table 7.9 Selected intersections by population density area division

Road Type	Entire State			Population Density Division					
				Dense Population Counties			Sparse Population Counties		
	Sample Size	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor	Sample Size (% of Total)	Average AADT Major	Average AADT Minor
R3ST	2,336	1,755	330	52%	2,309	468	48%	1,606	267
R4ST	933	1,893	346	47%	2,608	475	53%	1,547	274
R4SG	33	6,496	2,177	64%	7,865	3,158	36%	5,813	2,123
RM3ST	216	9,706	731	52%	11,066	870	48%	9,078	612
RM4ST	99	7,735	417	40%	9,238	452	60%	6,898	403
RM4SG	27	12,914	2,050	54%	16,176	2,671	46%	13,921	1,910
UM3ST	1,885	4,719	577	56%	6,044	635	44%	3,182	453
UM4ST	1,007	4,279	619	61%	4,983	694	39%	3,189	489
UM3SG	106	18,868	5,712	71%	20,972	6,329	29%	13,448	4,369
UM4SG	182	15,904	4,230	62%	19,891	4,969	38%	10,242	3,321

7.4 ROADWAYS CALIBRATION RESULTS

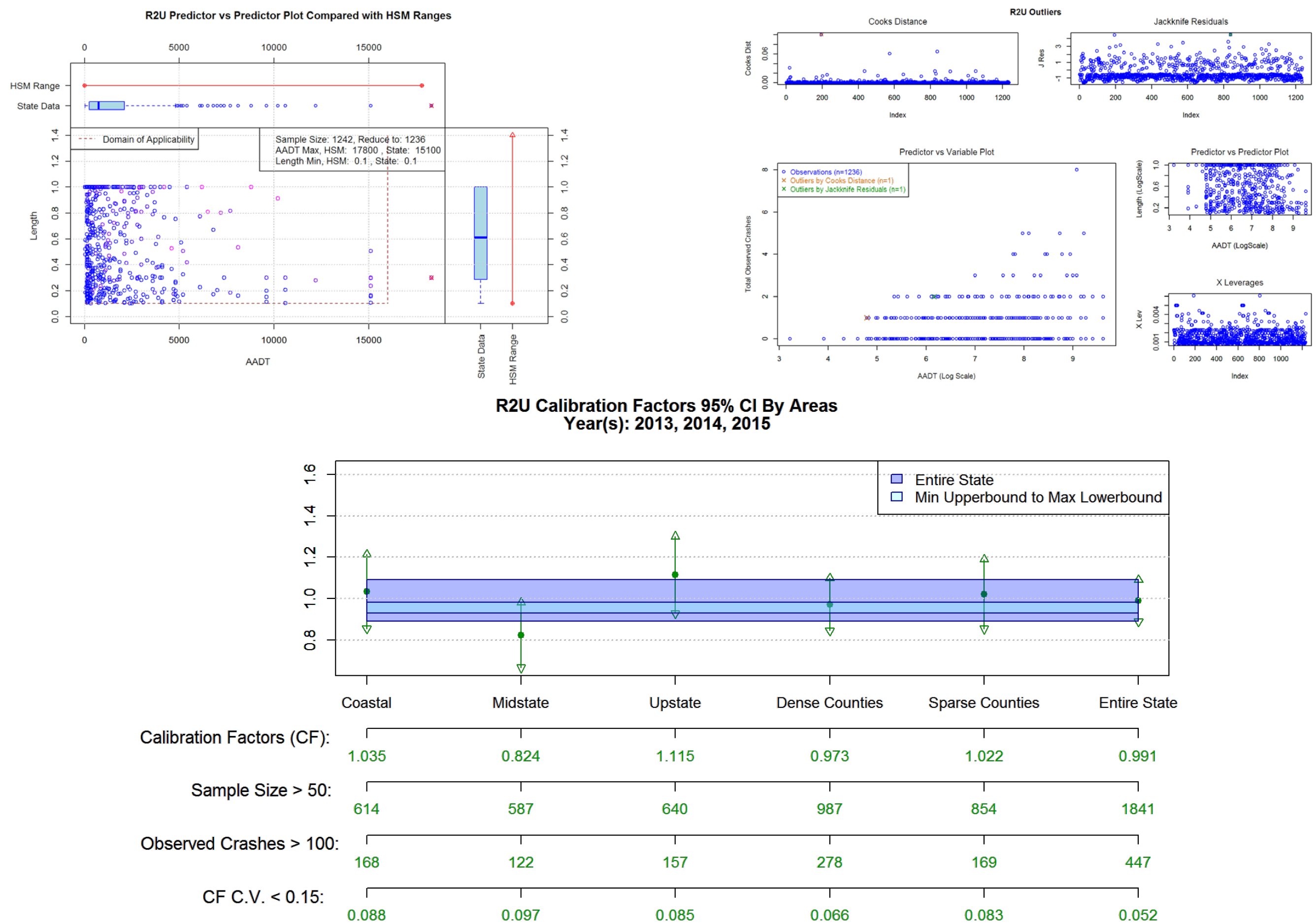
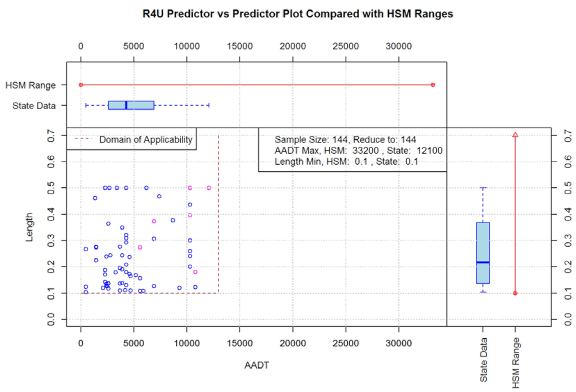
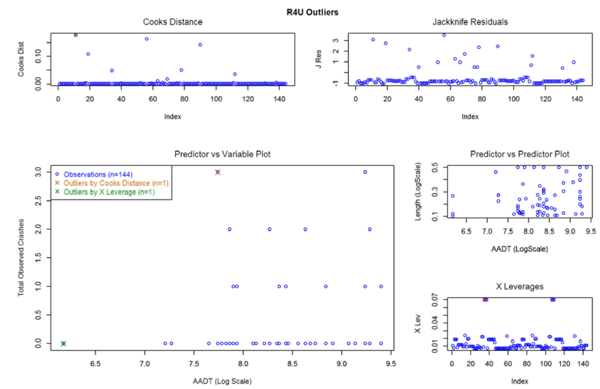


Figure 7.5 R2U Calibration factor summary 2013:2015





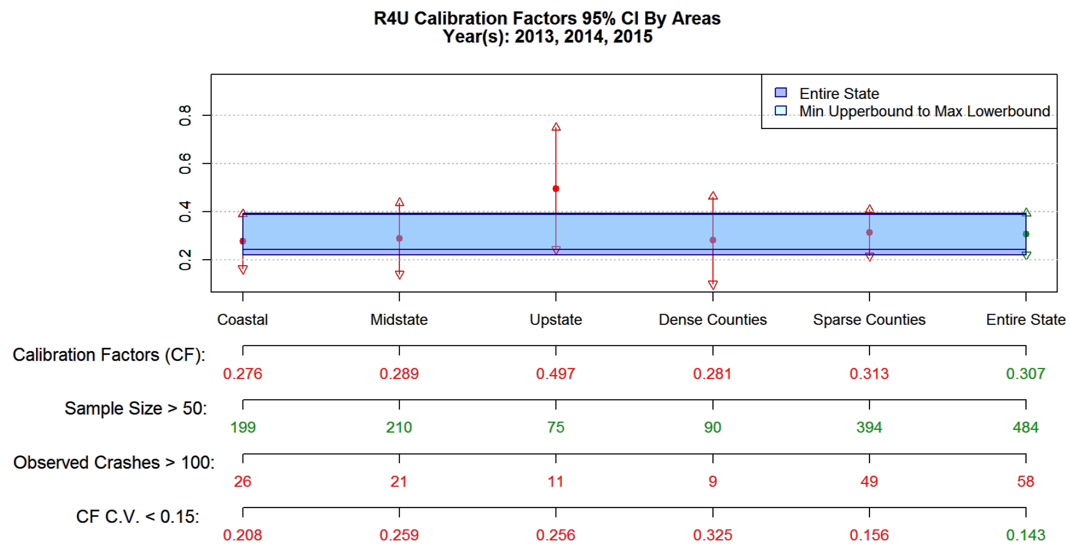


Figure 7.6 R4U Calibration factor summary 2013:2015

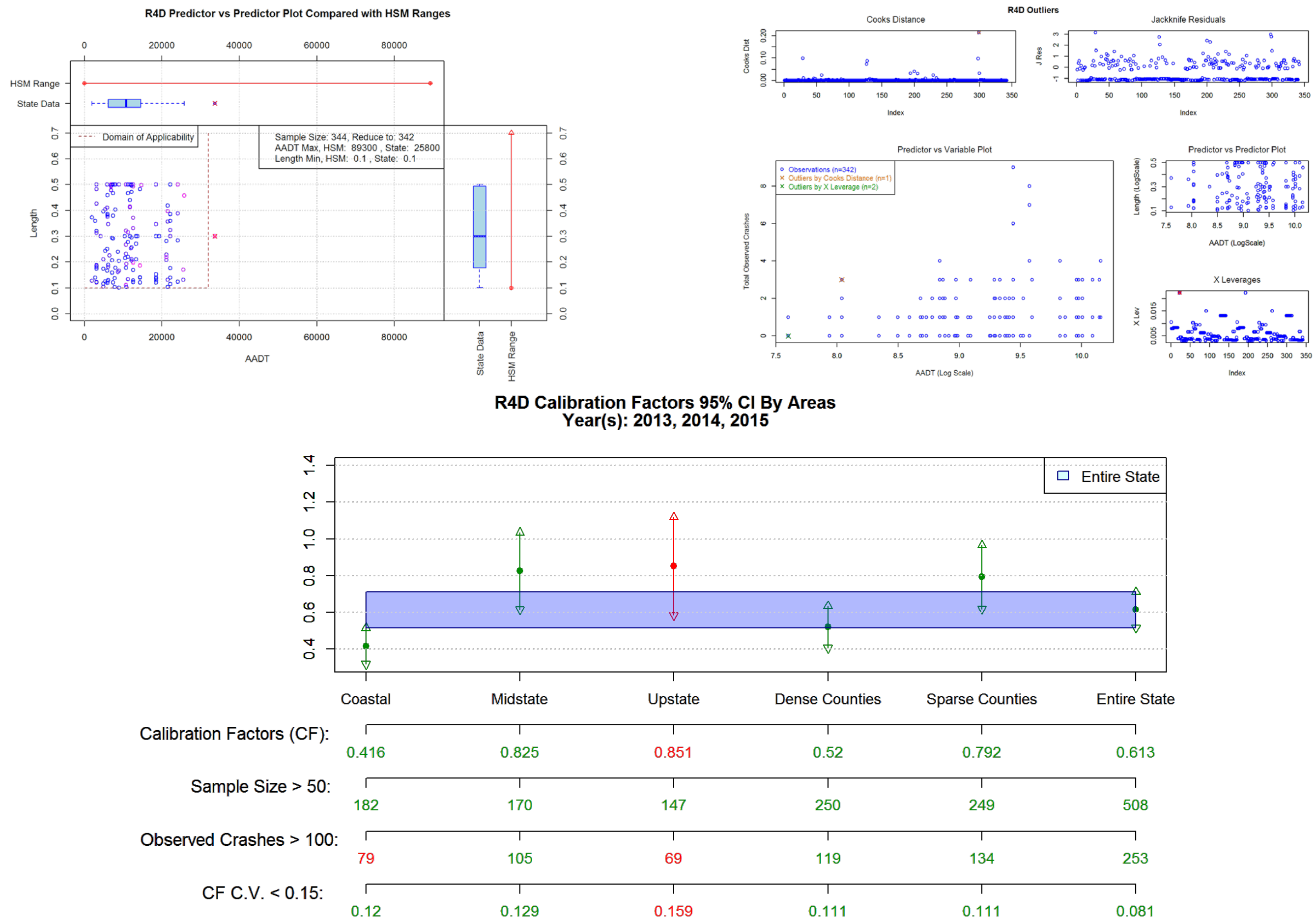


Figure 7.7 R4D Calibration factor summary 2013:2015

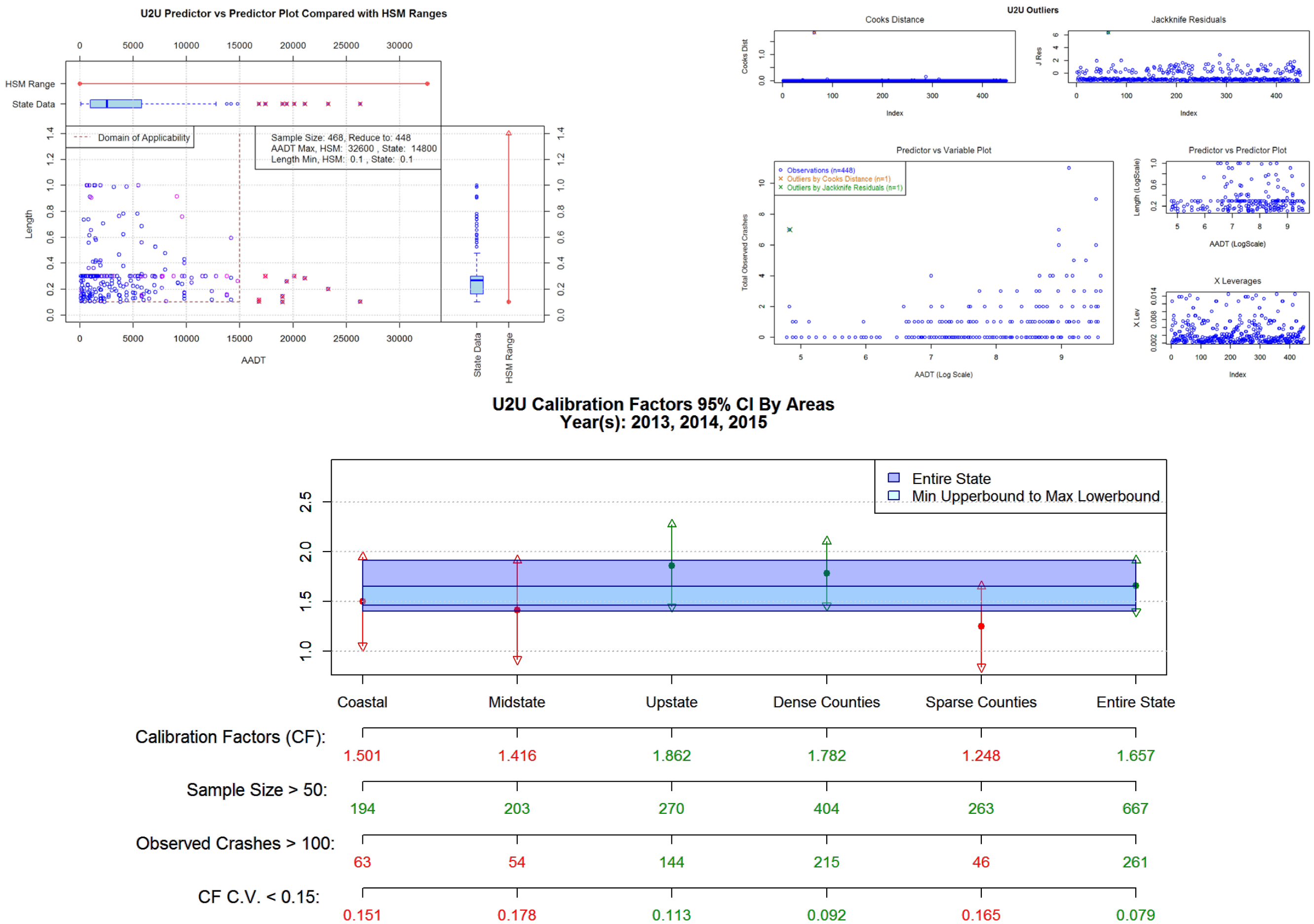


Figure 7.8 U2U Calibration factor summary 2013:2015

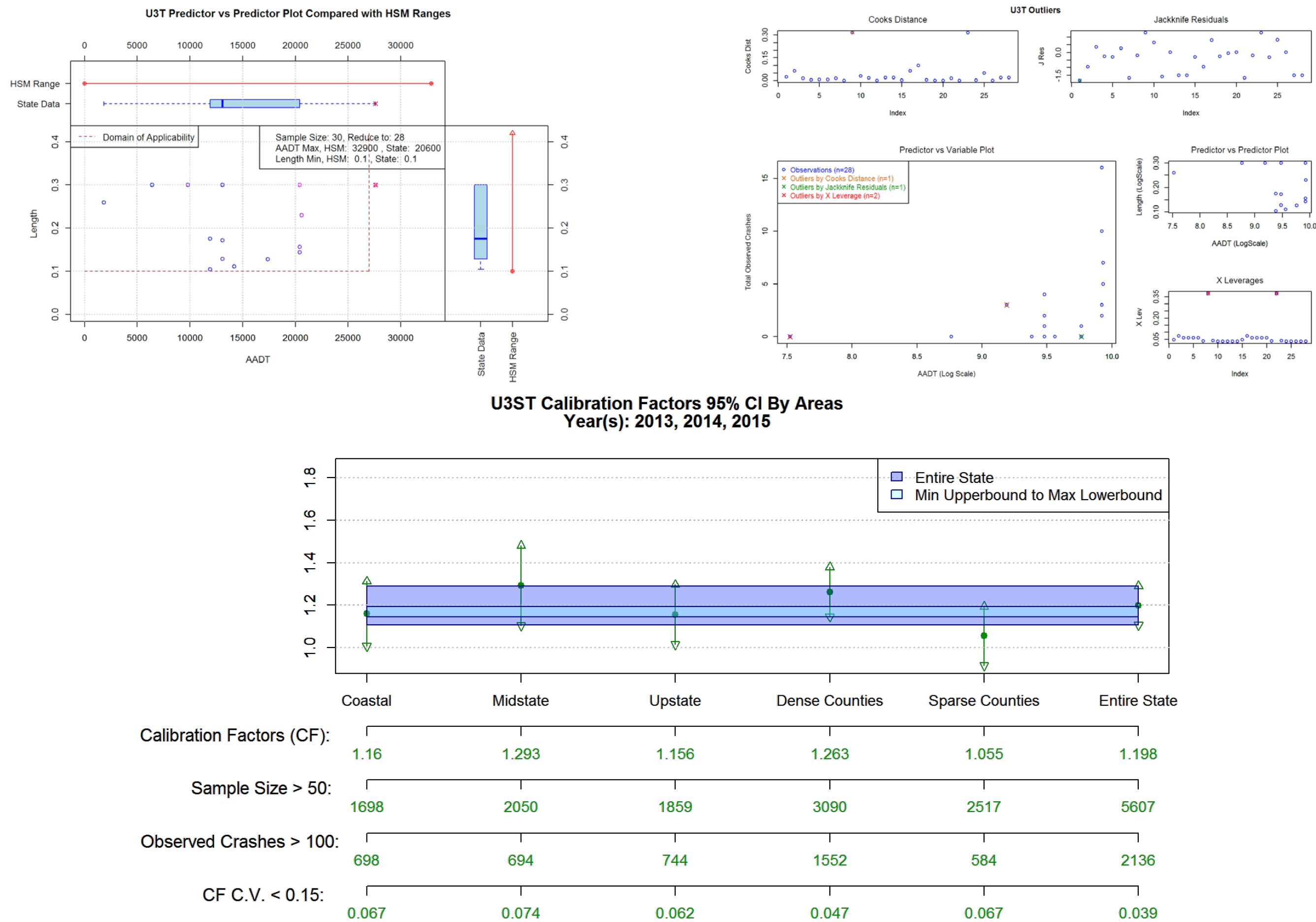


Figure 7.9 U3T Calibration factor summary 2013:2015

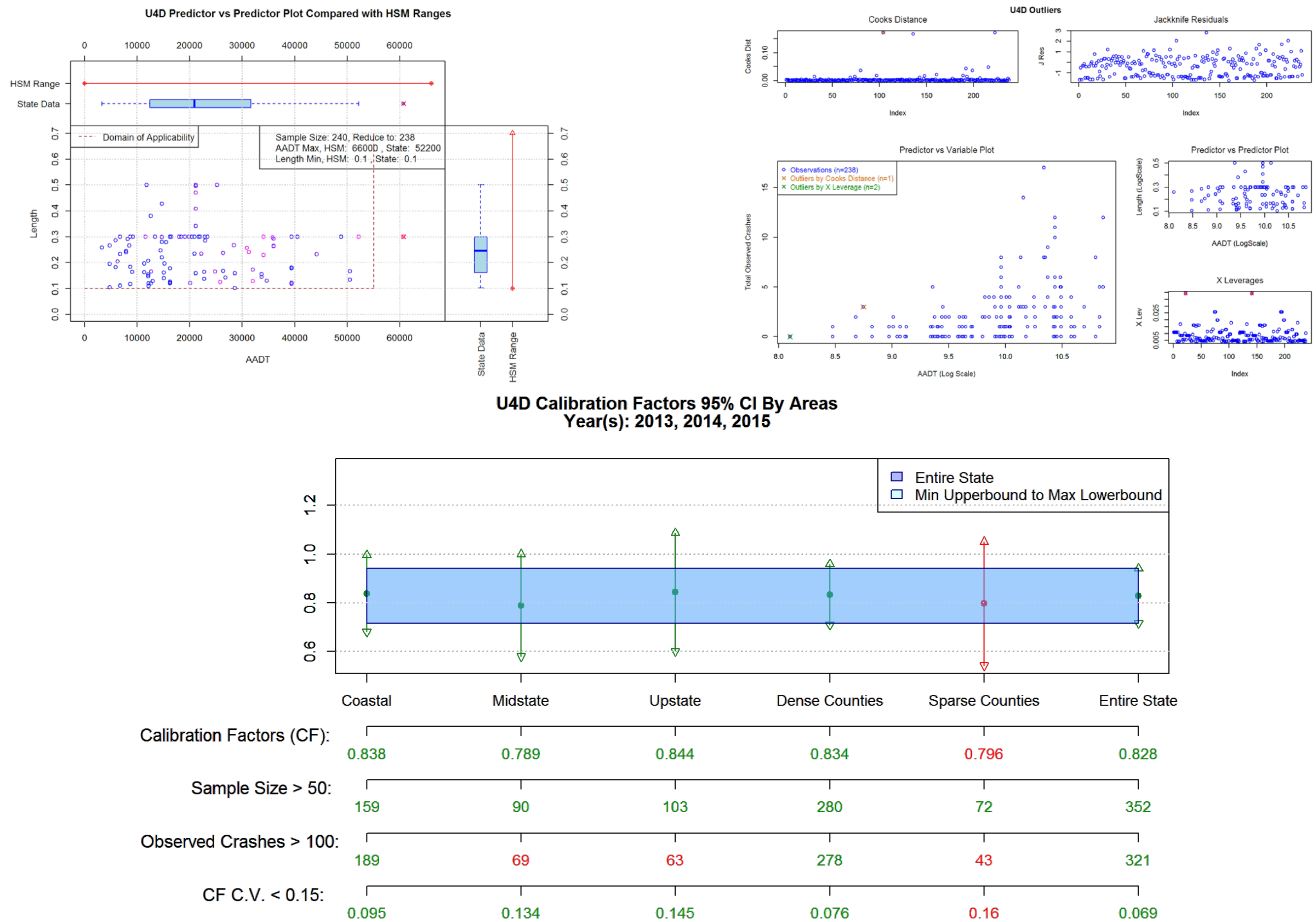


Figure 7.10 U4D Calibration factor summary 2013:2015

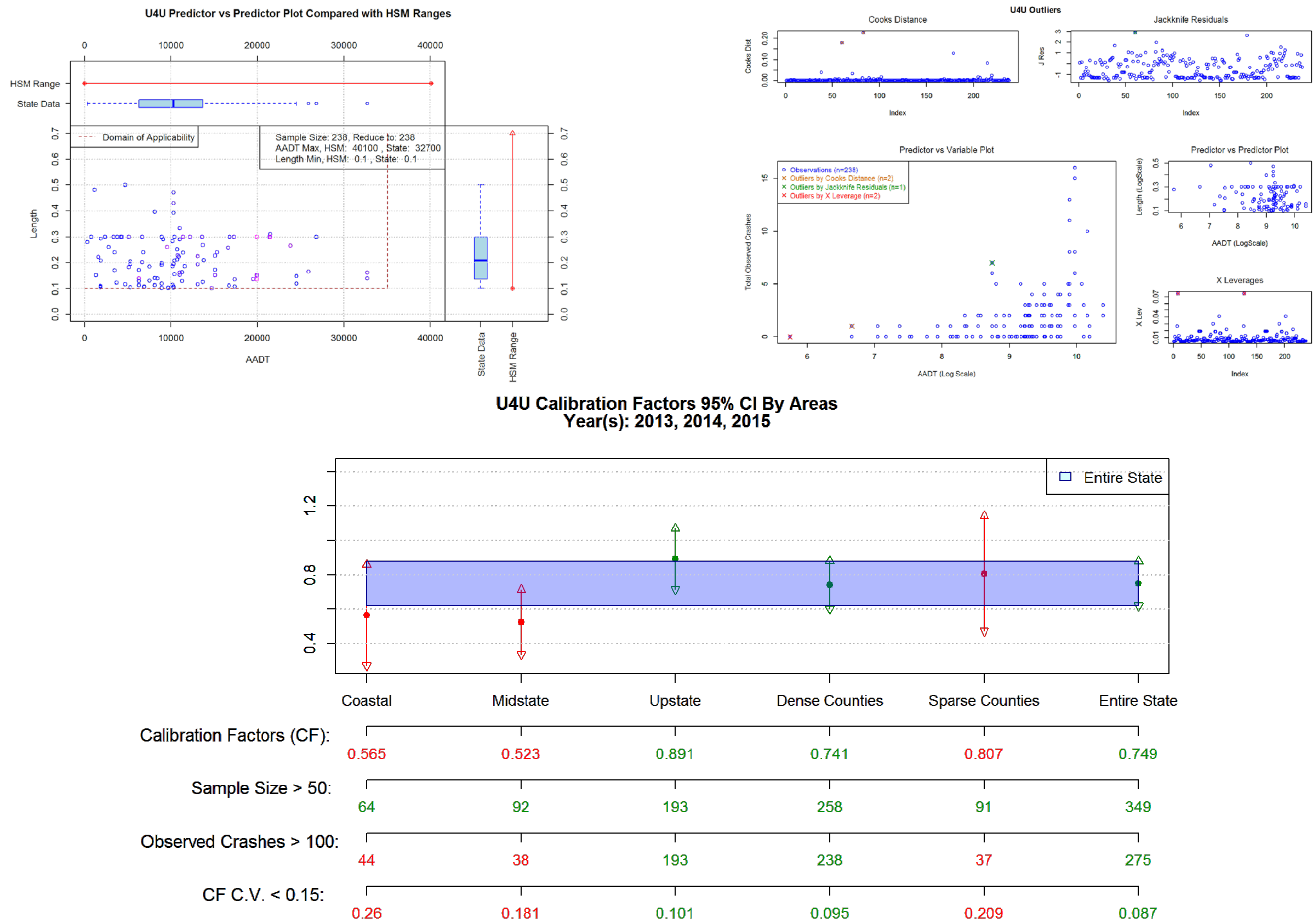


Figure 7.11 U4U Calibration factor summary 2013:2015

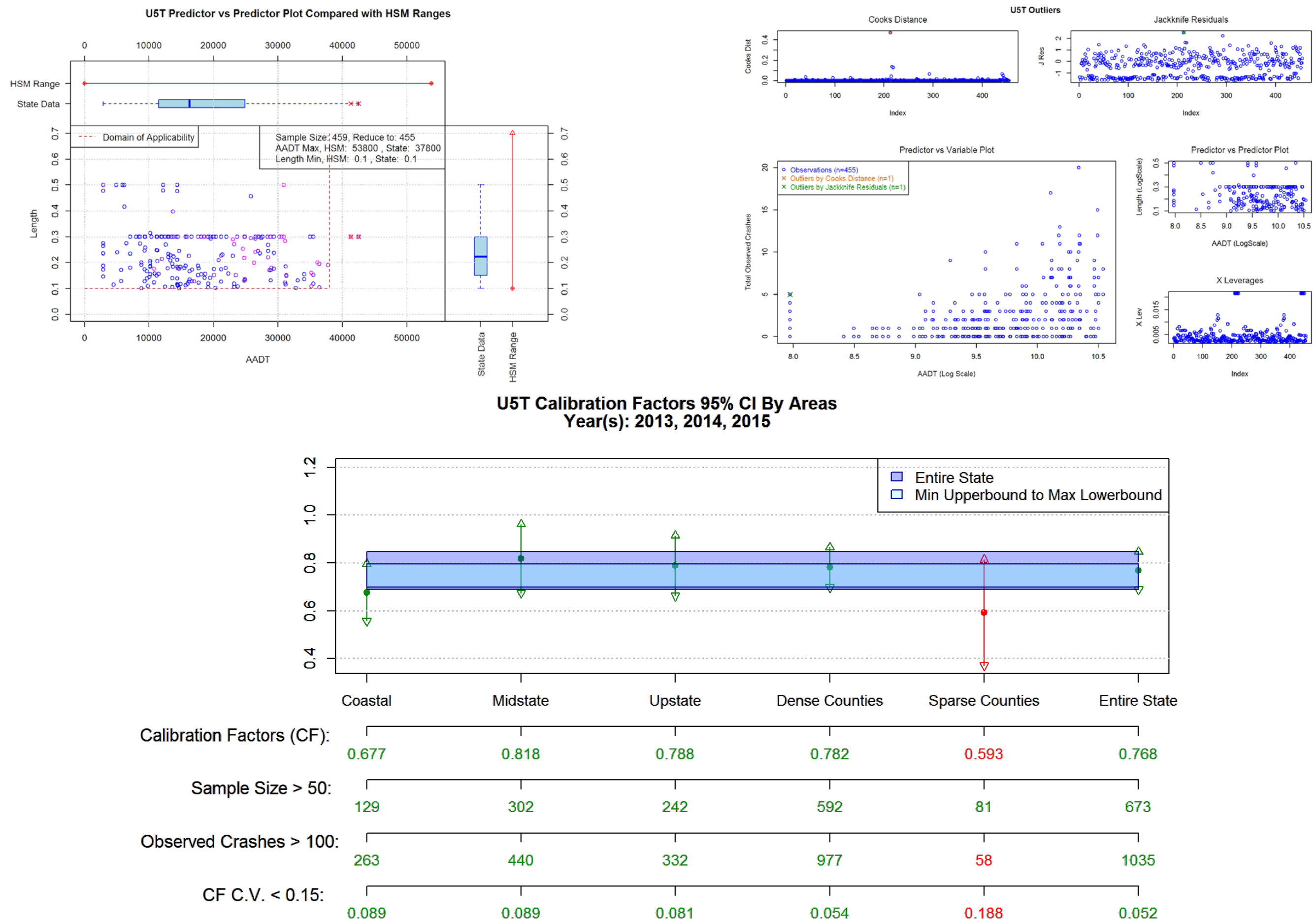


Figure 7.12 U5T Calibration factor summary 2013:2015

7.5 INTERSECTIONS CALIBRATION RESULTS

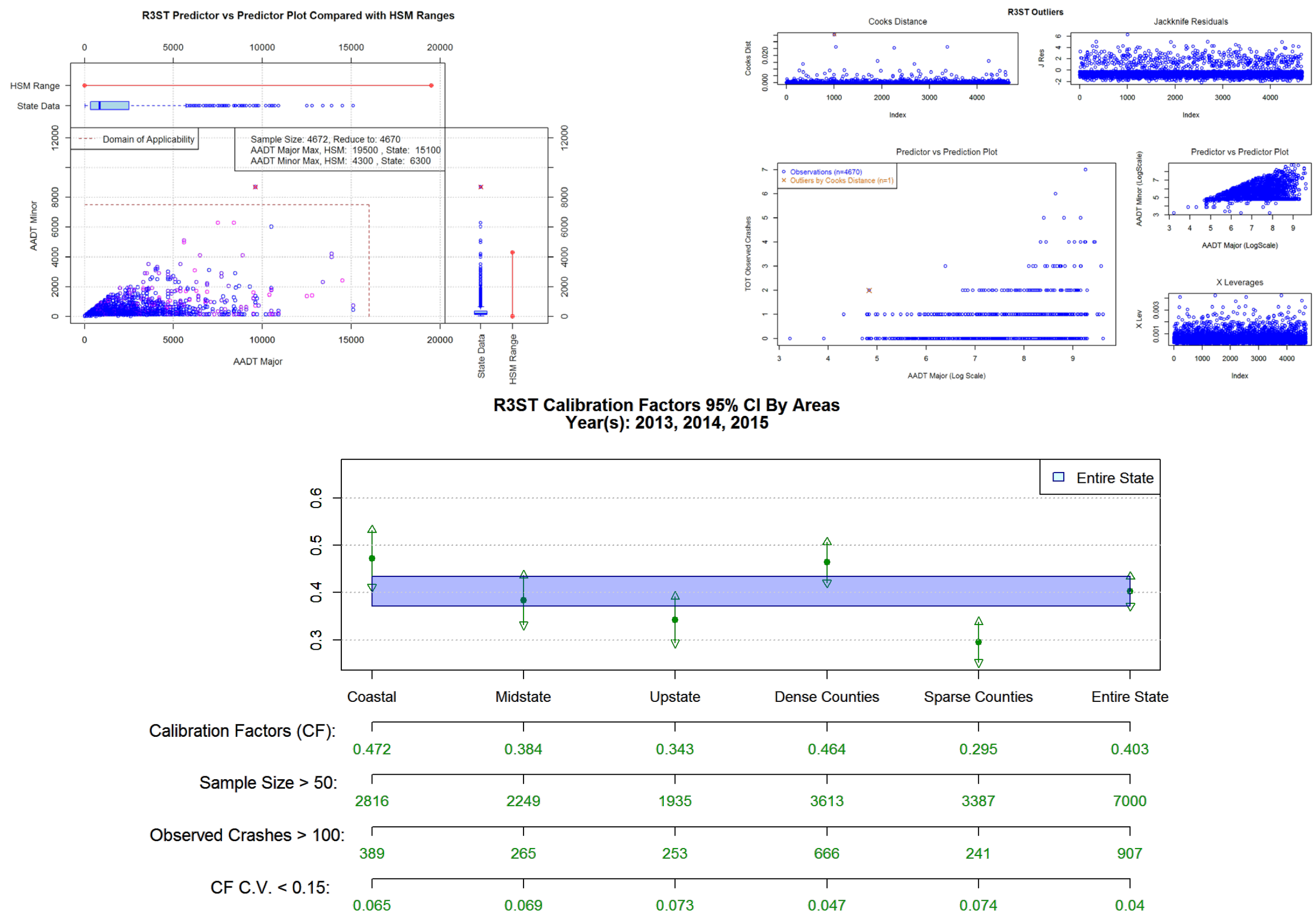


Figure 7.13 R3ST Calibration factor summary 2013:2015

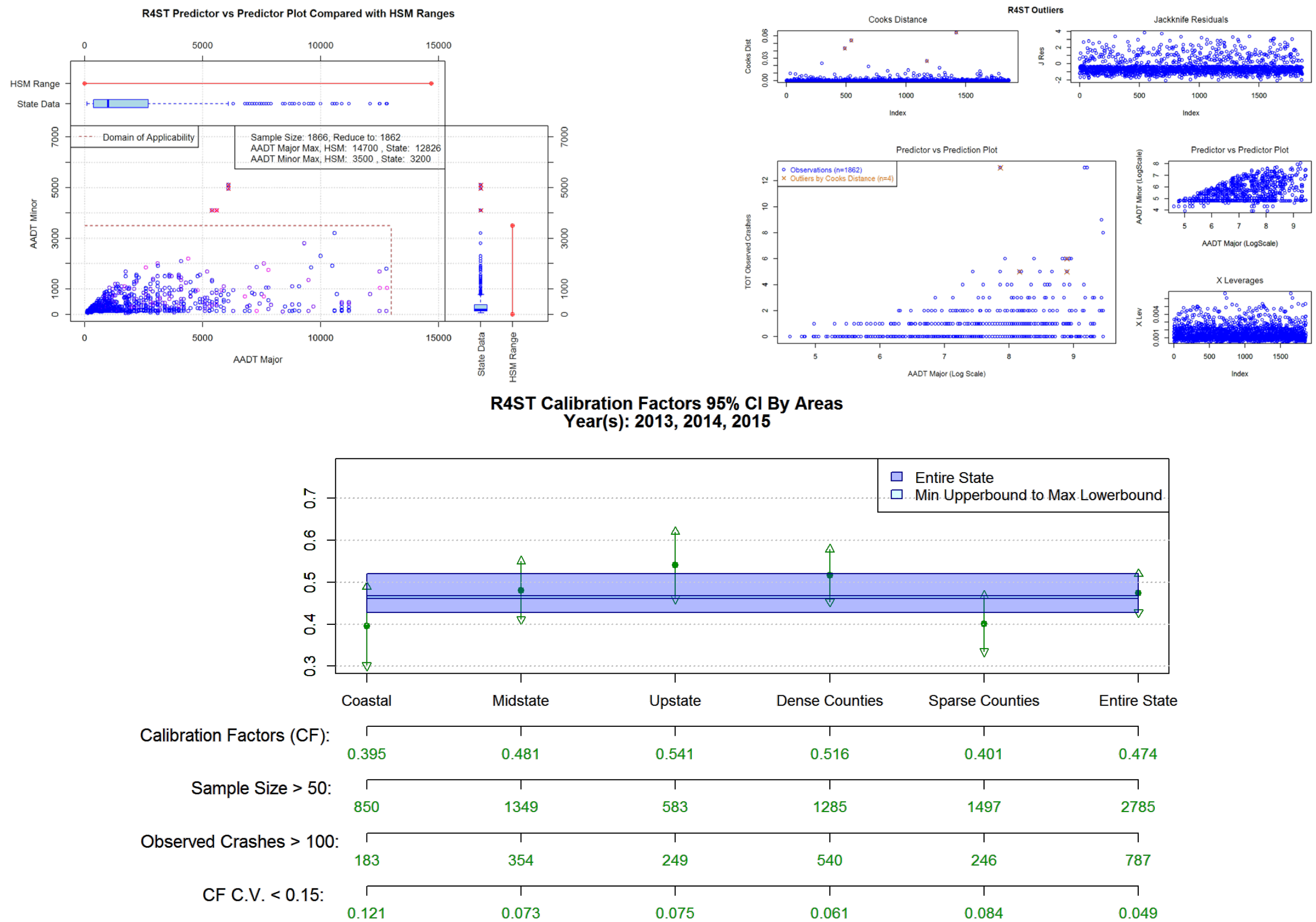


Figure 7.14 R4ST Calibration factor summary 2013:2015

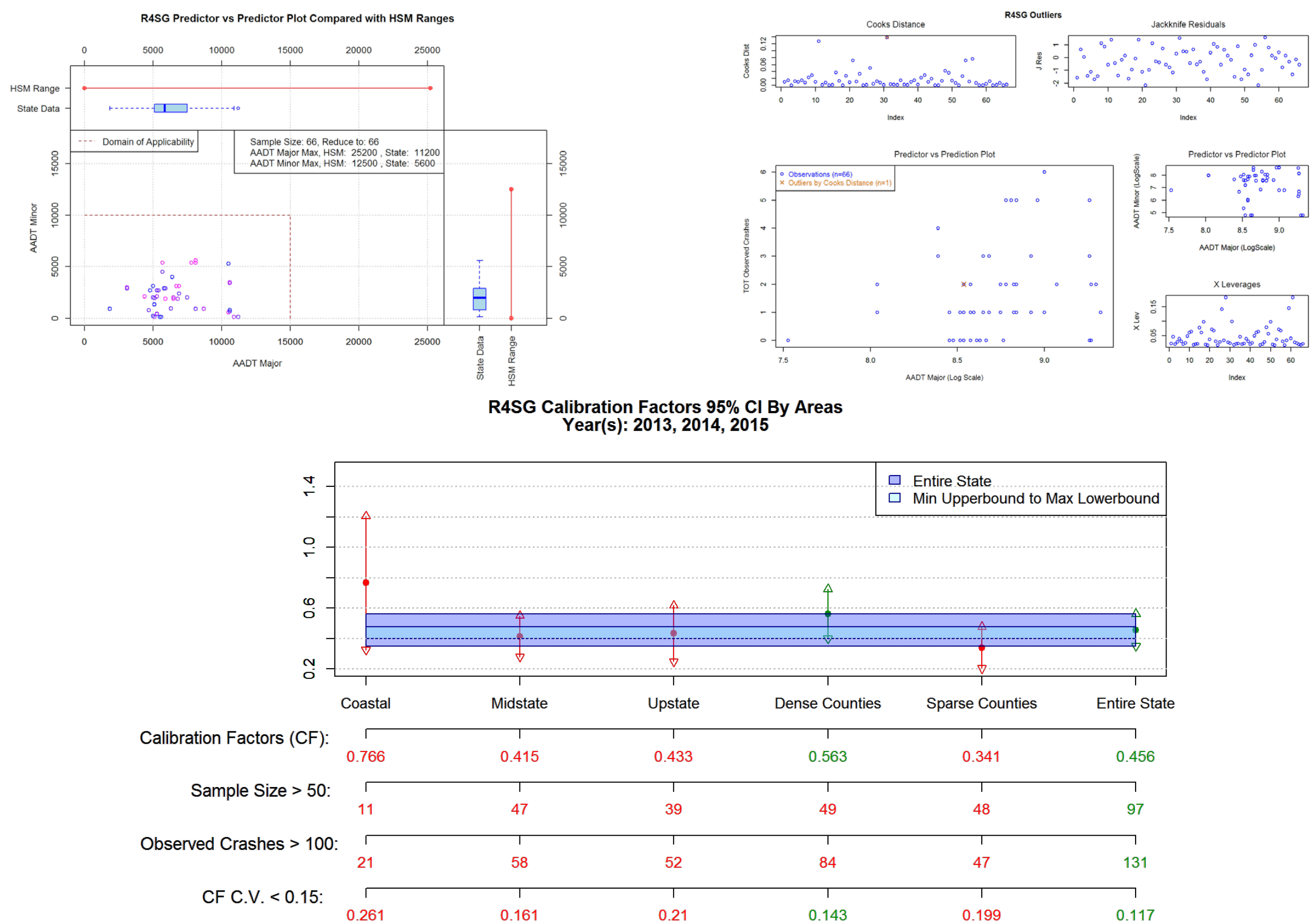


Figure 7.15 R4SG Calibration factor summary 2013:2015

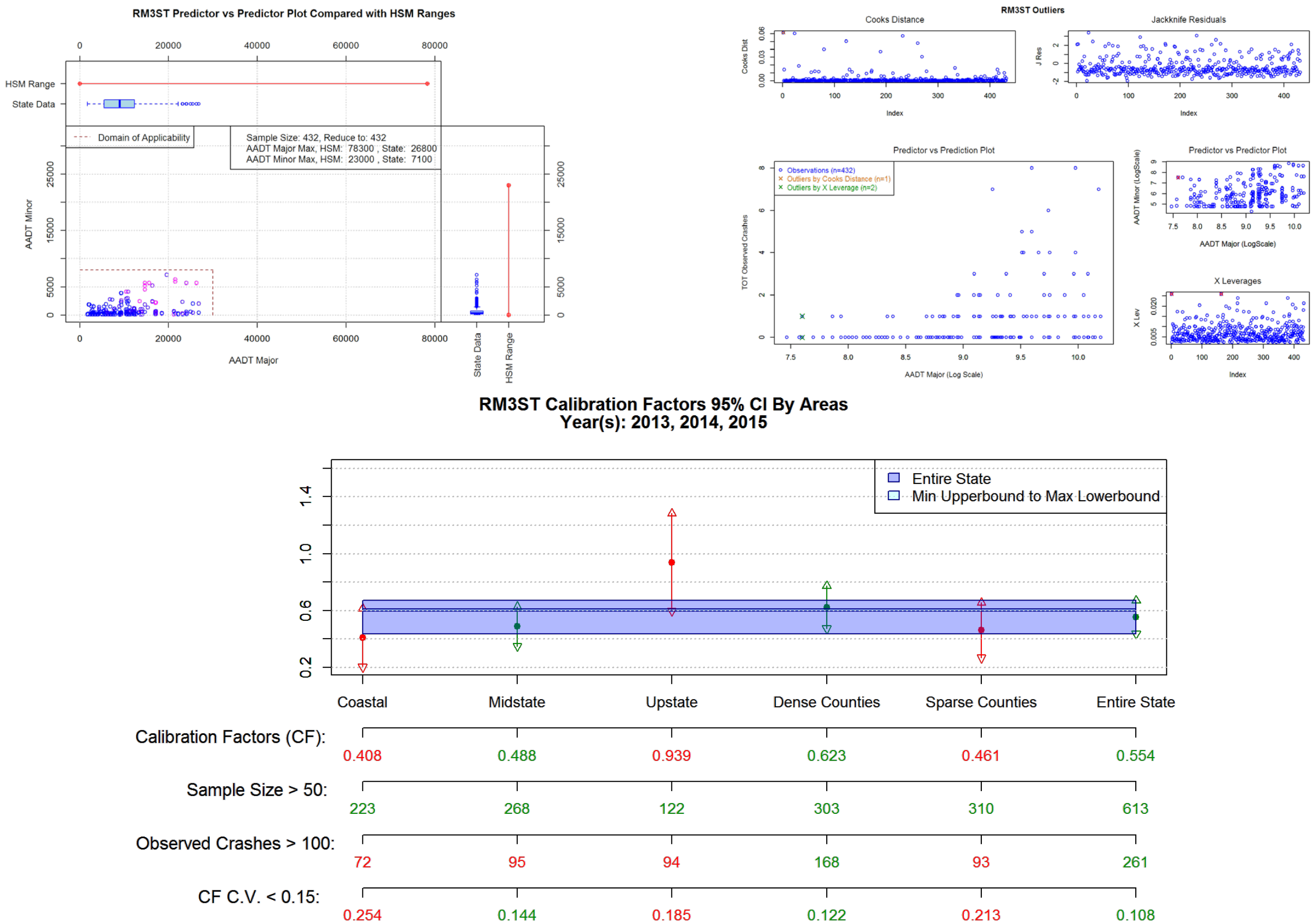


Figure 7.16 RM3ST Calibration factor summary 2013:2015

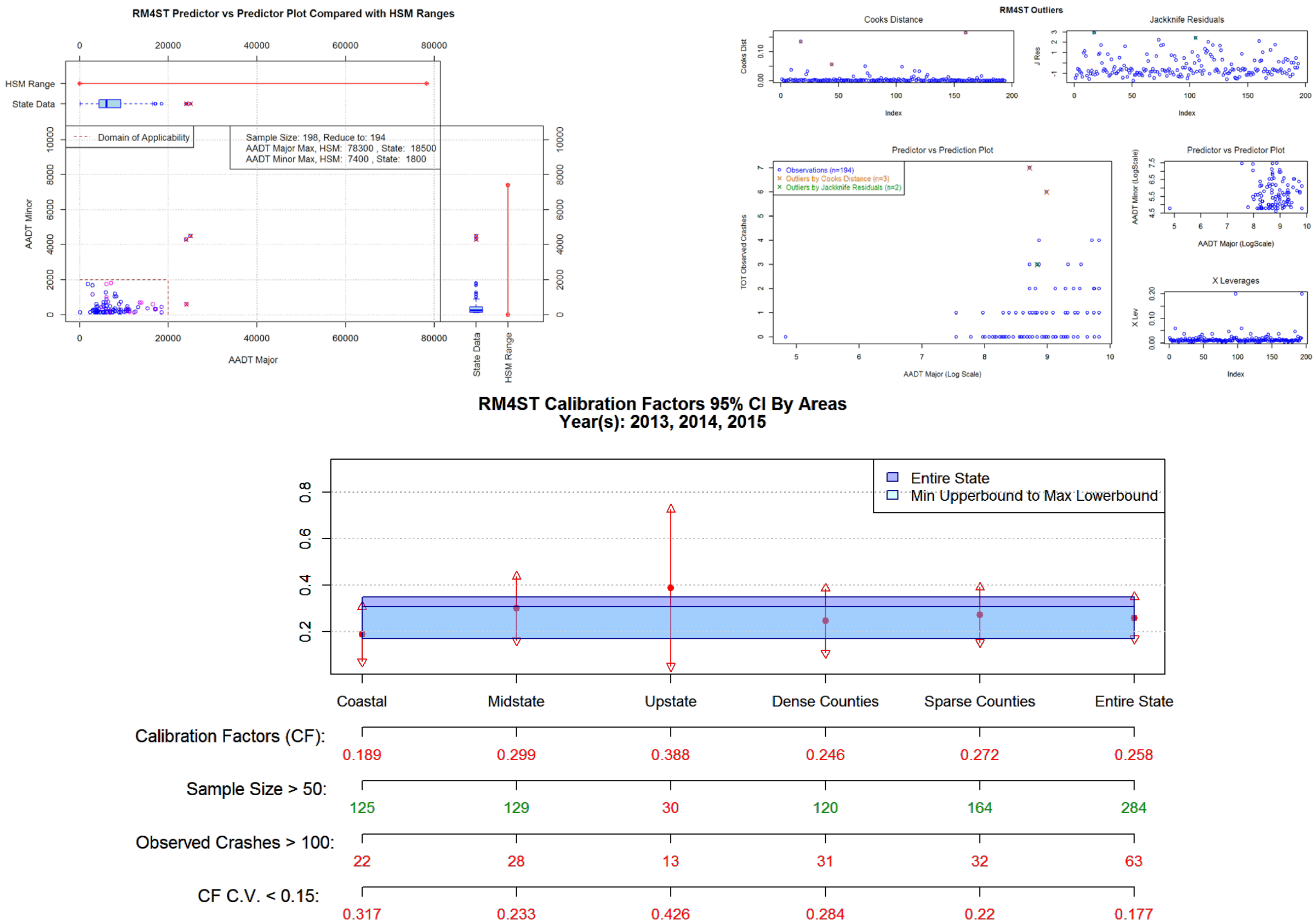


Figure 7.17 RM4ST Calibration factor summary 2013:2015

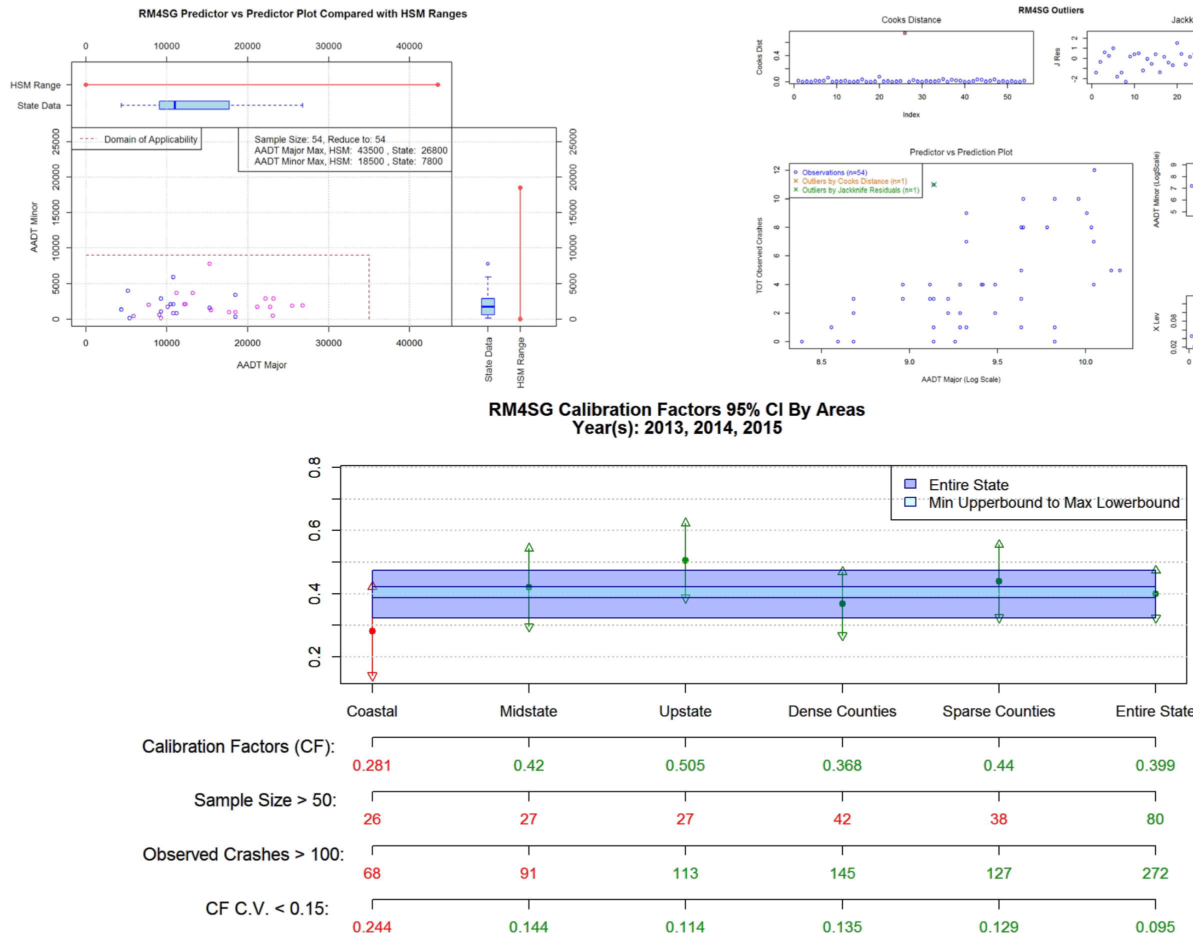


Figure 7.18 RM4SG Calibration factor summary 2013:2015

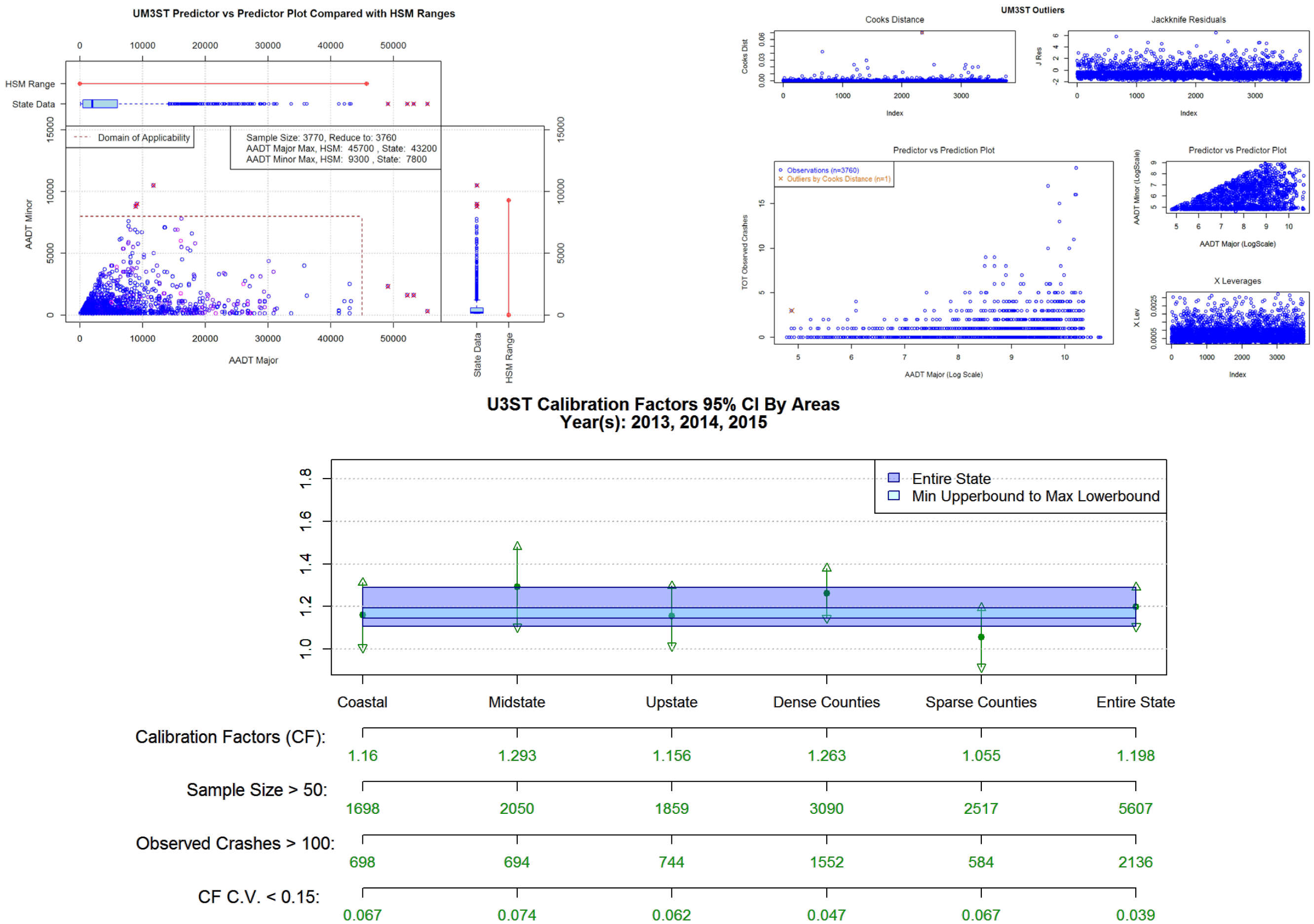


Figure 7.19 U3ST Calibration factor summary 2013:2015

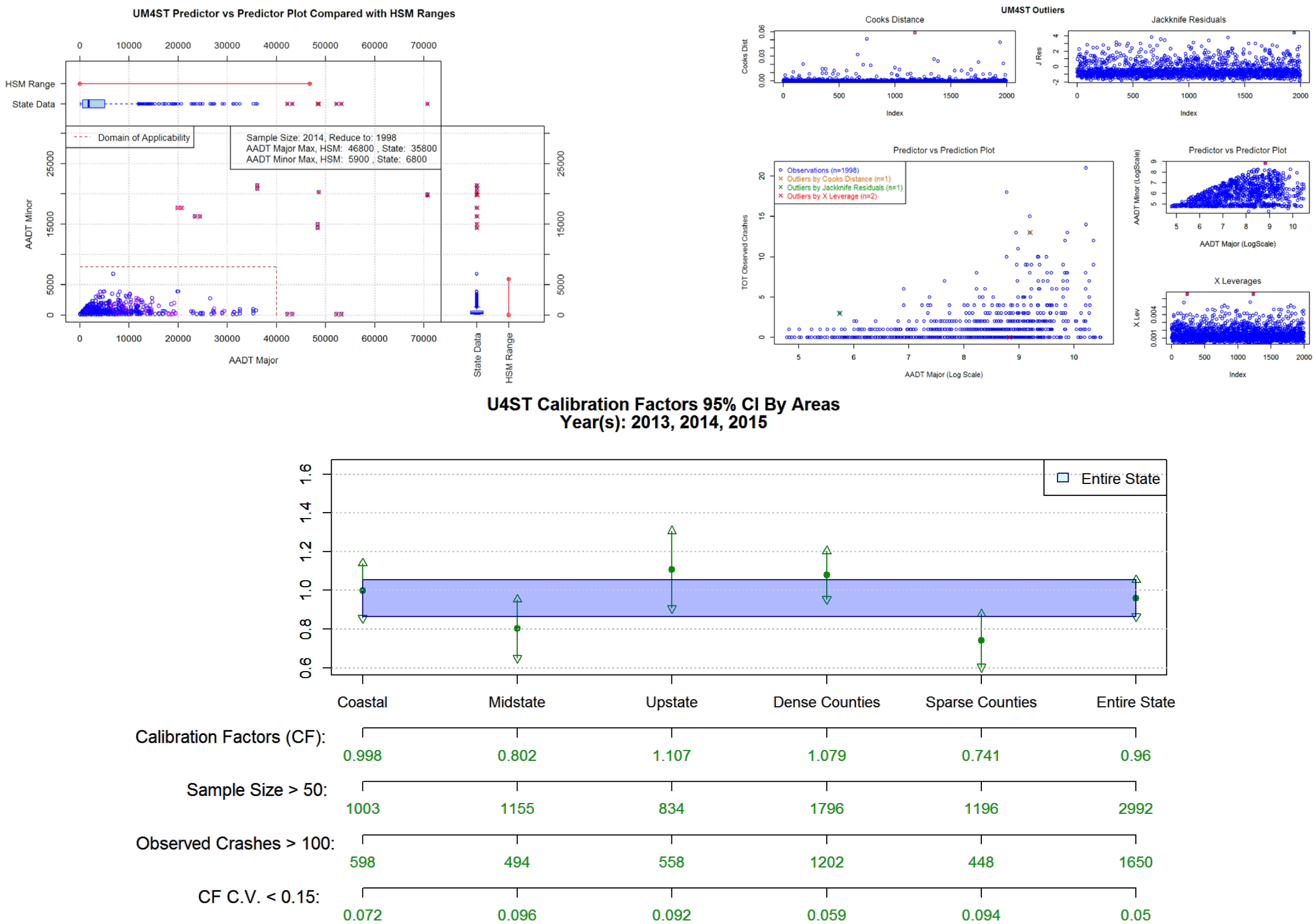


Figure 7.20 U4ST Calibration factor summary 2013:2015

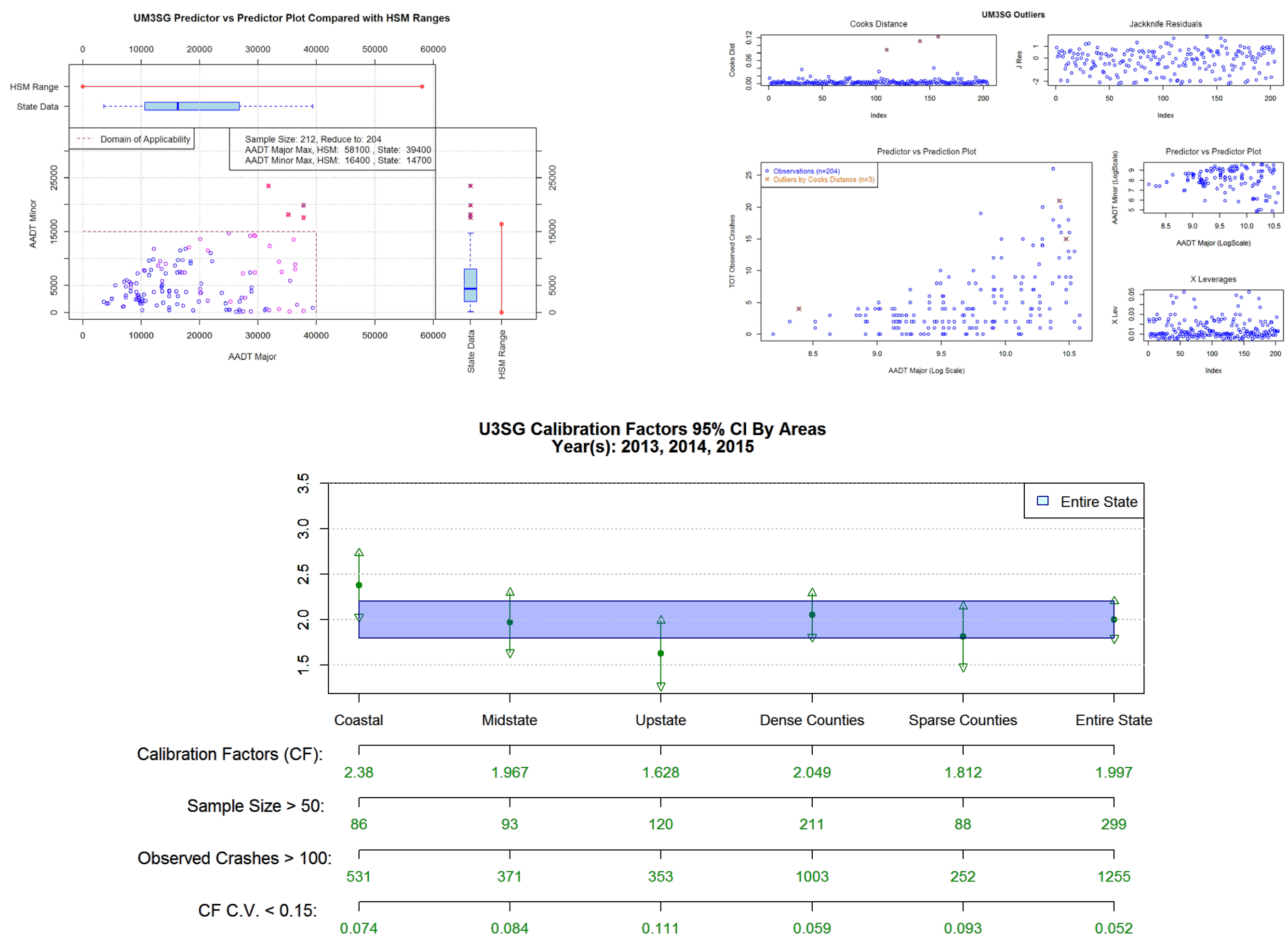


Figure 7.21 U3SG Calibration factor summary 2013:2015

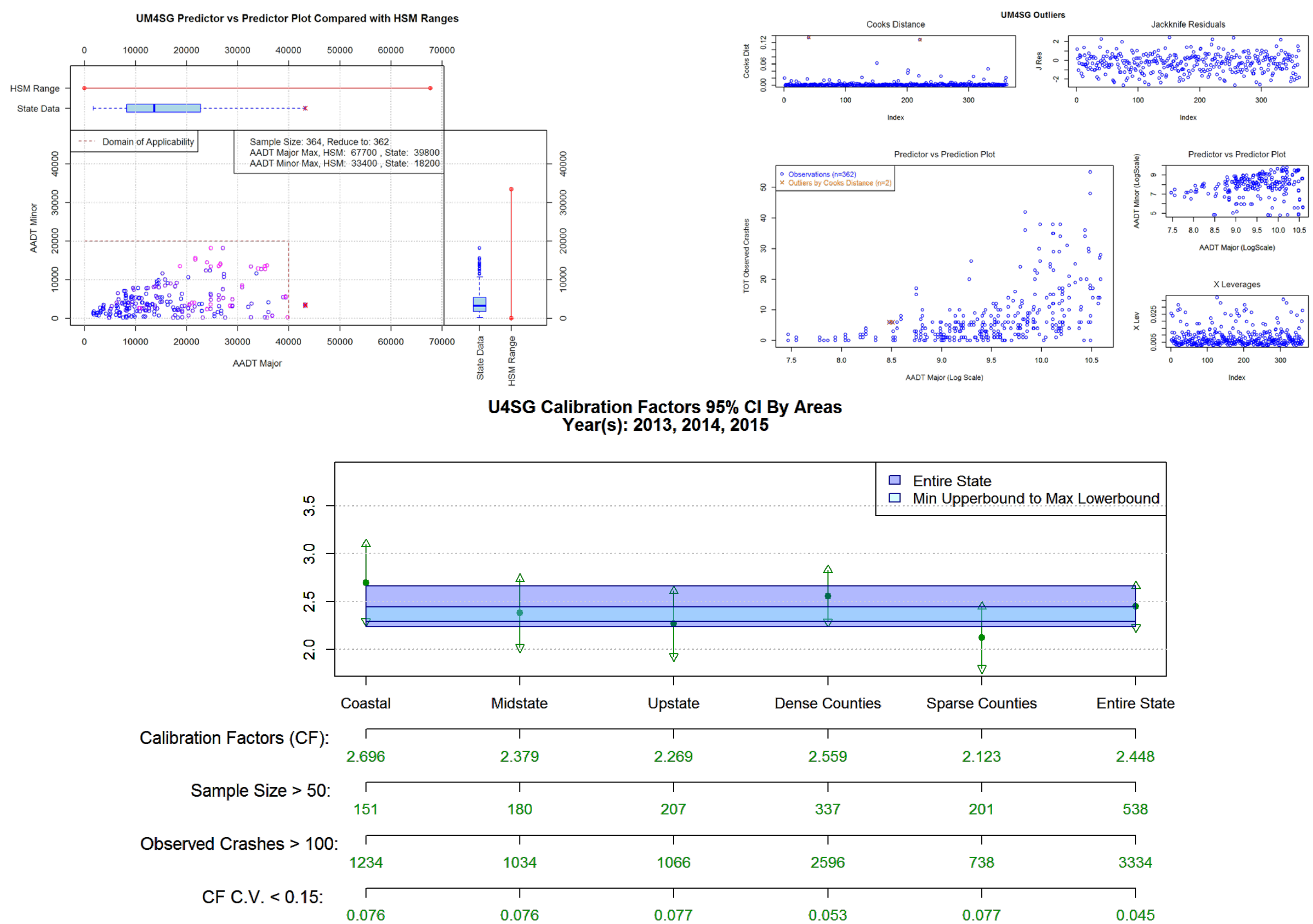


Figure 7.22 U4SG Calibration factor summary 2013:2015

7.6 STATE SPECIFIC SPFS

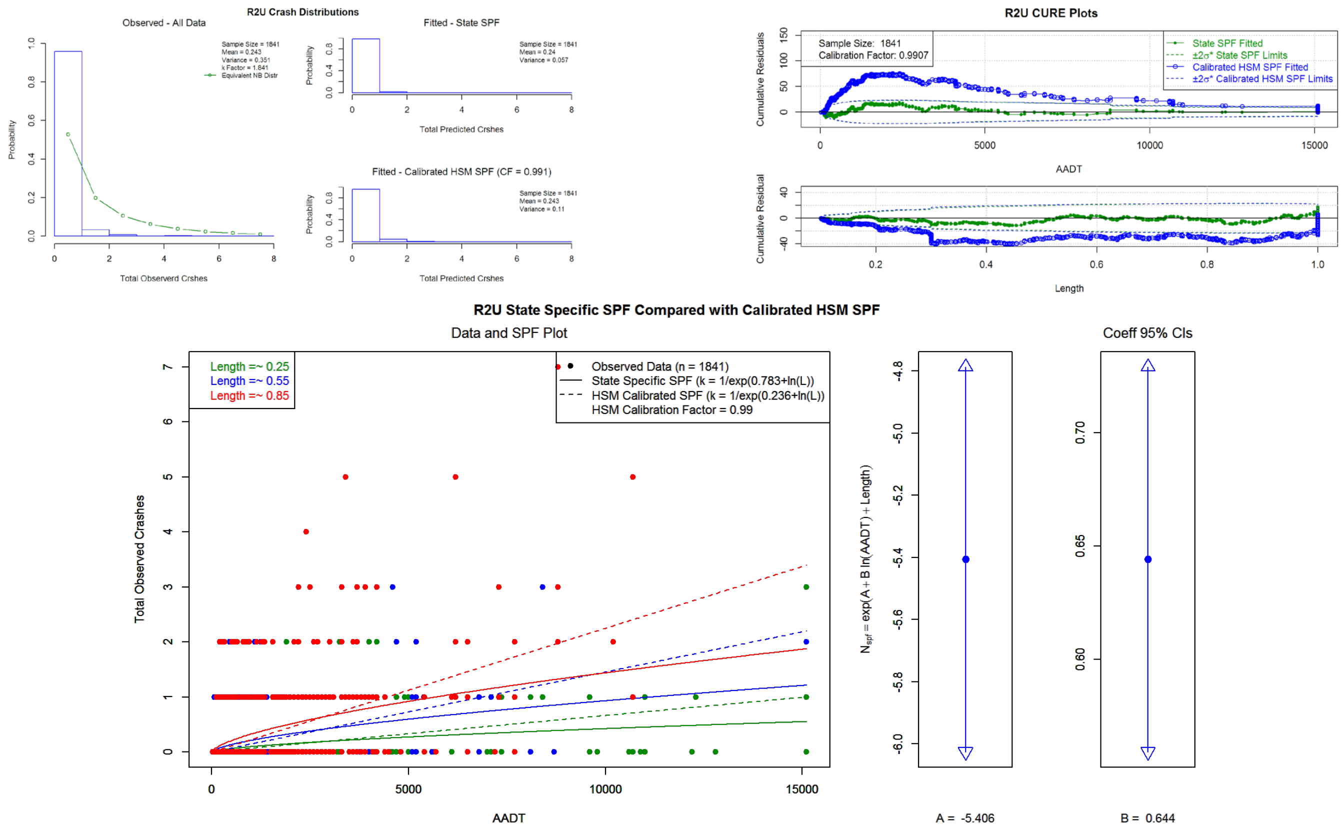


Figure 7.23 R2U state-specific SPF summary 2013:2015

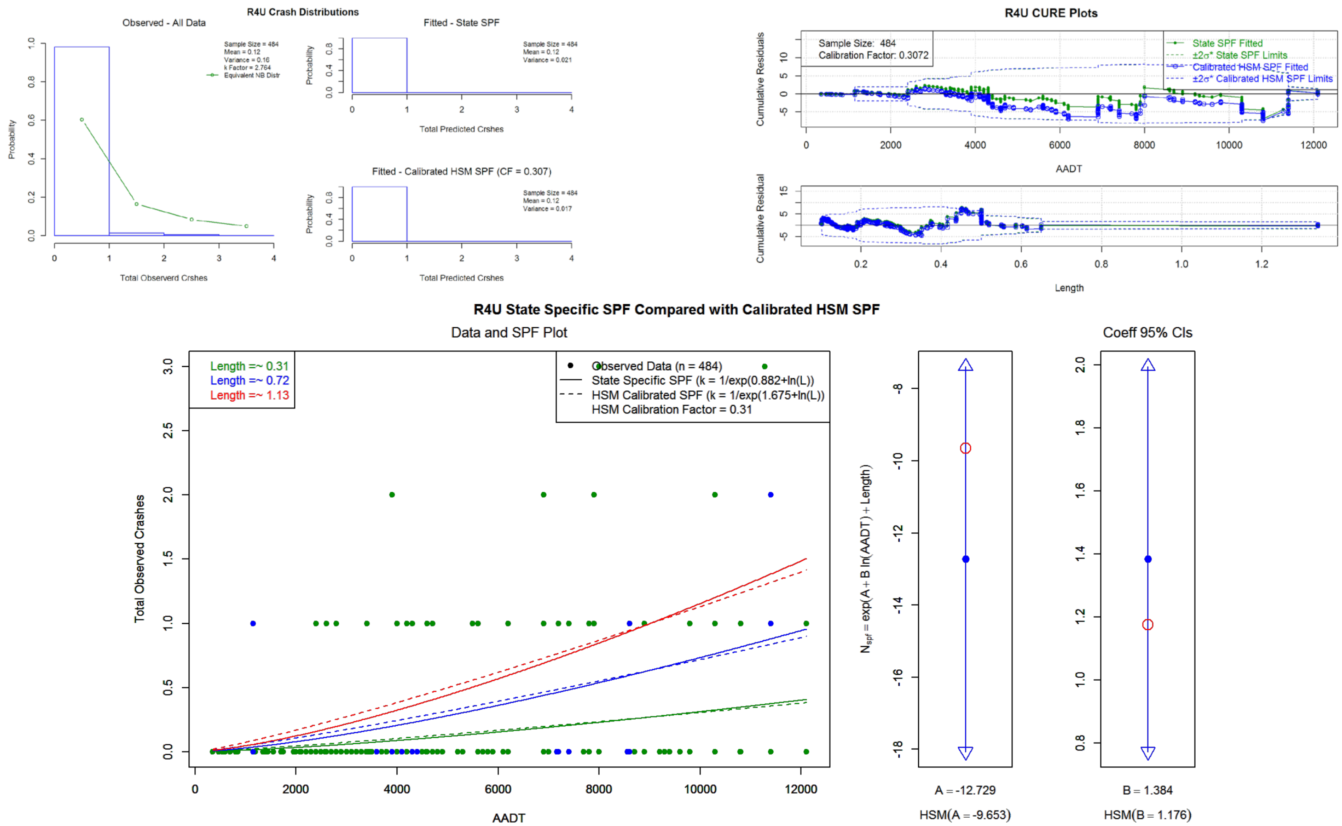


Figure 7.24 R4U state-specific SPF summary 2013:2015

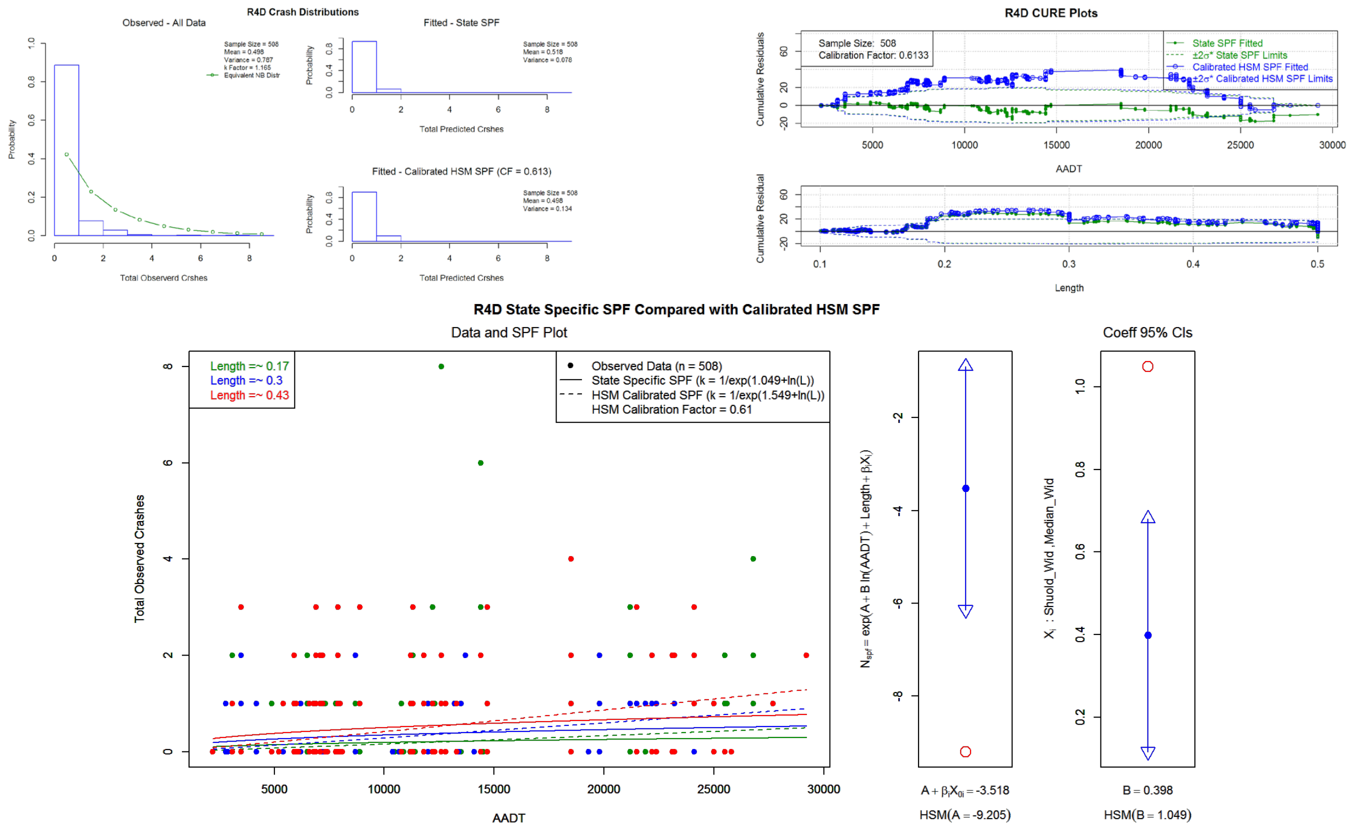


Figure 7.25 R4D state-specific SPF summary 2013:2015

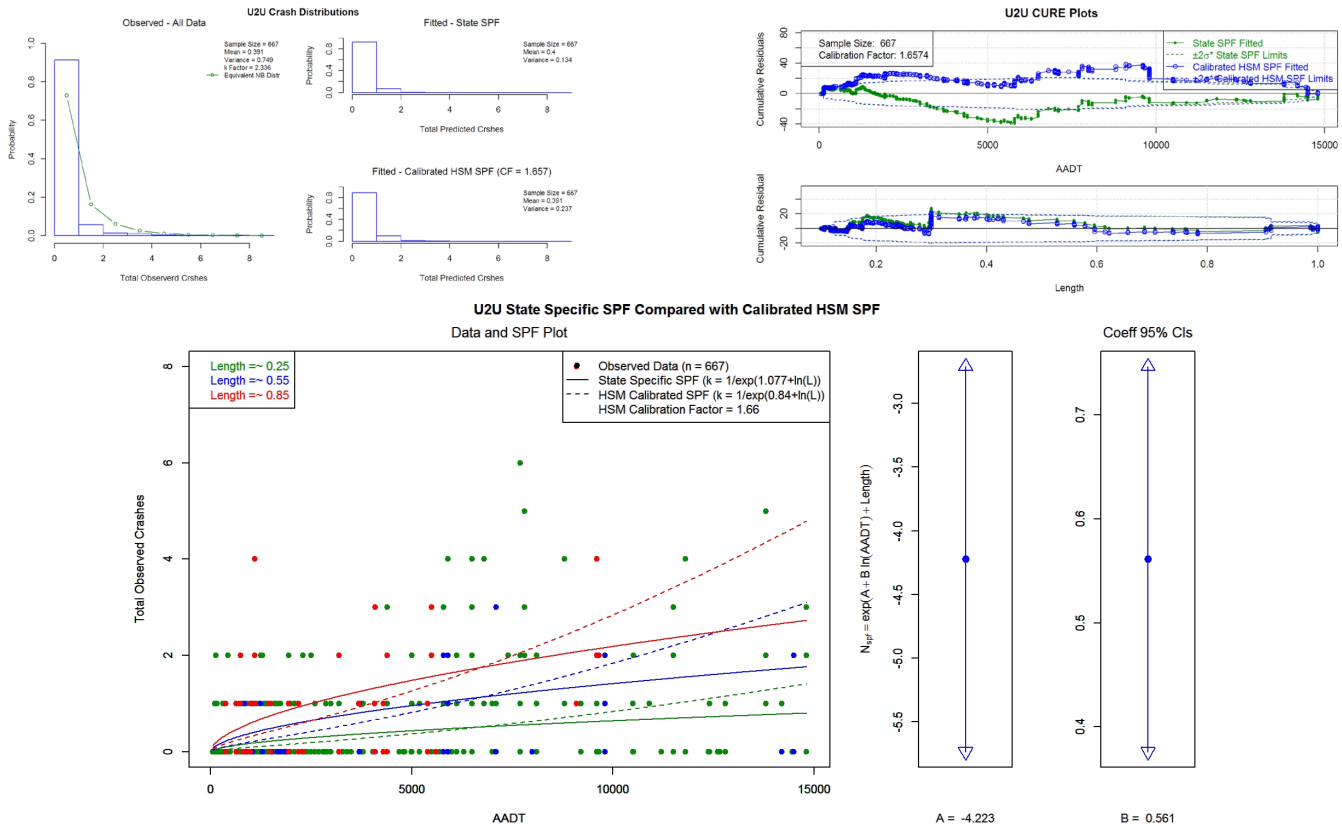


Figure 7.26 U2U state-specific SPF summary 2013:2015

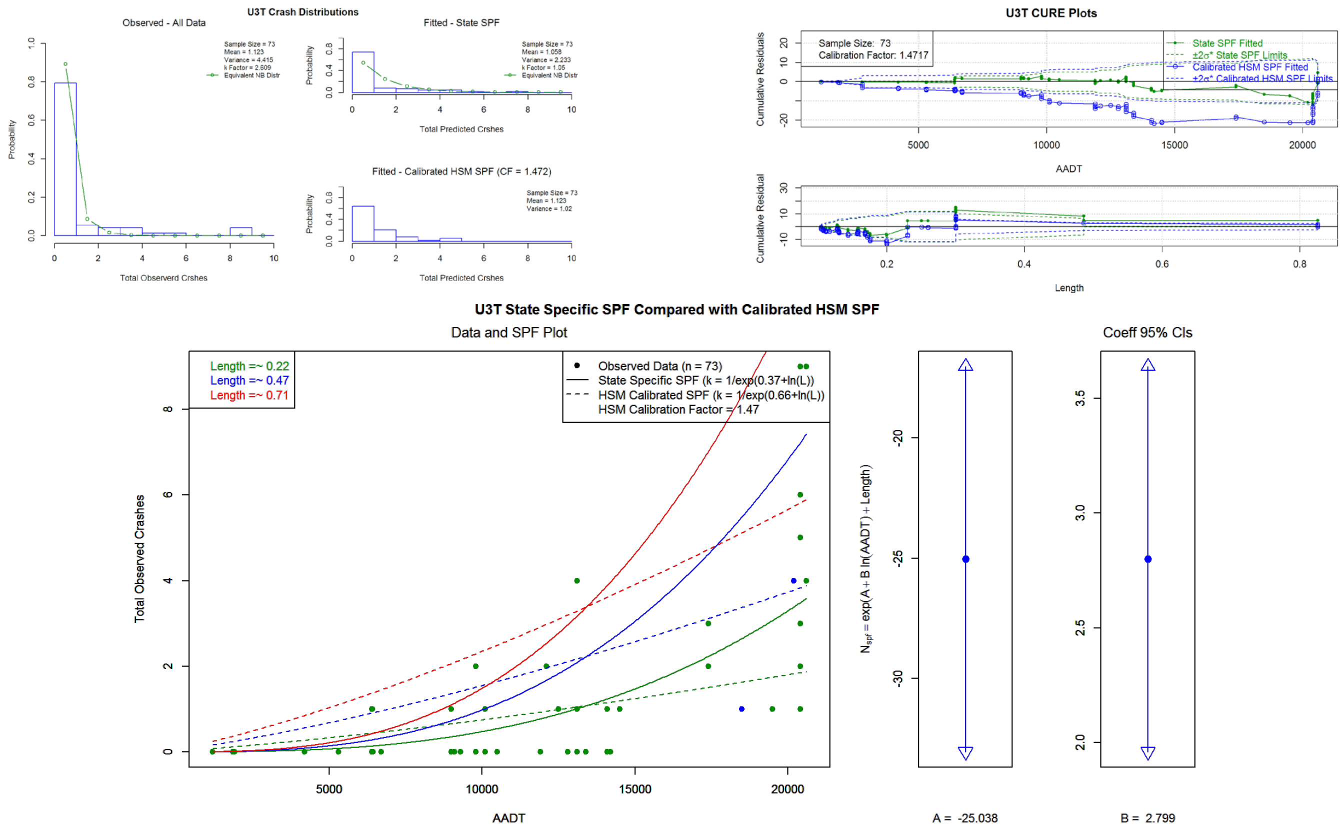


Figure 7.27 U3T state-specific SPF summary 2013:2015

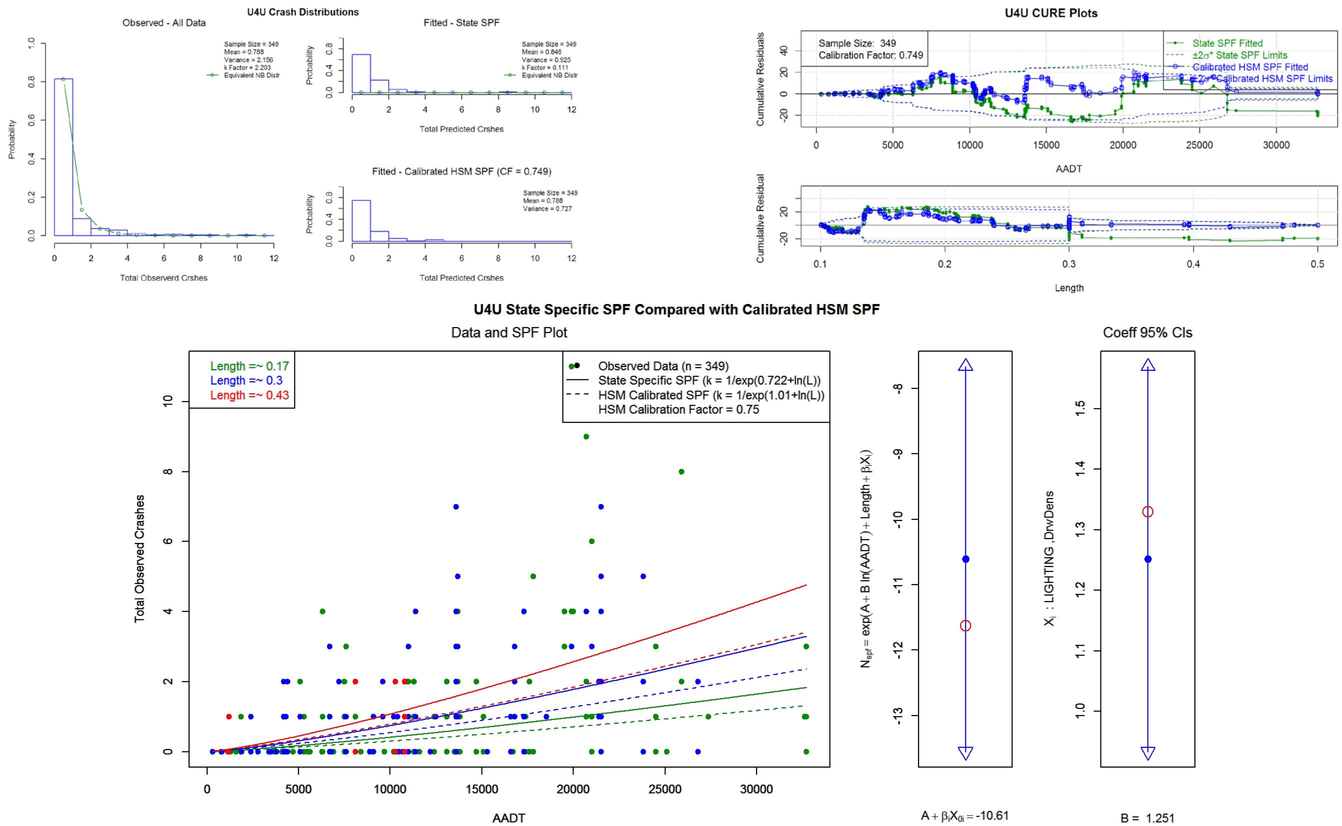


Figure 7.28 U4U state-specific SPF summary 2013:2015

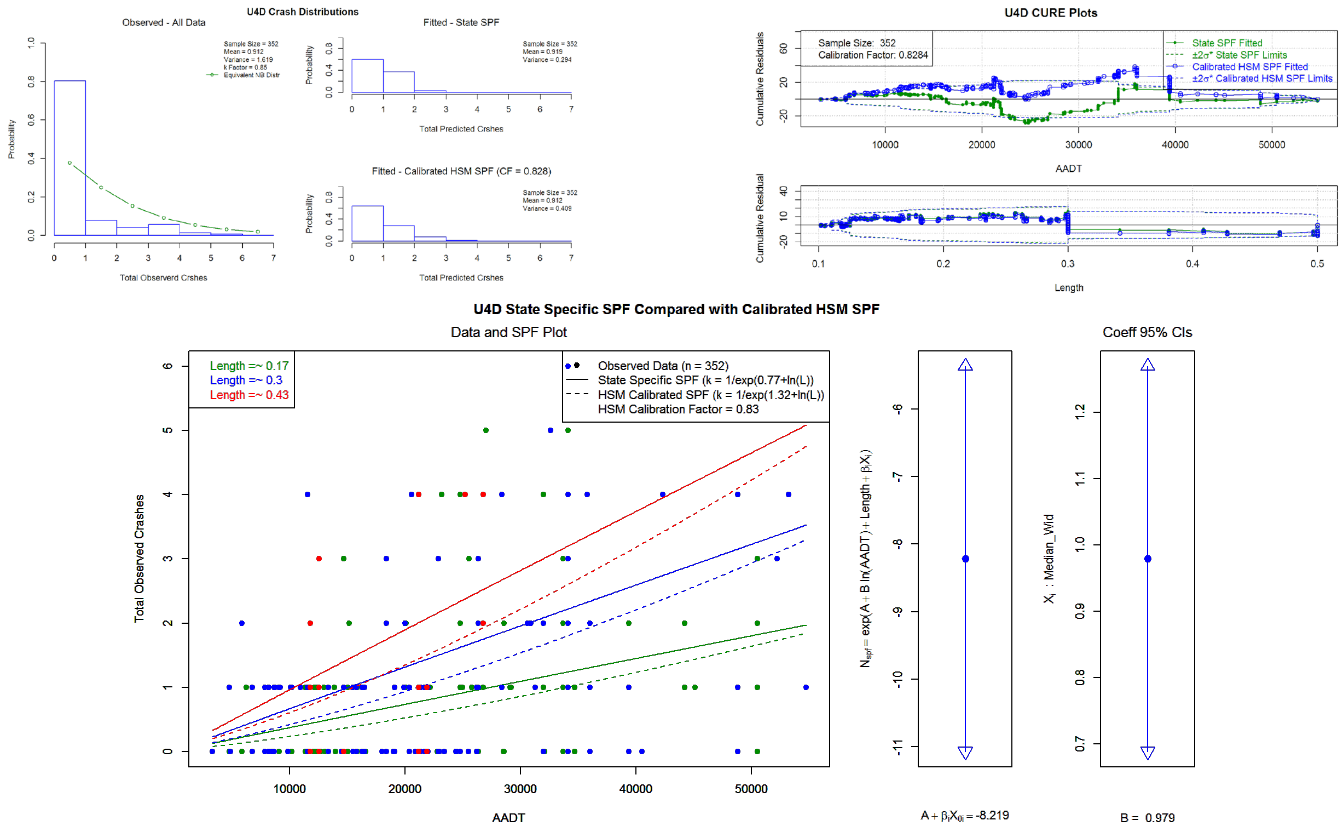


Figure 7.29 U4D state-specific SPF summary 2013:2015

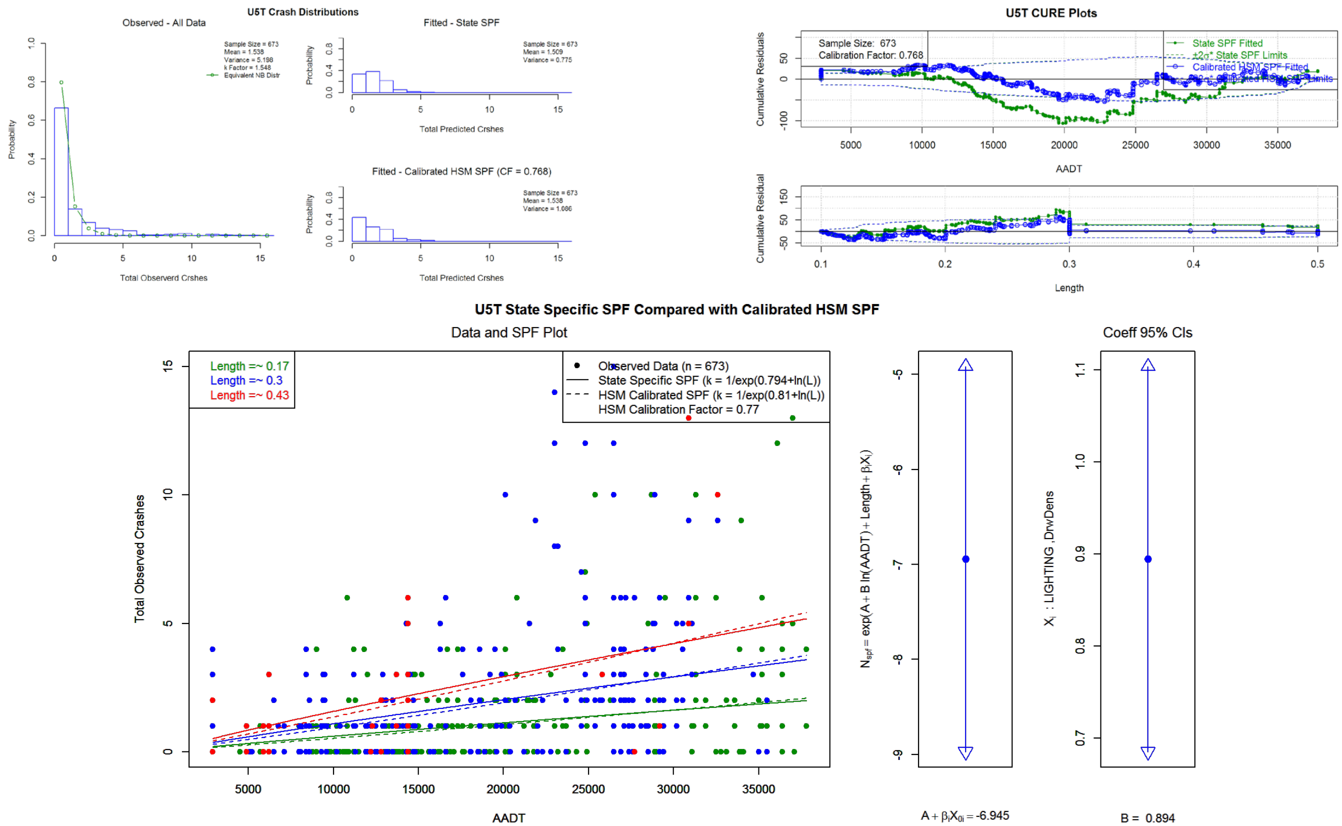


Figure 7.30 U5T state-specific SPF summary 2013:2015

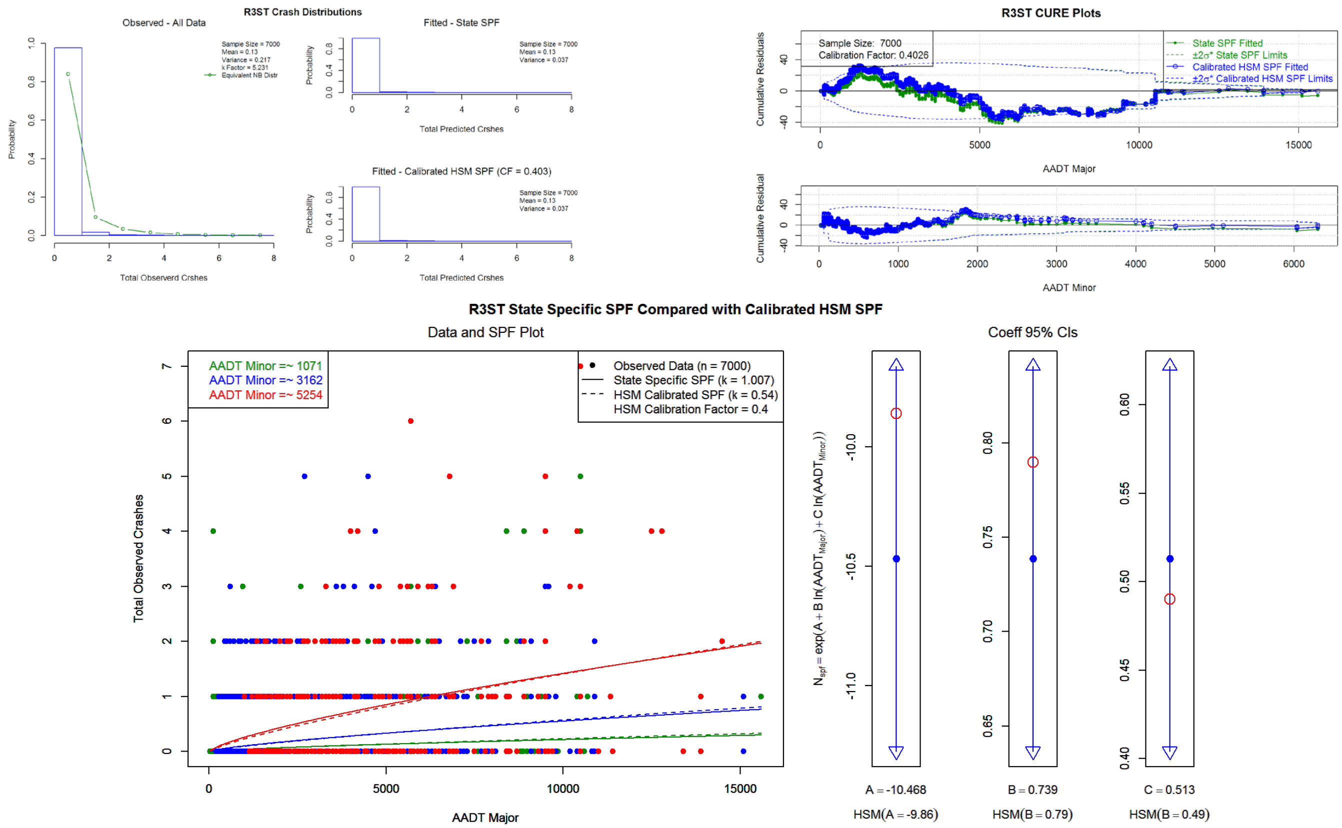


Figure 7.31 R3ST state-specific SPF summary 2013:2015

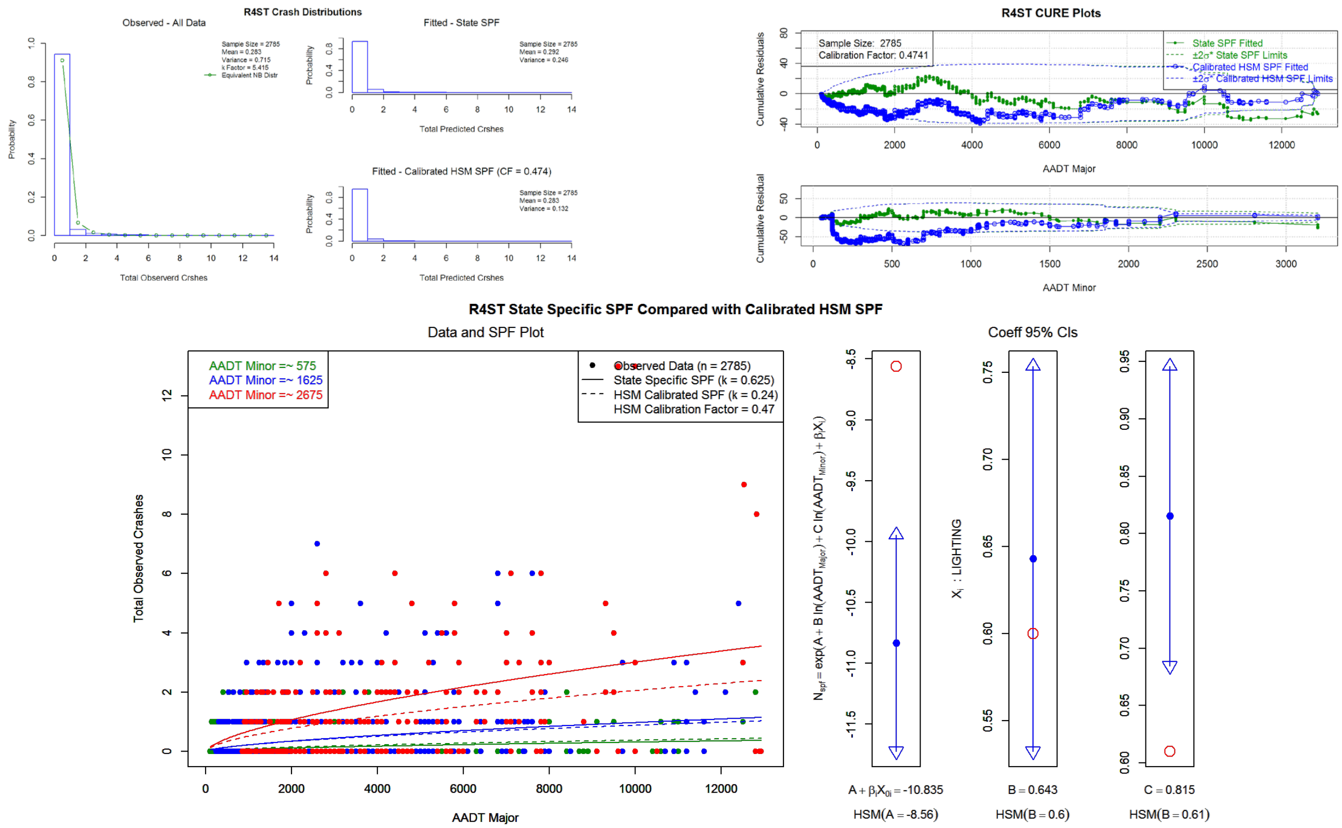


Figure 7.32 R4ST state-specific SPF summary 2013:2015

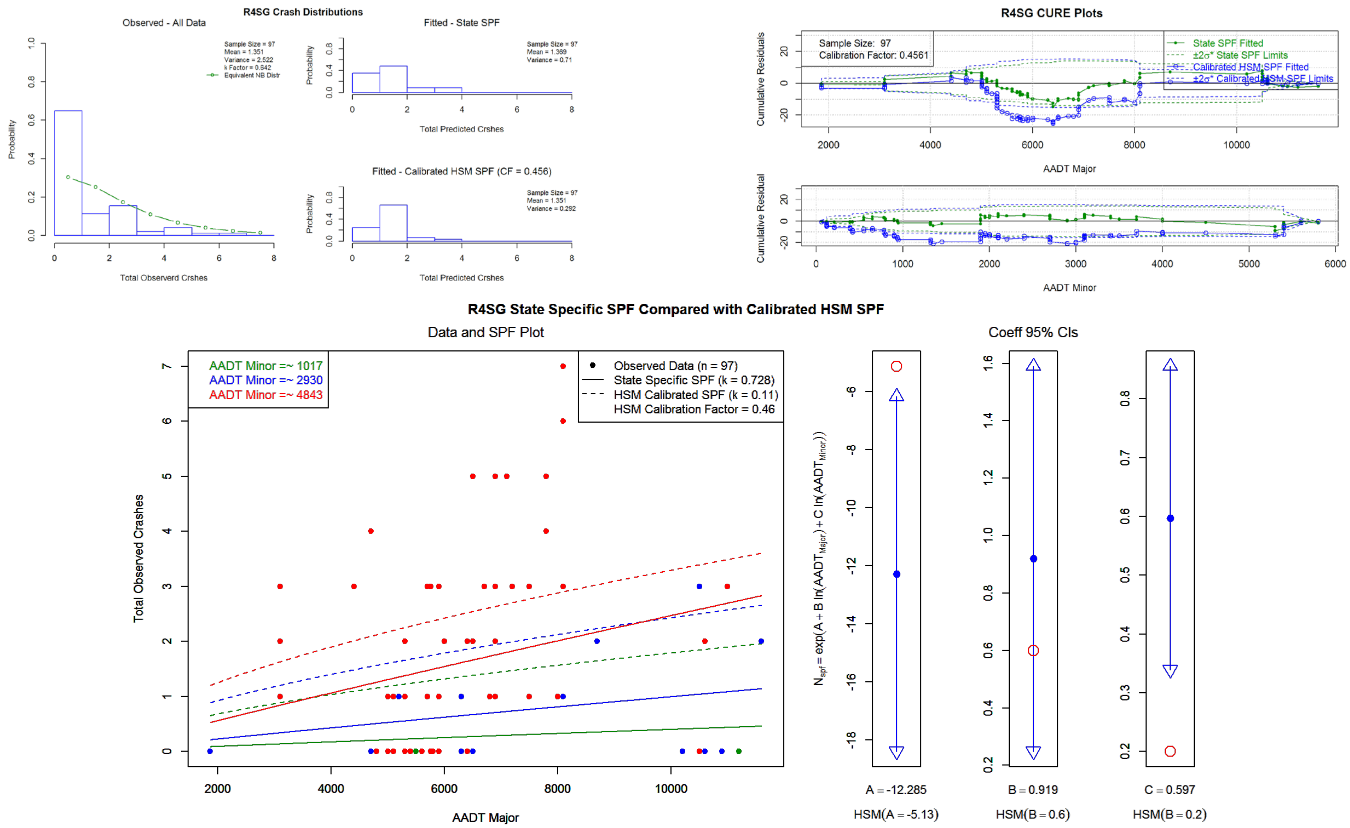


Figure 7.33 R4SG state-specific SPF summary 2013:2015

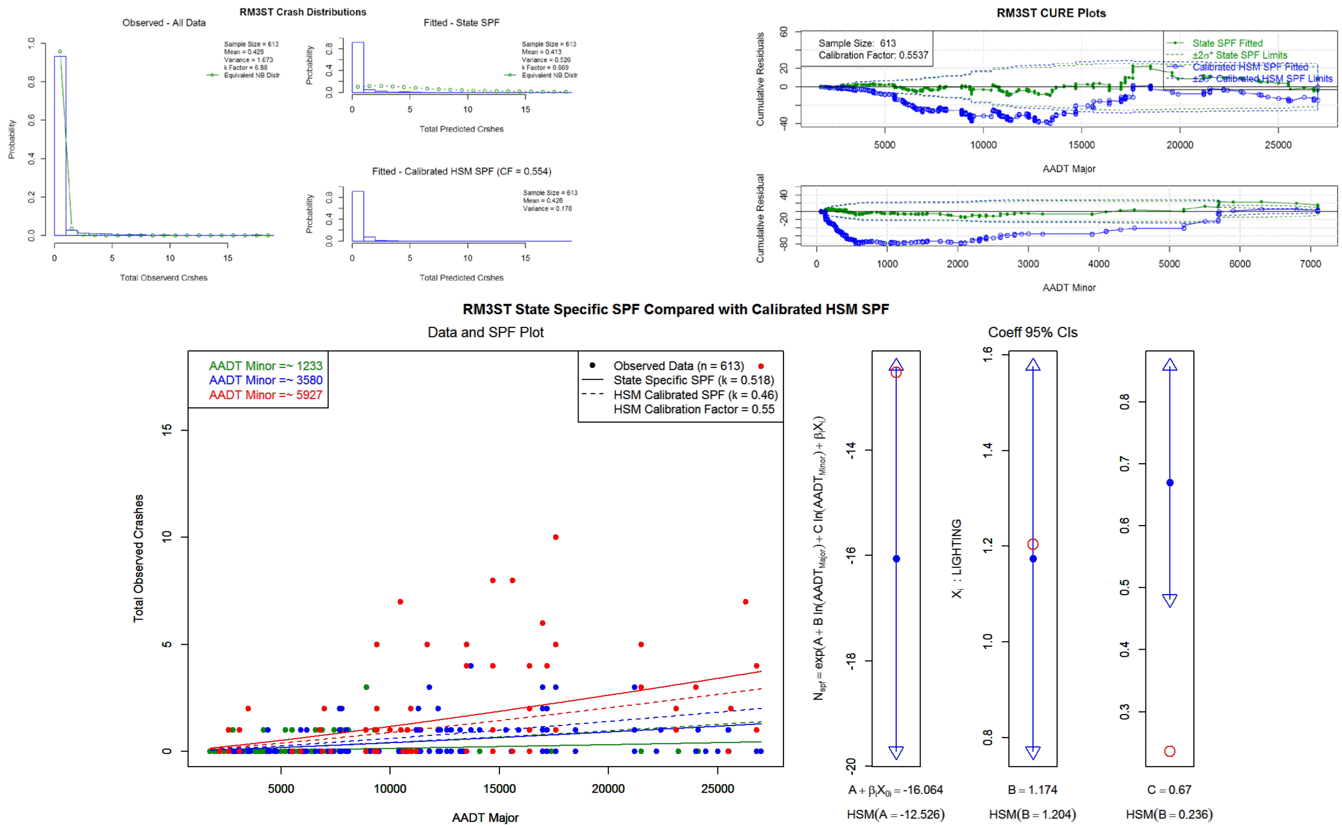


Figure 7.34 RM3ST state-specific SPF summary 2013:2015

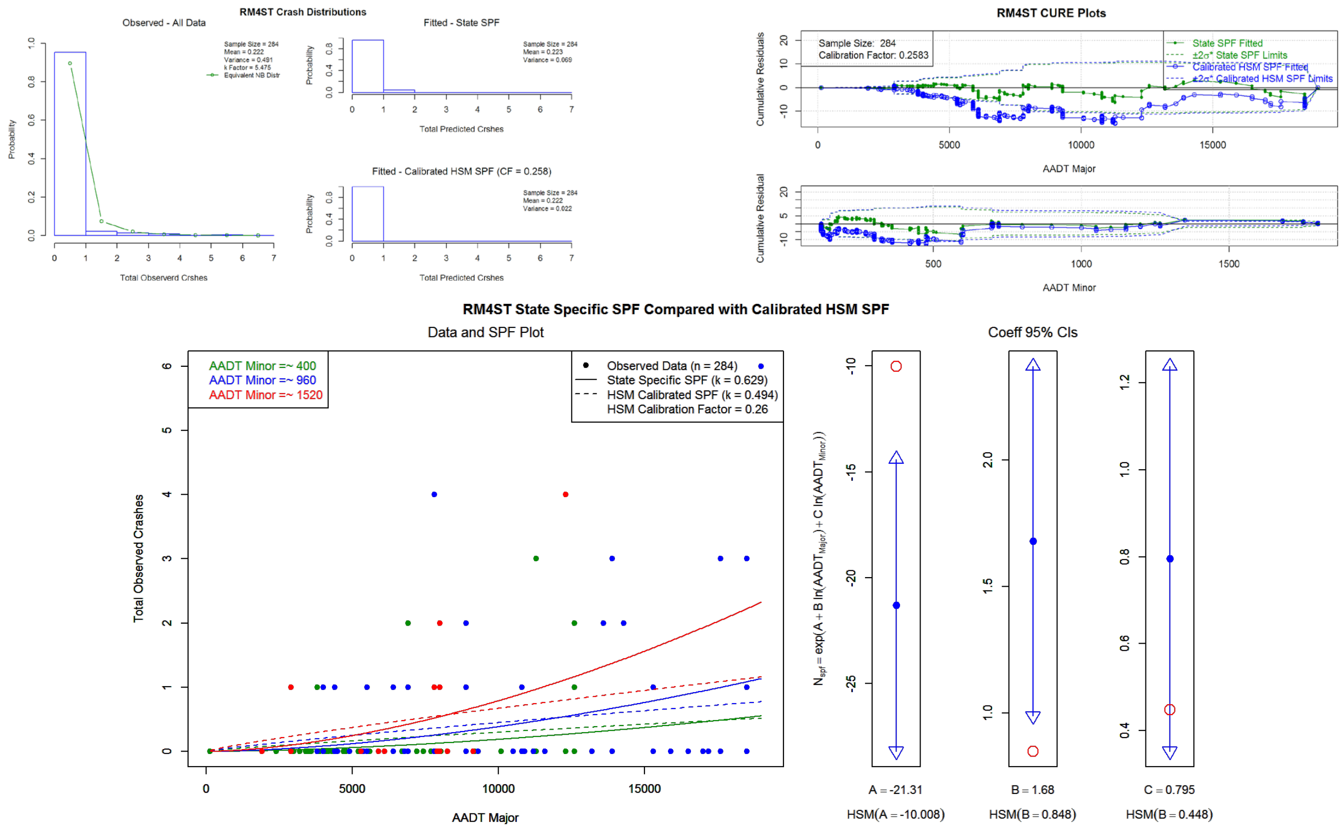


Figure 7.35 RM4ST state-specific SPF summary 2013:2015

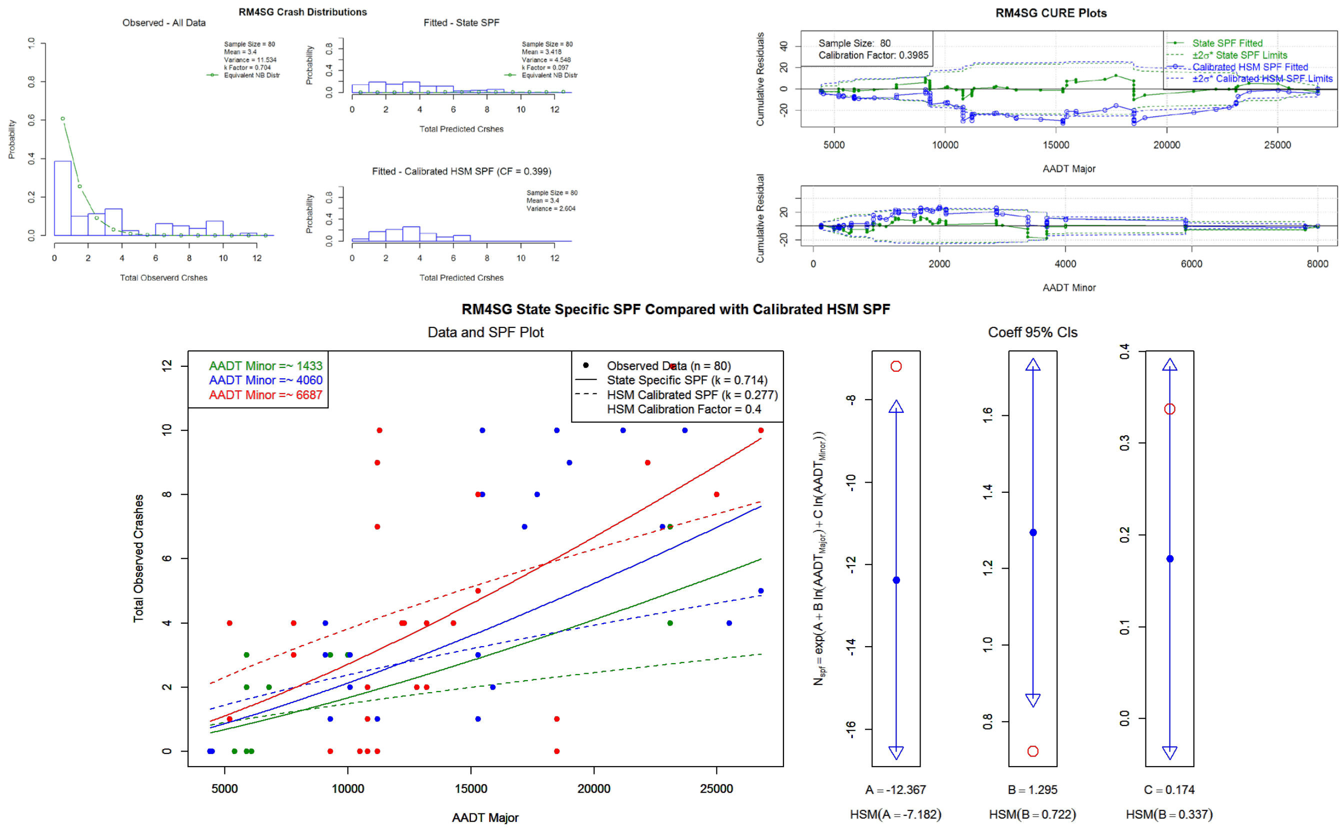


Figure 7.36 RM4SG state-specific SPF summary 2013:2015

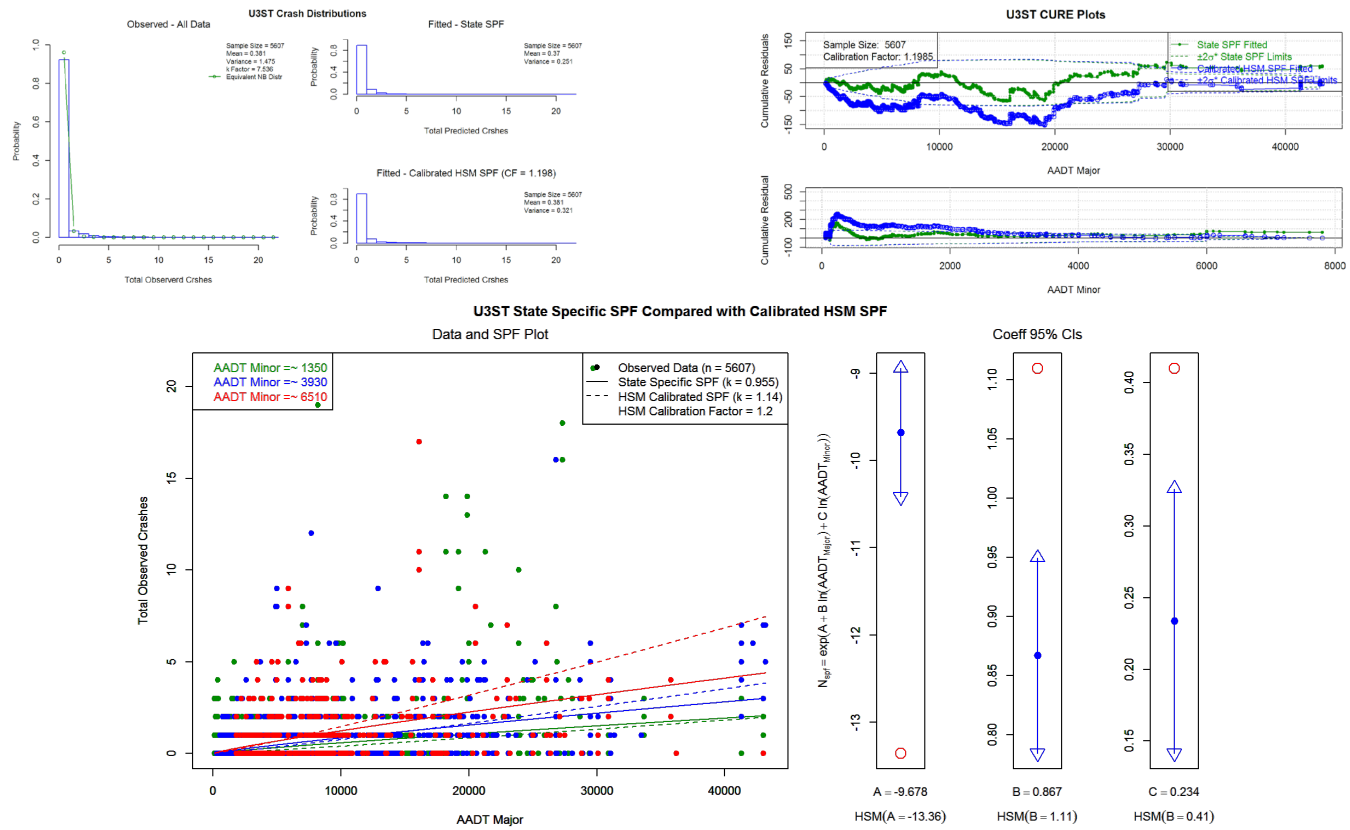


Figure 7.37 U3ST state-specific SPF summary 2013:2015

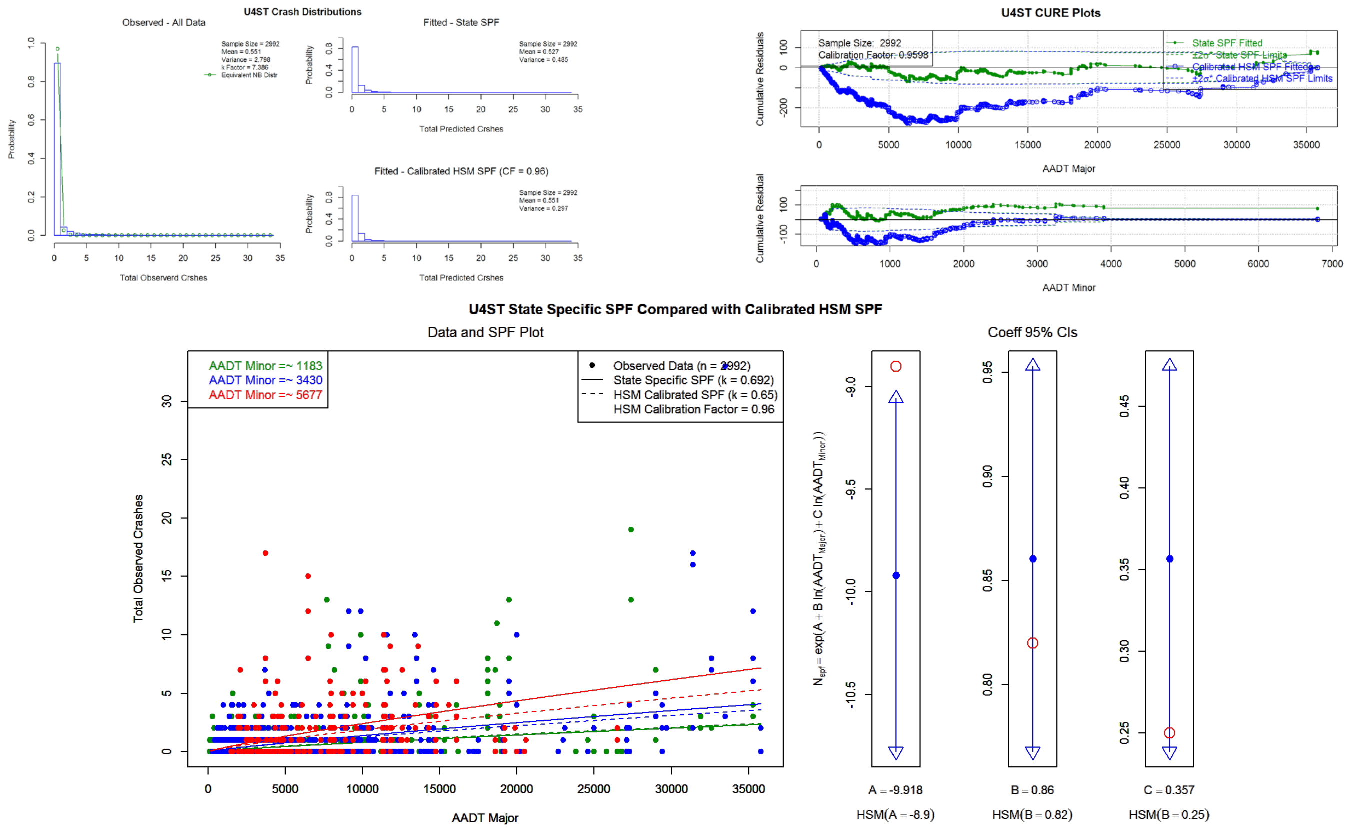


Figure 7.38 U4ST state-specific SPF summary 2013:2015

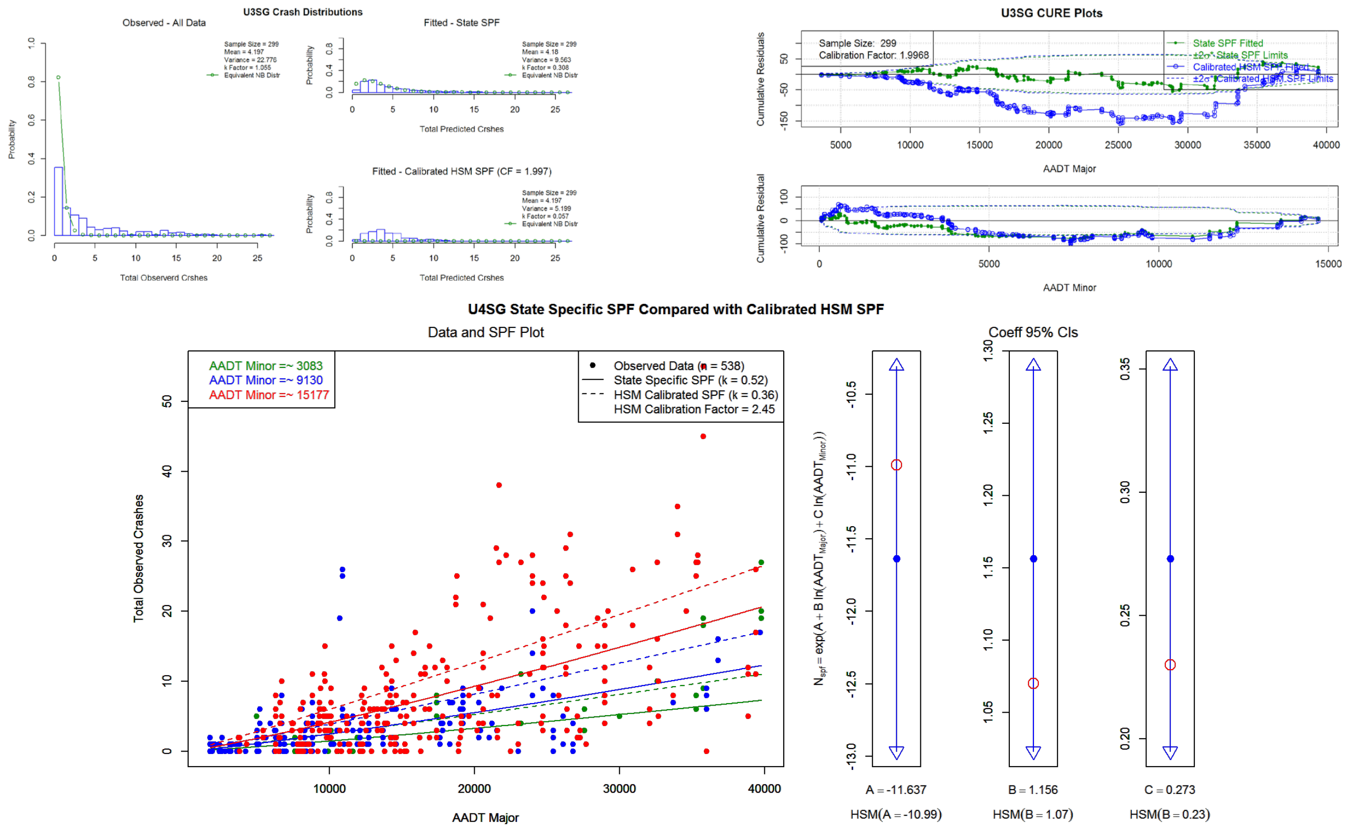


Figure 7.39 U3SG state-specific SPF summary 2013:2015

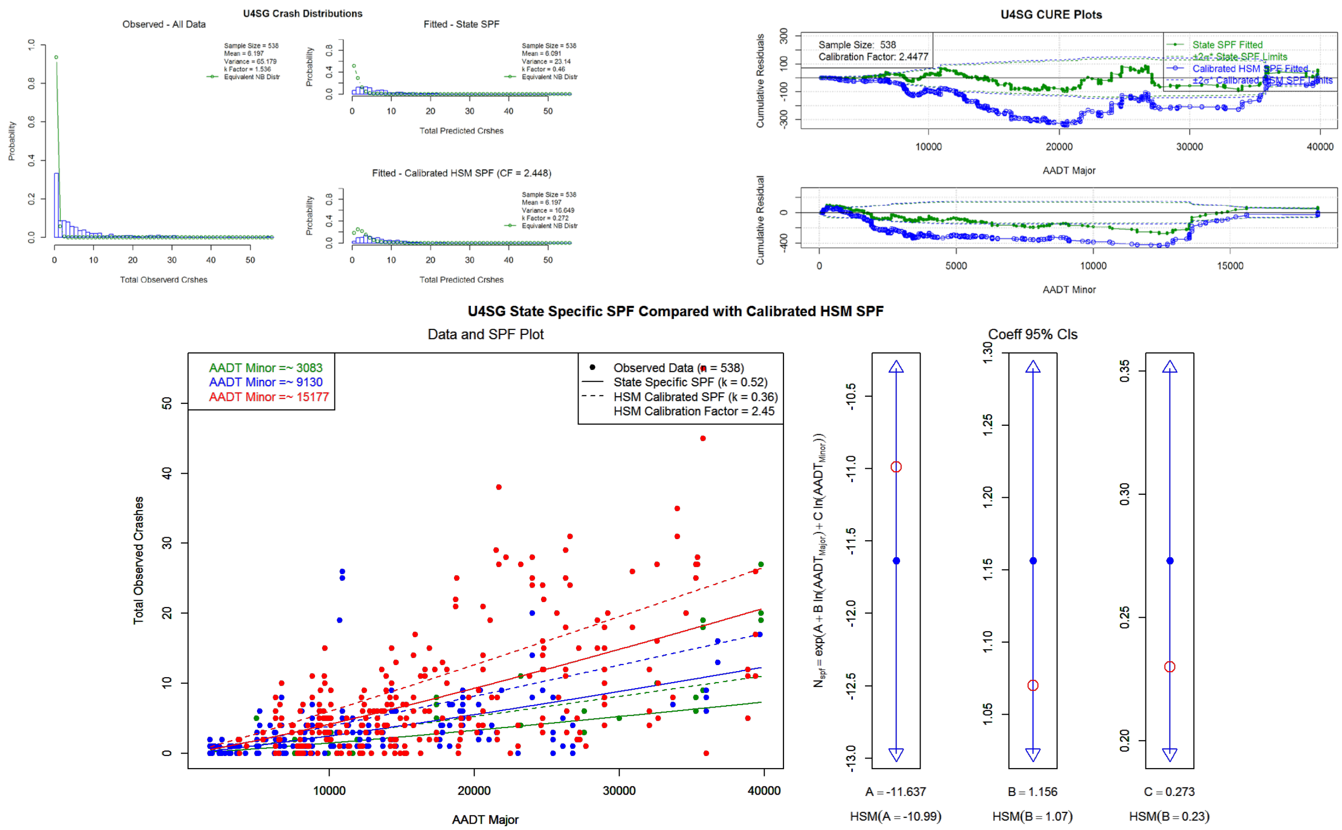


Figure 7.40 U4SG state-specific SPF summary 2013:2015

7.7 CRASH DISTRIBUTION TABLES

Table 7.10 Distribution for crash severity level on R2U segments plus locally-derived values (HSM Table 10-3)

Crash severity level	Percentage of total roadway segment crashes	
	HSM-Provided Values	Locally-Derived Values
Fatal	1.3	1.0
Incapacitating Injury	5.4	2.3
Nonincapacitating Injury	10.9	6.3
Possible Injury	14.5	26.8
Total Fatal Plus Injury	32.1	36.4
Property Damage Only	67.9	63.6
TOTAL	100.0	100.0

Note: HSM-provided crash severity data based on HSIS data for Washington (2002-2006)

Table 7.11 Default distribution by collision type for specific crash severity levels on R2U segments plus locally-derived values (HSM Table 10-4)

Collision type	Percentage of total roadway segment crashes by crash severity level					
	HSM-Provided Values			Locally-Derived Values		
	Total fatal and injury	Property damage only	TOTAL	Total fatal and injury	Property damage only	TOTAL
SINGLE-VEHICLE CRASHES						
Collision with animal	3.8	18.4	12.1	3.4	10.6	8.0
Collision with bicycle	0.4	0.1	0.2	0.7	0.1	0.3
Collision with pedestrian	0.7	0.1	0.3	1.6	0.4	0.8
Overturned	3.7	1.5	2.5	24.2	11.3	16.0
Ran off road	54.5	50.5	52.1	38.3	37.4	37.7
Other single-vehicle crash	0.7	2.9	2.1	3.1	4.3	3.8
Total single-vehicle crashes	63.8	73.5	69.3	71.2	64.1	66.7
MULTIPLE-VEHICLE CRASHES						
Angle collision	10.0	7.2	8.5	7.3	8.0	7.7
Head-on collision	3.4	0.3	1.6	3.2	0.7	1.6
Rear-end collision	16.4	12.2	14.2	10.5	14.2	12.9
Sideswipe collision	3.8	3.8	3.7	3.7	7.1	5.9
Other multiple-vehicle collision	2.6	3.0	2.7	4.1	5.9	5.3
Total multiple-vehicle crashes	36.2	26.5	30.7	28.8	35.9	33.3
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0

Note: HSM-provided values based on crash data for Washington (2002-2006); includes approximately 70 percent opposite-direction sideswipe and 30 percent same-direction sideswipe collisions.

Table 7.12 Nighttime crash proportions for unlighted R2U segments plus locally-derived values (HSM Table 10-12)

Roadway Type	HSM Default Values			Locally Derived Values		
	Proportion of total nighttime crashes by severity level		Proportion of crashes that occur at night	Proportion of total nighttime crashes by severity level		Proportion of crashes that occur at night
	Fatal and Injury pinr	PDO ppnr	pnr	Fatal and Injury pinr	PDO ppnr	pnr
2U	0.382	0.618	0.370	0.366	0.634	0.456

Note: HSM-provided values based on HSIS data for Washington (2002-2006)

Table 7.13 Default distribution for crash severity level at rural two-lane two-way intersections plus locally-derived values (HSM Table 10-5)

Collision type	Percentage of total crashes					
	HSM-Provided Values			Locally-Derived Values		
	R3ST	R4ST	R4SG	R3ST	R4ST	R4SG
Fatal	1.7	1.8	0.9	1.3	2.1	0.2
Incapacitating injury	4.0	4.3	2.1	2.8	4.1	2.9
Nonincapacitating injury	16.6	16.2	10.5	7.2	9.7	7.0
Possible injury	19.2	20.8	20.5	21.7	20.9	13.5
Total fatal plus injury	41.5	43.1	34.0	33.0	36.8	23.6
Property damage only	58.5	56.9	66.0	67.0	63.2	76.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Note: HSM-Provided values based on HSIS data for California (2002-2006)

Table 7.14 Default Distribution for Collision Type and Manner of Collision at Rural Two-Way Intersections plus Locally-Derived Values (HSM Table 10-6)

Collision type	Percentage of total crashes by collision type (HSM Default Values)									Percentage of total crashes by collision type (Locally Derived Values)								
	R3ST			R4ST			R4SG			R3ST			R4ST			R4SG		
	Fatal and Injury	PDO	Total	Fatal and injury	PDO	Total	Fatal and injury	PDO	Total	Fatal and Injury	PDO	Total	Fatal and injury	PDO	Total	Fatal and injury	PDO	Total
SINGLE-VEHICLE CRASHES										SINGLE-VEHICLE CRASHES								
Collision with animal	0.8	2.6	1.9	0.6	1.4	1.0	0.0	0.3	0.2	0.9	3.5	2.6	0.7	1.7	1.4	0.8	0.4	0.5
Collision with bicycle	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.6	0.0	0.2	0.5	0.1	0.2	0.0	0.0	0.0
Collision with pedestrian	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1	0.2	0.5	0.9	0.0	0.4	2.2	0.0	0.5
Overturned	2.2	0.7	1.3	0.6	0.4	0.5	0.3	0.3	0.3	9.8	4.3	6.1	3.7	2.0	2.7	2.2	1.0	1.3
Ran off road	24.0	24.7	24.4	9.4	14.4	12.2	3.2	8.1	6.4	24.6	26.7	26.0	8.6	11.5	10.4	3.2	3.8	3.7
Other single-vehicle crash	1.1	2.0	1.6	0.4	1.0	0.8	0.3	1.8	0.5	2.6	3.2	3.1	1.3	2.3	1.9	1.7	2.1	2.0
Total single-vehicle crashes	28.3	30.2	29.4	11.2	17.4	14.7	4.0	10.7	7.6	39.6	37.9	38.4	15.7	17.6	16.9	10.2	7.3	8.0
MULTIPLE-VEHICLE CRASHES										MULTIPLE-VEHICLE CRASHES								
Angle collision	27.5	21.0	23.7	53.2	35.4	43.1	33.6	24.2	27.4	29.0	23.1	25.1	65.5	51.3	56.5	61.9	36.1	42.2
Head-on collision	8.1	3.2	5.2	6.0	2.5	4.0	8.0	4.0	5.4	4.3	1.2	2.2	2.7	1.3	1.8	2.1	2.0	2.1
Rear-end collision	26.0	29.2	27.8	21.0	26.6	24.2	40.3	43.8	42.6	21.2	26.3	24.6	12.0	18.8	16.3	24.0	40.5	36.6

Sideswipe collision	5.1	13.1	9.7	4.4	14.4	10.1	5.1	15.3	11.8	3.2	5.9	5.0	1.9	4.5	3.5	0.9	6.8	5.4
Other multiple-vehicle collision	5.0	3.3	4.2	4.2	3.7	3.9	9.0	2.0	5.2	2.7	5.6	4.6	2.3	6.5	4.9	0.8	7.2	5.7
Total multiple-vehicle crashes	71.7	69.8	70.6	88.8	82.6	85.3	96.0	89.3	92.4	60.4	62.1	61.6	84.3	82.4	83.1	89.8	92.7	92.0
TOTAL CRASHES	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note: HSM-Provided values based on HSIS data for California (2002-2006)

Table 7.15 Nighttime crash proportions for unlighted intersections (HSM Table 10-15)

Intersection Type	Proportion of crashes that occur at night, pni	
	HSM Provided Values	Locally-Derived Values
3ST	0.260	0.404
4ST	0.244	0.430
4SG	0.286	0.251

Note: HSM-Provided values based on HSIS data for California (2002-2006)

Table 7.16 Distribution of Crashes by Collision Type and Crash Severity Level for R4U (HSM Table 11-4)

Collision type	Proportion of crashes by collision type and crash severity level							
	HSM-Provided Values				Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.009	0.029	0.043	0.001	0.004	0.016	0.000	0.000
Sideswipe	0.098	0.048	0.044	0.120	0.149	0.080	0.196	0.178
Rear-end	0.246	0.305	0.217	0.220	0.282	0.327	0.350	0.259
Angle	0.356	0.352	0.348	0.358	0.268	0.241	0.350	0.281
Single	0.238	0.238	0.304	0.237	0.262	0.301	0.104	0.245
Other	0.053	0.028	0.044	0.064	0.034	0.036	0.000	0.037

NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Table 7.17 Distribution of Crashes by Collision Type and Crash Severity Level for R4D (HSM Table 11-6)

Collision type	Proportion of crashes by collision type and crash severity level							
	HSM-Provided Values				Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO	Total	Fatal and injury	Fatal and injury [a]	PDO
Head-on	0.006	0.013	0.018	0.002	0.007	0.017	0.034	0.003
Sideswipe	0.043	0.027	0.022	0.053	0.116	0.062	0.067	0.133
Rear-end	0.116	0.163	0.114	0.088	0.258	0.263	0.342	0.256
Angle	0.043	0.048	0.045	0.041	0.081	0.106	0.140	0.073
Single	0.768	0.727	0.778	0.792	0.461	0.497	0.365	0.449
Other	0.024	0.022	0.023	0.024	0.079	0.054	0.051	0.086

NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Table 7.18 Night-time crash proportions for unlighted R4U and R4D (HSM Tables 11-15 and 11-19)

Roadway Type	HSM-Provided Values			Locally-Derived Values		
	Proportion of total night-time crashes by severity level		Proportion of crashes that occur at night	Proportion of total night-time crashes by severity level		Proportion of crashes that occur at night
	Fatal and injury, pinr	PDO, ppnr	pnr	Fatal and injury, pinr	PDO, ppnr	pnr
4U	0.361	0.639	0.255	0.300	0.700	0.342
4D	0.323	0.677	0.426	0.251	0.749	0.345

Table 7.19 Distribution of intersection crashes by collision type and crash severity (HSM Table 11-9)

Collision type	Proportion of crashes by collision type and crash severity level							
	HSM-Provided Values				Locally-Derived Values			
	Total	Fatal and injury	Fatal and injury [a]	PDO	Total	Fatal and injury	Fatal and injury [a]	PDO
RM3ST								
Head-on	0.029	0.043	0.052	0.020	0.011	0.025	0.040	0.005
Sideswipe	0.133	0.058	0.057	0.179	0.099	0.040	0.030	0.125
Rear-end	0.289	0.247	0.142	0.315	0.248	0.219	0.263	0.260
Angle	0.263	0.369	0.381	0.198	0.365	0.443	0.551	0.330
Single	0.234	0.219	0.284	0.244	0.229	0.236	0.077	0.227
Other	0.052	0.064	0.084	0.044	0.048	0.036	0.039	0.053
RM4ST								
Head-on	0.016	0.018	0.023	0.015	0.009	0.010	0.011	0.008
Sideswipe	0.107	0.042	0.040	0.156	0.054	0.026	0.023	0.070
Rear-end	0.228	0.213	0.108	0.240	0.176	0.139	0.092	0.197
Angle	0.395	0.534	0.571	0.292	0.477	0.599	0.746	0.406
Single	0.202	0.148	0.199	0.243	0.237	0.208	0.098	0.253
Other	0.052	0.045	0.059	0.054	0.047	0.018	0.029	0.066
RM4SG								
Head-on	0.054	0.083	0.093	0.034	0.017	0.037	0.053	0.009
Sideswipe	0.106	0.047	0.039	0.147	0.083	0.034	0.022	0.100
Rear-end	0.492	0.472	0.314	0.505	0.397	0.295	0.202	0.434
Angle	0.256	0.315	0.407	0.215	0.408	0.528	0.698	0.365
Single	0.062	0.041	0.078	0.077	0.059	0.089	0.010	0.047
Other	0.030	0.042	0.069	0.022	0.037	0.016	0.014	0.045

NOTE: [a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Table 7.20 Distribution of multiple-vehicle nondriveway collisions for roadway segments by manner of collision type (HSM Table 12-4)

Collision type	Proportion of crashes by severity level for specific road types									
	HSM-Provided Values									
	U2U		U3T		U4U		U4D		U5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.730	0.778	0.845	0.842	0.511	0.506	0.832	0.662	0.846	0.651
Head-on collision	0.068	0.004	0.034	0.020	0.077	0.004	0.020	0.007	0.021	0.004
Angle collision	0.085	0.079	0.069	0.020	0.181	0.130	0.040	0.036	0.050	0.059
Sideswipe, same direction	0.015	0.031	0.001	0.078	0.093	0.249	0.050	0.223	0.061	0.248
Sideswipe, opposite direction	0.073	0.055	0.017	0.020	0.082	0.031	0.010	0.001	0.004	0.009
Other multiple-vehicle collision	0.029	0.053	0.034	0.020	0.056	0.080	0.048	0.071	0.018	0.029
Collision type	Locally-Derived Values									
	U2U		U3T		U4U		U4D		U5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.534	0.557	0.526	0.549	0.495	0.475	0.707	0.652	0.531	0.542
Head-on collision	0.076	0.017	0.059	0.011	0.048	0.016	0.023	0.006	0.035	0.010
Angle collision	0.237	0.205	0.333	0.289	0.311	0.244	0.139	0.095	0.342	0.259
Sideswipe, same direction	0.029	0.059	0.028	0.097	0.071	0.198	0.077	0.176	0.059	0.152
Sideswipe, opposite direction	0.057	0.060	0.017	0.014	0.015	0.015	0.005	0.004	0.008	0.007
Other multiple-vehicle collision	0.067	0.102	0.038	0.039	0.059	0.053	0.050	0.068	0.025	0.030

Note: HSM-Provided values based on HSIS data for Washington (2002-2006)

Table 7.21 Distribution of single-vehicle collisions for roadway segments by collision type (Table 12-6)

Collision type	Proportion of crashes by severity level for specific road types									
	HSM-Provided Values									
	U2U		U3T		U4U		U4D		U5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with animal	0.026	0.066	0.001	0.001	0.001	0.001	0.001	0.063	0.016	0.049
Collision with fixed object	0.723	0.759	0.688	0.963	0.612	0.809	0.500	0.813	0.398	0.768
Collision with other object	0.010	0.013	0.001	0.001	0.020	0.029	0.028	0.016	0.005	0.061
Other single-vehicle collision	0.241	0.162	0.310	0.035	0.367	0.161	0.471	0.108	0.581	0.122
Collision type	Locally-Derived Values									
	U2U		U3T		U4U		U4D		U5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with animal	0.024	0.082	0.042	0.133	0.034	0.077	0.023	0.114	0.031	0.183
Collision with fixed object	0.586	0.687	0.519	0.684	0.411	0.575	0.505	0.698	0.401	0.586
Collision with other object	0.138	0.129	0.154	0.099	0.425	0.294	0.131	0.091	0.318	0.153
Other single-vehicle collision	0.252	0.102	0.284	0.084	0.130	0.054	0.341	0.097	0.250	0.078

Source: HSIS data for Washington (2002-2006)

Table 7.22 Proportion of Fixed-Object Collisions (HSM Table 12-21)

Road Type	HSM-Provided Values	Locally-Derived Values
	Proportion of Fixed-Object Collisions (p_{fo})	Proportion of Fixed-Object Collisions (p_{fo})
U2U	0.059	0.346
U3T	0.034	0.122
U4U	0.037	0.121
U4D	0.036	0.216
U5T	0.016	0.076

Table 7.23 Nighttime crash proportions for unlighted roadway segments (HSM Table 12-23)

Road Type	HSM-Provided Values			Locally-Derived Values		
	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury (p_{inr})	PDO (p_{pnr})	(p_{nr})	Fatal and Injury (p_{inr})	PDO (p_{pnr})	(p_{nr})
U2U	0.424	0.576	0.316	0.305	0.695	0.363
U3T	0.429	0.571	0.304	0.254	0.746	0.247
U4U	0.517	0.483	0.365	0.306	0.694	0.248
U4D	0.364	0.636	0.410	0.241	0.759	0.265
U5T	0.432	0.568	0.274	0.268	0.732	0.229

Table 7.24 distribution of multiple-vehicle collisions for intersections by collision type (HSM Table 12-11)

Collision type	Proportion of crashes by severity level for specific intersection types							
	HSM-Provided Values							
	U3ST		U3SG		U4ST		U4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.421	0.440	0.549	0.546	0.338	0.374	0.450	0.483
Head-on collision	0.045	0.023	0.038	0.020	0.041	0.030	0.049	0.030
Angle collision	0.343	0.262	0.280	0.204	0.440	0.335	0.347	0.244
Sideswipe	0.126	0.040	0.076	0.032	0.121	0.044	0.099	0.032
Other multiple-vehicle collision	0.065	0.235	0.057	0.198	0.060	0.217	0.055	0.211
Collision type	Locally-Derived Values							
	U3ST		U3SG		U4ST		U4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.398	0.433	0.427	0.530	0.203	0.290	0.379	0.484
Head-on collision	0.050	0.016	0.043	0.015	0.049	0.024	0.044	0.015
Angle collision	0.462	0.369	0.472	0.304	0.681	0.536	0.520	0.347
Sideswipe	0.053	0.114	0.041	0.112	0.037	0.093	0.039	0.113
Other multiple-vehicle collision	0.037	0.068	0.017	0.039	0.030	0.057	0.018	0.041

Note: HSM-Provided values based on HSIS data for California (2002-2006)

Table 7.25 distribution of single-vehicle crashes for intersections by collision type (HSM Table 12-13)

Collision type	Proportion of crashes by severity level for specific intersection types							
	HSM-Provided Values							
	U3ST		U3SG		U4ST		U4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with parked vehicle	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001
Collision with animal	0.003	0.018	0.001	0.003	0.001	0.026	0.002	0.002
Collision with fixed object	0.762	0.834	0.653	0.895	0.679	0.847	0.744	0.870
Collision with other object	0.090	0.092	0.091	0.069	0.089	0.070	0.072	0.070
Other single-vehicle collision	0.039	0.023	0.045	0.018	0.051	0.007	0.040	0.023
Noncollision	0.105	0.030	0.209	0.014	0.179	0.049	0.141	0.034
Collision type	Locally-Derived Values							
	U3ST		U3SG		U4ST		U4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with parked vehicle	0.037	0.160	0.030	0.130	0.048	0.244	0.036	0.174
Collision with animal	0.009	0.055	0.005	0.062	0.007	0.029	0.004	0.029
Collision with fixed object	0.533	0.674	0.337	0.639	0.464	0.611	0.325	0.621
Collision with other object	0.221	0.039	0.409	0.080	0.298	0.048	0.431	0.078
Other single-vehicle collision	0.007	0.009	0.002	0.020	0.008	0.017	0.019	0.033
Noncollision	0.193	0.062	0.216	0.069	0.174	0.050	0.185	0.066

Source: HSM-Provided values base on HSIS data for California (2002-2006)

Table 7.26 Nighttime Crash Proportions for Unlighted Intersections (HSM Table 12-27)

Intersection Type	Proportion of crashes that occur at night, p_{ni}	
	HSM-Provided Values	Locally-Derived Values
U3ST	0.238	0.285
U4ST	0.229	0.254
U3SG	0.235	0.258
U4SG	0.235	0.250

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