RESEARCH & DEVELOPMENT

NCDOT 2016-09: Updated and Regional Calibration Factors for Highway Safety Manual Crash Prediction Models

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Final Report

UPDATED AND REGIONAL CALIBRATON FACTORS FOR HIGHWAY SAFETY MANUAL CRASH PREDICTION MODELS

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16. Abstract

The overall objective was to estimate the calibration factors for all the prediction models in Part C of the 1st edition of the HSM that are of interest to NCDOT as well as calibration factors for freeway models that are slated to be part of the next HSM based on the latest six years of roadway, traffic, and crash data from North Carolina. For some of the models, separate calibration factors were developed for the three different regions in North Carolina (Coast, Mountain, and Piedmont). The project also produced state-specific crash type proportions to be used along with the calibration factors. For rural two lane roads, calibration functions were also estimated. Roadway and crash data from 2010 to 2015 were used in this effort.

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EXECUTIVE SUMMARY

It is clear that one of the objectives of state agencies is to reduce the number and severity of crashes within the limits of available resources, science, technology, and legislatively mandated priorities. In order to achieve the greatest return on the investment of limited budgets, it is imperative that decisions are made based on the best information regarding the safety implications of various design alternatives and engineering treatments. The Highway Safety Manual (HSM), developed through funding from the American Association of State and Highway Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) provides analytical tools and techniques for quantifying the safety effects of decisions made in planning, design, operations, and maintenance.

In order to be able to use the advanced tools in the HSM, it is necessary for each jurisdiction to employ crash prediction models (also called safety performance functions, SPFs) that relate crash frequency and severity to roadway characteristics for different types of facilities. The HSM does not recommend using the SPFs directly from the HSM without calibration because the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including climate, driver populations, animal populations, accident reporting thresholds, and crash report system procedures. Two previous NCDOT projects (2009-07 and 2010-09) produced North Carolina-specific calibration factors for the prediction models from Part C of the 1st edition of the HSM. This effort aims to update these previous efforts as well as including new models which have not yet had calibration factors estimated. Results are shown in the following tables. Factors that are based on the HSM desired sample size of at least 100 observed crashes per year are indicated in *bold italics*. In these tables, 2U represent two-lane undivided roads, 4U represents four-lane undivided roads, 4D represents four-lane divided roads, 3T represents roads with two through lanes and a center TWLTL, and 5T represents roads with four through lanes with a center TWLTL. For freeways, MV,FI represents multiple-vehicle fatal and injury, SV,FI represents single-vehicle fatal and injury, MV,PDO represents multiple-vehicle PDO, and SV,PDO represents single-vehicle PDO. For intersections, 3ST represents 3-leg intersections with a stop sign on the minor leg, 4ST represents 4-leg intersections with a stop sign on the minor legs, 3SG represents 3-leg signalized intersections, and 4SG represents 4-leg signalized intersections.

Calibration Factors for Segment Facility Types

Segment Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 2U – Coast	***1.93***	***1.81***	***1.66***	***1.77***	***1.80***	***1.73***	***1.78***
Rural 2U – Mountain	***0.79***	***0.67***	***0.82***	***0.82***	***0.80***	***0.80***	***0.78***
Rural 2U – Piedmont	***1.34***	***1.09***	***1.31***	***1.19***	***1.16***	***1.17***	***1.21***
Rural 2U – Total	***1.15***	***0.99***	***1.11***	***1.10***	***1.09***	***1.08***	***1.09***
Rural 4D – Coast	***1.36***	***1.26***	***1.10***	***1.40***	***1.34***	***1.17***	***1.27***
Rural 4D – Mountain	***0.83***	***0.67***	***0.72***	***0.82***	***0.83***	***0.79***	***0.78***
Rural 4D – Piedmont	***0.93***	***0.73***	***0.76***	***0.97***	***0.74***	***0.86***	***0.83***
Rural 4D – Total	***1.02***	***0.86***	***0.84***	***0.97***	***0.95***	***0.93***	***0.93***
Urban 2U	1.21	1.07	1.19	1.03	1.20	***1.34***	1.17
Urban 3T	1.56	1.31	***1.62***	1.48	***1.75***	***1.56***	1.55
Urban 4U	2.66	1.60	2.43	2.09	2.01	2.73	2.25
Urban 4D	1.69	1.58	***2.01***	***2.41***	***2.54***	***2.63***	***2.14***
Urban 5T	***1.37***	***1.46***	***1.29***	***1.63***	***1.35***	***1.30***	***1.40***
Rural Frwy – 4ln MV,FI	***1.20***	***1.48***	***1.21***	***0.99***	***1.18***	***1.67***	***1.29***
Rural Frwy – 4ln SV,FI	***0.77***	***0.87***	***0.58***	***0.70***	***0.34***	***0.64***	***0.65***
Rural Frwy – 4ln MV,PDO	***1.49***	***2.05***	***1.42***	***1.98***	***1.02***	***1.45***	***1.57***
Rural Frwy – 4ln SV,PDO	***1.91***	***1.54***	***1.33***	***1.26***	***1.58***	***1.30***	***1.48***
Urban Frwy – 4ln MV,FI	0.79	1.19	0.36	0.78	0.88	***0.75***	0.79
Urban Frwy – 4ln SV,FI	0.73	0.49	0.43	0.43	0.55	***0.91***	0.59

Segment Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Urban Frwy – 4ln MV,PDO	0.64	0.75	0.79	0.76	1.00	***1.10***	0.84
Urban Frwy – 4ln SV,PDO	0.71	0.61	0.59	0.59	0.63	***1.01***	0.69
Urban Frwy – 6ln MV,FI	***0.51***	***0.71***	***0.85***	***0.85***	***0.52***	***1.22***	***0.78***
Urban Frwy – 6ln SV,FI	***0.85***	***0.48***	***0.96***	***0.76***	***0.92***	***1.08***	***0.84***
Urban Frwy – 6ln MV,PDO	***0.74***	***0.70***	***0.64***	***0.68***	***0.65***	***1.30***	***0.78***
Urban Frwy – 6ln SV,PDO	***0.88***	***0.92***	***1.20***	***1.27***	***1.20***	***1.51***	***1.16***
Urban Frwy – 8ln MV,FI	***0.97***	0.72	0.31	0.46	0.51	***0.56***	0.59
Urban Frwy – 8ln SV,FI	***1.07***	0.66	0.24	0.57	0.48	***0.88***	0.65
Urban Frwy – 8ln MV,PDO	***1.03***	0.65	0.45	0.41	0.84	***1.16***	0.76
Urban Frwy – 8ln SV,PDO	***1.15***	0.62	0.85	0.85	0.54	***1.11***	0.86

Calibration Factors for Rural Two-Lane Undivided Intersections

Intersection Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 2U 3ST – Coast	0.41	0.51	0.42	0.45	0.64	0.61	0.51
Rural 2U 3ST – Mountain	0.61	0.76	0.77	0.60	0.61	0.80	0.69

Intersection Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 2U 3ST – Piedmont	0.60	0.49	0.60	0.53	0.47	0.63	0.55
Rural 2U 3ST – Total	***0.58***	***0.56***	***0.61***	***0.53***	***0.53***	***0.67***	***0.58***
Rural 2U 4SG – Coast	0.85	0.86	0.87	1.03	***1.05***	***1.25***	0.99
Rural 2U 4SG – Mountain	0.62	0.75	0.63	0.60	0.52	0.67	0.63
Rural 2U 4SG – Piedmont	***0.68***	***0.67***	***0.60***	***0.71***	***0.73***	***0.86***	***0.71***
Rural 2U 4SG – Total	***0.71***	***0.73***	***0.68***	***0.78***	***0.78***	***0.93***	***0.77***
Rural 2U 4ST – Coast	0.53	0.58	0.58	0.73	0.67	***0.80***	0.65
Rural 2U 4ST – Mountain	0.63	0.59	0.59	0.34	0.49	0.39	0.50
Rural 2U 4ST – Piedmont	***0.70***	0.59	0.60	0.62	0.66	***0.85***	0.67
Rural 2U 4ST – Total	***0.62***	***0.58***	***0.59***	***0.61***	***0.63***	***0.75***	***0.63***

Calibration Factors for Rural Multilane and Urban Arterial Intersections

Intersection Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 4-lane – 3ST	0.19	0.20	0.42	0.31	0.56	0.47	0.36
Rural 4-lane – 4SG	***0.34***	***0.45***	***0.36***	***0.41***	***0.42***	***0.45***	***0.41***
Rural 4-lane – 4ST	1.32	1.38	1.30	1.37	1.84	1.45	1.44
Urban – 3ST	1.88	1.67	1.81	1.46	1.27	1.56	1.61
Urban – 3SG	***2.03***	***2.11***	***2.06***	***2.13***	***2.17***	***2.53***	***2.17***
Urban – 4ST	1.79	1.98	1.60	1.50	1.81	***2.06***	1.79
Urban – 4SG	***3.03***	***2.98***	***2.92***	***2.93***	***3.10***	***3.46***	***3.07***

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Introduction

Background

It is clear that one of the objectives of state agencies is to reduce the number and severity of crashes within the limits of available resources, science, technology, and legislatively mandated priorities. In order to achieve the greatest return on the investment of limited budgets, it is imperative that decisions are made based on the best information regarding the safety implications of various design alternatives and engineering treatments. The Highway Safety Manual (HSM), developed through funding from the American Association of State and Highway Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) provides analytical tools and techniques for quantifying the safety effects of decisions made in planning, design, operations, and maintenance.

Purpose and Scope

In order to be able to use the advanced tools in the HSM, it is necessary for each jurisdiction to employ crash prediction models (also called safety performance functions, SPFs) that relate crash frequency and severity to roadway characteristics for different types of facilities. The HSM does not recommend using the SPFs directly from the HSM without calibration because the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including climate, driver populations, animal populations, accident reporting thresholds, and accident report system procedures. Three previous NCDOT projects (2009-06, 2009-07, and 2010-09) produced North Carolina-specific calibration factors for the prediction models from Part C of the 1st edition of the HSM.

These calibration factors have been extensively used by the NCDOT Traffic Safety Unit (TSU) as part of their decision making process, but they are based on data that is now over five years old. The HSM recommends that these calibration factors be updated every three years. The TSU has been utilizing the HSM methodologies (and calibration factors) over the past three years in analyzing alternatives for TIP projects from a safety perspective. They expect the demand for this type of analysis to continue to increase as the Department increasingly emphasizes the need for data-driven decisions.

In addition, the TSU desires to have separate calibration factors for the three different regions in North Carolina (Coast, Mountain, and Piedmont) to properly account for differences in terrain, climate, and driver population. The previous research effort found large differences between these regions in the preliminary calibration factors, however, the sample sizes were too small to develop final calibration factors. This effort aimed at increasing the sample size for some of these regional areas to produce reliable regional calibration factors.

Research Objectives

The overall objective was to estimate the calibration factors for all the prediction models in Part C of the 1st edition of the HSM that are of interest to NCDOT as well as calibration factors for freeway models that are slated to be part of the 2nd edition of the HSM. The calibration analysis was based on the latest six years of roadway, traffic, and crash data from North Carolina. For some of the models, the researchers developed separate calibration factors for the three different regions in North Carolina (Coast, Mountain, and Piedmont). The project also produced state-specific crash type proportions to be used along with the calibration factors. In addition, the researchers estimated calibration functions for selected facility types, and these are discussed in Appendix A.

Organization of the Report

The following sections are included in this report

Results of Literature Review

This section gives an overview of the HSM including the prediction methodology, and previous NCDOT projects where various researchers produced North Carolina-specific calibration factors.

Calibration of the HSM Prediction Models

This section gives an overview of the HSM prediction model calibration procedure and the data elements necessary to produce calibration factors specific to North Carolina.

Findings and Conclusions

This section discusses the results and findings of the calibration factors developed in this effort. The researchers estimated calibration factors for seven segment facility types, ten intersection facility types, and four freeway facility types.

Recommendations

This section gives an overview of recommendations for future efforts.

Result of Literature Review

Highway Safety Manual

The AASHTO Highway Safety Manual (HSM) was published in 2010 as a groundbreaking resource for highway safety professionals. It consists of four parts:

Part A gives an overview of the HSM along with describing its scope and purpose. An overview of human factors principles is also provided along with the fundamentals that are required to understand the new approaches that are described in the HSM.

Part B presents the steps that can be used to monitor, improve, and maintain safety on an existing safety network. It includes methods for identifying improvement sites, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation.

Part C contains analytical methods, predictive models, and algorithms that can be used to estimate the safety performance at existing sites, predict the future safety performance of existing sites and predict the safety effects of alternative roadway design improvements. For roadway sections, SPFs are presented for:

- Rural two lane roads
- Rural four-lane divided and undivided roads
- Two lane, three lane, four lane divided, four lane undivided, and five lane roads in urban and suburban arterials

For intersections, predictive models are presented for:

- Three and four leg stop controlled and four leg signalized intersections on rural two lane roads
- Three and four leg stop controlled and four leg signalized intersections on rural four lane roads
- Three and four leg stop controlled and signalized intersections on urban and suburban arterials

The predictive models for roadway segments and intersections in rural areas were estimated using data from California, Washington, Michigan, Minnesota, and Texas. For urban and suburban arterials, data from Charlotte, Michigan, Minnesota, and Toronto were used. None of the models were specifically estimated using data from roads in North Carolina with the exception of the urban/suburban arterial intersection types.

All the SPFs in Part C were estimated using negative binomial regression, which is the state of the art for estimating SPFs. The Appendix to Part C indicates that for applying these SPFs for a particular jurisdiction, the SPFs have to be calibrated to that jurisdiction using the procedure outlined in Part C or that jurisdiction has to develop jurisdiction-specific SPFs using negative binomial regression. Jurisdiction-specifics SPFs are expected to provide more accurate results but also require a larger sample of sites to develop.

Part D provides the expected safety impacts of various engineering treatments in roadway segments, intersections, interchanges, special facilities, and road networks. Crash modification factors (CMFs) along with some information about the precision of the CMFs (e.g., standard errors) is presented for each treatment.

Overview of the HSM Prediction Methodology

The predictive method in Part C of the HSM is an 18-step procedure to estimate the average expected crash frequency at a site. A site in the HSM is defined as an intersection or a homogenous roadway segment. The predictive method utilizes crash prediction models that were developed from observed crash data for a number of similar sites. The method uses three types of components to predict the average expected crash frequency at a site – the base model, called a safety performance function (SPF); crash modification factors (CMFs) to adjust the estimate for additional site specific conditions; and a calibration factor to adjust the estimate for accuracy in the state or local area. These components are used in the general form below:

$N_{predicted} = N_{spf} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yz}) \times C_x$

Where:

> $N_{predicted}$ = predicted average crash frequency for a specific year for site type x;
>
> N_{spf} = predicted average crash frequency determined for base conditions of the SPF developed for site type x;
>
> CMF_{nx} = crash modification factors specific to SPF for site type x; and
>
> C_x = calibration factor to adjust SPF for local conditions for site type x.

As indicated, each predictive model is specific to a facility or site type (e.g., urban four-lane divided segments) and a specific year. The HSM stresses that the advantage of using these predictive models is that the user will obtain a value for long-term expected average crash frequency rather than short-term observed crash frequency. This will minimize the error due to selecting sites for treatment that look hazardous based on short term observations, or in other terms, a bias called regression-to-the-mean. It should also be noted that the predictive method can be used to predict crashes for past years based on observed AADT or for future years based on forecast AADT.

The steps for the predictive method are presented in detail in section C.5. of Volume 2 of the HSM. In short, they are:

- Decide which facilities and roads will be used in the predictive process and for what period of time
- Identify homogenous sites and assemble geometric conditions, crash data, and AADT data for the sites to be used
- Apply the safety performance function, any applicable crash modification factors, and a calibration factor if available
- Apply site- or project-specific empirical Bayes method if applicable
- Repeat for all sites and years, sum, and compare results

NCHRP 17-45: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges

The purpose of NCHRP 17-45 (Bonneson, et al., 2012) was to develop safety prediction methodology for freeways and interchanges for inclusion in the 2nd edition of the HSM. Two proposed chapters are included in the appendices of the final report. The predictive models were estimated using data from California, Washington, and Maine. Chapter 18 describes the predictive models for the following freeway facility types:

- Freeway segments (multiple- and single- vehicle FI and PDO predictive models)
    - Rural 4-, 6-, and 8-lane
    - Urban 4-, 6-, 8-, and 10-lane
- Freeway speed-change lanes (total FI and PDO predictive models)
    - Ramp entrance to four-lane divided (4EN)
    - Ramp entrance to six-lane divided (6EN)
    - Ramp entrance to eight-lane divided (8EN)
    - Ramp entrance to 10-lane divided (10EN) (urban only)
    - Ramp exit to four-lane divided (4EX)
    - Ramp exit to six-lane divided (6EX)
    - Ramp exit to eight-lane divided (8EX)
    - Ramp exit to 10-lane divided (10EX) (urban only)

Chapter 19 describes the predictive models for ramps and collector-distributor (C-D) roadways:

- Ramp segments (rural and urban multiple- and single- vehicle FI and PDO predictive models)
    - One-lane entrance ramp (1EN)
    - Two-lane entrance ramp (2EN) (urban only)
    - One-lane exit ramp (1EX)
    - Two-lane exit ramp (2EX) (urban only)
- C-D road segments (rural and urban multiple- and single- vehicle FI and PDO predictive models)
    - One-lane C-D road (1)
    - Two-lane C-D road (2) (urban only)

- Crossroad ramp terminals (see table 19-2 in Bonneson et al., 2012)

Previous SPF Calibration Efforts in North Carolina

NCDOT 2009-06

NCDOT 2010-06 “Superstreet Benefits and Capacities” (Hummer et al., 2010b) evaluated the safety of synchronized street (formerly known as superstreet) intersections on rural multilane roads. These intersections were controlled by stop signs on the minor roads before the synchronized street design was implemented. As part of their safety analysis of synchronized streets, the authors calibrated the predictive models in the HSM for North Carolina roads. Specifically, the authors developed calibration factors for rural multilane minor leg stop-controlled three- and four-leg intersections using data from 2004 to 2009.

NCDOT 2009-07

NCDOT 2010-07 “Procedure for Curve Warning Signing, Delineation and Advisory Speeds for Horizontal Curves” (Hummer et al., 2010a) examined curve crash characteristics, developed a manual field investigation procedure for curves, developed GIS methods for finding key curve parameters, and developed a calibration factor for the predictive model in the HSM for rural two-lane undivided roadways.

NCDOT 2010-09

NCDOT 2010-09 “Development of Safety Performance Functions for North Carolina” (Srinivasan and Carter, 2011) developed state-specific safety performance functions for nine crash types for sixteen roadway types in North Carolina. The authors primarily developed these state-specific SPFs for the purpose of network screening. Additionally, the authors developed North Carolina-specific calibration factors for six segment and eight intersection facility types using data from 2007 to 2009.

SPF Calibration Efforts in Other States

Many other states have developed calibration factors for the HSM safety performance functions. FHWA regularly compiles information on these calibration efforts and their results. The spreadsheet with this information can be found at http://www.cmfclearinghouse.org/resources_spf.cfm.

Calibration of the HSM Prediction Models

Why Calibrate?

The HSM recommends that the predictive models be calibrated using data from a jurisdiction where these models will be applied because the models were developed using data from many states around the country. Calibration is important because "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 system procedures" (HSM, page C-18). The development and use of calibration factors will assist NCDOT personnel in arriving at crash predictions that are more accurate for North Carolina sites.

Calibration Process

The process of developing calibration factors for the Part C predictive models is laid out in Appendix A of Part C (Volume 2) of the HSM. The steps are as follows:

1. Identify facility types for which the applicable Part C predictive model is to be calibrated
2. Select sites for calibration of the predictive model for each facility type
3. Obtain data for each facility type applicable to a specific calibration period
4. Apply the applicable Part C predictive model to predict total crash frequency for each site during the calibration period as a whole
5. Compute calibration factors for use in Part C predictive model

The sections below discuss how the researchers executed each step in the development of the North Carolina calibration factors.

Step 1 – Identify facility types for which the applicable Part C predictive model is to be calibrated

There are predictive models in the HSM for eight types of roadway segments and ten types of intersections. For this effort, calibration factors were developed for seven of the roadway types and all ten of the intersection types. Additionally, calibration factors were developed for four of the freeway models presented in NCHRP 17-45 and slated to be part of the 2nd edition of the HSM. The remaining models listed were not included in this effort as there is insufficient mileage in North Carolina to warrant estimating calibration factors for these facility types.

Included in this effort:

Roadway Segments

- Rural 2-lane undivided segments (regional calibration factors also developed)
- Rural 4-lane divided segments (regional calibration factors also developed)
- Urban 2-lane undivided segments (2U)
- Urban 2-lane with TWLTL segments (3T)
- Urban 4-lane divided segments (4D)
- Urban 4-lane undivided segments (4U)
- Urban 4-lane with TWLTL segments (5T)
- Rural freeways (4 through lanes)

- Urban freeways (4 through lanes)
- Urban freeways (6 through lanes)
- Urban freeways (8 through lanes)

Intersections

- Rural 2-lane, minor road stop-controlled 3-leg intersections (3ST) (regional calibration factors also developed)
- Rural 2-lane, minor road stop-controlled 4-leg intersections (4ST) (regional calibration factors also developed)
- Rural 2-lane, signalized 4-leg intersections (4SG) (regional calibration factors also developed)
- Rural 4-lane, minor road stop-controlled 3-leg intersections (3ST)
- Rural 4-lane, minor road stop-controlled 4-leg intersections (4ST)
- Rural 4-lane, signalized 4-leg intersections (4SG)
- Urban arterial, stop-controlled 3-leg intersections (3ST)
- Urban arterial, signalized 3-leg intersections(3SG)
- Urban arterial, stop-controlled 4-leg intersections (4ST)
- Urban arterial, signalized 4-leg intersections (4SG)

<u>NOT</u> included in this effort:

Roadway segments

- Rural 4-lane undivided segments (4U)
- Rural freeways (6 through lanes)
- Rural freeways (8 through lanes)
- Urban freeways (10 through lanes)

Step 2 – Select sites for calibration of the predictive model for each facility type

The calibration process requires detailed data on each site. Hence, the calibration process must be based on a sample of miles or intersections for which detailed data can be collected. The selection of this sample is important. The sites must be selected in as random a manner as possible, so as not to bias the calibration process. The HSM instructs that sites should not be selected so as to limit the sample only to either high or low crash frequencies. The size of the sample is also important. The HSM recommends that the desired minimum sample size for each facility type is 30 to 50 sites and that the entire group of the sample for each facility type should represent at least 100 crashes per year in order for the calibration to be reliable. Furthermore, the recently published NCHRP calibration guide (Bahar, 2014) provides guidance on determining the needed sample size for calibration based on the desired standard deviation (or precision) of the calibration factor (C). A larger sample is needed for a smaller standard deviation (0.1*C is suggested in the guide).

For this effort, the researchers used several sources to select sites starting with a review of the sites used in previous research efforts including NCDOT 2010-09. To supplement the segment site lists for the facility types used in previous research efforts (and for the new freeway facility types), the researchers obtained a list of North Carolina road segments from the Highway Safety Information System (HSIS). HSIS maintains an archived database of roadway inventory, traffic volumes, and crash data for nine states, including North Carolina. Various data elements in HSIS were used to classify the HSM facility type of a particular segment for inclusion in this effort. The researchers identified new classified segments by randomly selecting a route and selecting all segments on that route. This allowed for diversity in road classes while maintaining efficiency in the data collection process by selecting segments adjacent to each other on a particular route. To supplement the intersection sites lists for the facility types used in previous research efforts, additional intersections were marked and coded during the data collection process for the segment facility types.

Step 3 – Obtain data for each facility type applicable to a specific calibration period

The HSM SPFs require data for each site on various geometric and cross-sectional characteristics, traffic volumes, and crash data. The researchers used various sources including HSIS, NCDOT databases and GIS files, Google Earth imagery (including Streetview) to collect the needed data elements. Trained research assistants collected the geometric and cross-sectional characteristics. Through NCDOT, the Traffic Engineering Accident Analysis System (TEAAS) provided all crash data.

Table 1 and Table 2 show the data elements collected for segments and intersections and the data source for each element.

Table 1. Data elements and sources for roadway segments

Facility Type	Data Element	Source
All	Segment length	HSIS
All	Traffic volume	HSIS NCDOT GIS
All	Presence of lighting	Aerial/Streetview imagery
All	Use of automated speed enforcement	n/a – not used in North Carolina
Rural 2U, 4D, and Freeways	Lane width	HSIS, Aerial imagery
Rural 2U and 4D	Shoulder type	HSIS
Rural 2U, 4D, and Freeways	Shoulder width	HSIS, NCDOT database
Rural 2U, Urban arterials	Presence of TWLTL	Aerial/Streetview imagery
Rural 2U, Freeways	Lengths of horizontal curves and tangents	NCDOT GIS
Rural 2U, Freeways	Radii of horizontal curves	NCDOT GIS

Facility Type	Data Element	Source
Urban arterials and freeways	Number of through traffic lanes	HSIS (verified visually)
Rural 2U	Presence of spiral transition for horizontal curves	Aerial imagery, NCDOT GIS
Rural 2U	Superelevation variance for horizontal curves	n/a – used default value in HSM
Rural 2U	Percent grade	n/a – used default value in HSM*
Rural 2U	Driveway density	Aerial/Streetview imagery
Rural 2U	Presence of passing lane	Aerial/Streetview imagery
Rural 2U	Presence of short 4-lane section	Aerial/Streetview imagery
Rural 2U	Presence of centerline rumble strips	Aerial/Streetview imagery
Rural 2U	Roadside hazard rating	n/a – used default value in HSM
Urban arterials	Presence of median	HSIS (verified visually)
Urban arterials	Number of driveways by land use type	Aerial/Streetview imagery
Urban arterials	Low speed vs intermediate or high speed	Aerial/Streetview imagery
Urban arterials	Presence of on-street parking	Aerial/Streetview imagery
Urban arterials	Type of on-street parking	Aerial/Streetview imagery
Urban arterials	Roadside fixed object density	Aerial/Streetview imagery
Freeways	Area type	HSIS
Freeways	Median width	HSIS (verified visually)
Freeways	Length of rumble strips on inside and outside shoulders	Aerial/Streetview imagery
Freeways	Length of (and offset to) median barrier	Aerial/Streetview imagery
Freeways	Length of (and offset to) outside barrier	Aerial/Streetview imagery
Freeways	Clear zone width	Aerial/Streetview imagery

*HSM indicates a CMF = 1.00 for level terrain; 1.06 for rolling terrain; and CMF = 1.14 for mountainous terrain. These categories align with the three regions in North Carolina identified for this effort (Coast, Piedmont, and Mountain, respectively) thus the researchers used these default values.

Table 2. Data elements and sources for intersections

Facility Type	Data Element	Source
All	Number of intersection legs	Aerial/Streetview imagery
All	Type of traffic control	Aerial/Streetview imagery
All	Major and minor road AADT	NCDOT GIS
All	Number of approaches with left-turn lanes	Aerial/Streetview imagery
All	Number of approaches with right-turn lanes	Aerial/Streetview imagery
All	Presence of lighting	Aerial/Streetview imagery
Rural 2U and multilane	Intersection skew angle	NCDOT GIS
Urban arterials	Presence of left-turn phasing	Aerial/Streetview imagery
Urban arterials	Type of left-turn phasing	Aerial/Streetview imagery
Urban arterials	Use of right-turn-on-red signal operation	Aerial/Streetview imagery
Urban arterials	Use of red-light cameras	Aerial/Streetview imagery
Urban arterials	Pedestrian volume	
Urban arterials	Max number of lanes crossed by pedestrians on any approach	Aerial/Streetview imagery
Urban arterials	Presence of bus stop within 1,000 ft	n/a*
Urban arterials	Presence of schools within 1,000 ft	n/a*
Urban arterials	Presence of alcohol sales establishments within 1,000 ft	n/a*

*These were not collected in this effort since the HSM prediction models that use these elements were developed using North Carolina data.

Following are details and challenges regarding the data collection process for each facility type.

Segment characteristics data collection

In order to accurately track mileposts and collect the required data, it was necessary for the research assistants to track along the route in both the GIS environment and Google imagery. To accomplish this, the research assistants would delineate each segment in the GIS line layer (using the indicated begin and end mileposts), then export that layer to a file that could be read into Google Earth. Since the segments either originated from previous research efforts or were selected from the HSIS list according to entire routes, the research assistant could track along the route, collecting data on each segment sequentially. This method greatly improved the efficiency of data collection, as opposed to jumping around to randomly selected segments, which would take considerably more time.

The first task for the research assistants for segments used in previous efforts, was to verify that no major changes occurred to the segment between when the previous research was conducted and 2014 (most current available at the time of data collection). If changes were noted (e.g., major construction or change in classification or other attributes), the site was dropped. For new segments originating from the HSIS list, the research assistants' first task on each segment was to confirm that it was indeed the correct facility type indicated in HSIS (e.g., rural four-lane divided) and confirm that the beginning and ending mileposts were correct. Sometimes it was the case that a road would be a different facility type than was indicated in HSIS, either due to miscoding in the initial NCDOT Universe file, or due to the fact that the road had been upgraded since its initial entry in the inventory system. When confirming segment end points, it was often the case that the beginning or ending milepost of a segment had to be redefined due to the fact that the segment as defined in HSIS encompassed two or more non-homogenous sections (e.g., the median was discontinued partway through the indicated segment). Additionally, if there was an intersection in the segment, the segment would be broken into two new segments, with the beginning or ending points of the new segments defined to exclude 250 feet on either side of the intersection. The research assistants would note the locations of these intersections and they would be collected separately for the intersection sample.

Once each segment was confirmed and accurately defined, the research assistants would collect the necessary geometric and cross-section characteristics using a combination of aerial and Streetview imagery. Figure 1 shows an example image of the two types of views and indicates below the images which elements the research assistants collected from each.

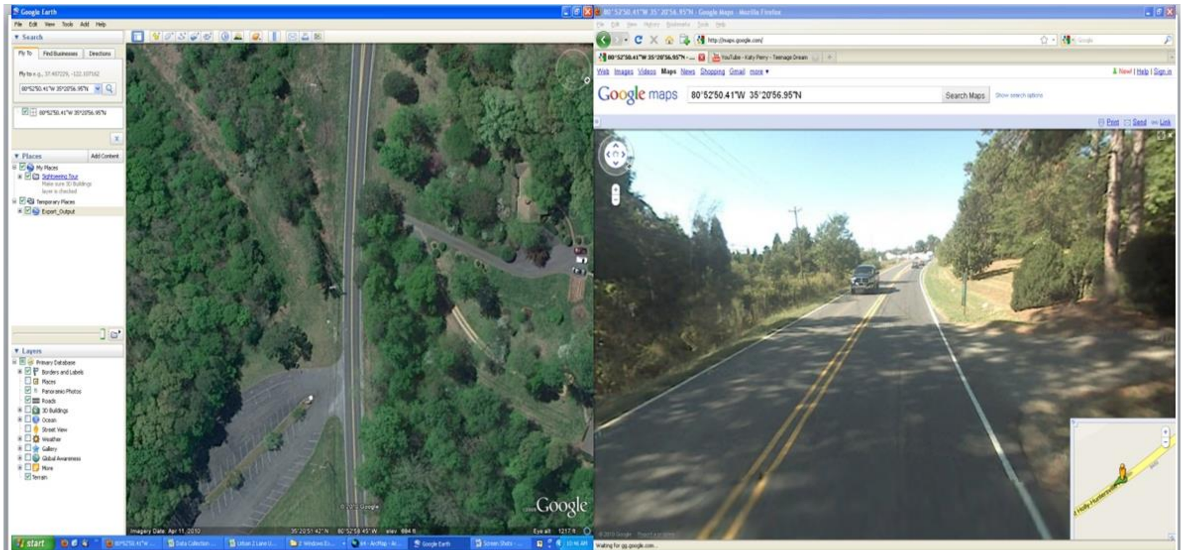

Figure 1. Examples of online imagery with lists of data elements collected from each

Following are specific notes and/or challenges for each segment facility type.

Rural two-lane undivided roadway segments

The most challenging elements to collect for rural two-lane undivided roadway segments were those involving alignment data. NCDOT initially provided alignment data that was collected as part of a separate effort but the data was unusable for rural two-lane roads. The majority of the randomly selected sample of segments for rural two-lane roads were secondary routes (SR) which were not included in the alignment data provided by NCDOT (only higher order routes were collected - Interstate, US, and NC routes). Therefore, other methods were explored for collecting alignment data such as New Hampshire DOT's Curve Finder program (which is no longer supported) and Florida DOT's "Curvature" curve measurement tool (both of these tools are GIS based and were used in NCDOT 2009-07). Additionally, researchers in other States were contacted who have calculated calibration factors for rural two-lane roads to see if the methods used in other efforts could be applied to North Carolina. After reviewing all options, the researchers chose the Florida DOT "Curvature" curve measurement tool (Florida Department of Transportation, 2015) as it was the most efficient tool to use to collect the needed curve alignment data for this effort.

With the exception of data elements requested from HSIS, research assistants collected the remaining data following the guidance in the HSM. The HSM segment-based predictive models predict only non-intersection crashes, so it was important to make sure that segments did not include intersection influence areas. To address this issue, the researchers redefined the segments so as to exclude 250 feet on either side of the intersection. The HSM also recommends limiting segment length to 0.10 miles. This requirement was sometimes difficult to adhere to because of the nature of where curves fell along a segment.

Rural four-lane divided roadway segments

The researchers dropped approximately two-thirds of the rural four-lane divided roadway segments included in NCDOT 2010-09 for this effort. Reasons included incorrect facility type classification or major construction. Therefore, the researchers generated additional segments from HSIS in the same manner as previously described. Minimum segment length retained was 0.10 miles.

Urban arterials

The researchers were unable to retain all of the urban arterial segments from NCDOT 2010-09 for this effort, so in order to meet sample size recommendations, the researchers used data from HSIS to generate supplemental lists of urban arterial segments for data collection. Additionally, the researchers used data collected as part of NCHRP 17-62 to supplement the urban 5T arterial list.

The HSM recommendation for limiting segment length to a minimum of 0.10 miles to "decrease data collection management efforts" was difficult to adhere to in an urban environment. The original homogenous segment lengths were already fairly short and cropping segments to account for intersection influence area often made the final segment length shorter than 0.10 miles. After discussion and reviewing the original research behind Chapter 12 in the HSM, the researchers decided to limit segment length to 0.05 miles for urban arterial segments.

Freeways

As rural and urban freeway calibration factors were not developed in any previous research efforts, the researchers used data from HSIS to generate a list of freeway segments for data collection for each of the freeway facility types included in this effort. The researchers followed the guidance in Appendix C (Chapter 18), "Proposed HSM Freeways Chapter", of the final report for NCHRP 17-45, "Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges" (Bonneson et al., 2012). The researchers used curve alignment data provided by NCDOT in conjunction with the Florida DOT "Curvature" curve measurement tool (Florida Department of Transportation, 2015) used for rural two-lane undivided segments. Additionally, NCDOT provided inside shoulder width data from the NCDOT pavement database (inside shoulder width was not available in HSIS).

Because there is little ramp data available in North Carolina to collect the needed elements for the speed change lane models included in Chapter 18, these models were not included in this analysis. Furthermore, for the freeway segment models, it became apparent to the researchers that it was necessary to define a "ramp influence area" (similar to intersection influence area) to avoid including segments in the analysis that were near ramps. To address this issue, the researchers redefined the freeway segments so as to exclude 0.5 miles on either side of a ramp (measuring from the taper point). For rural freeways, a minimum segment length of 0.10 miles was used and for urban freeways, a minimum segment length of 0.05 miles was used.

Intersection characteristics data collection

The researchers collected intersection data in a similar manner to the segment data. Research assistants collected geometric data, traffic control, configuration, and other characteristics through viewing the Google aerial and Streetview imagery. The researchers obtained traffic volumes from the GIS file. Research assistants collected all identifying route names and numbers for both the major and minor roads for use in obtaining crash data. Additionally, the research assistants recorded the latitude and longitude of the intersection to allow for quick locating of the intersection if needed in the future.

Following are specific notes and/or challenges for each intersection facility type.

Rural two-lane and multilane intersections

This effort began by reviewing the intersections originally collected as part of NCDOT 2010-09. The first step was to verify and correct any discovered inaccuracies in the attribute data previously collected. The researchers eliminated intersections that incurred changes between 2009 and 2014, including changes due to major road construction.

So that the researchers could estimate regional calibration factors for rural two-lane intersections, the site list from NCDOT 2010-09 was supplemented with a selection of the site list from NCDOT 2013-11 (Srinivasan et al., 2014). The researchers also reviewed and verified these additional intersections for inclusion in this effort.

In order to have a larger sample size for rural multilane intersections, the researchers reviewed the intersections identified during the data collection for rural four-lane divided road segments. After reviewing the intersections identified during the rural four-lane divided road segment data collection process, the researchers still needed additional intersections in order to increase sample size, so the researchers randomly selected additional intersections from NCDOT GIS layers.

Urban arterial intersections

This effort began by examining the intersections for each urban/suburban facility type used in NCDOT 2010-09 for inclusion in this effort. The researchers eliminated any intersections that incurred changes between 2009 and 2014, including changes due to major road construction. The researchers used data collected as part of NCHRP 17-62 to supplement the urban 3SG and 4ST intersection lists.

Traffic volume data collection

The researchers obtained traffic volumes (AADT) from HSIS for roadway segments and from NCDOT GIS data for intersections. For segments, HSIS provided yearly AADT for each roadway segment in the initial list that the researchers used for site selection, so the AADT information was easily obtained. For intersections, the researchers obtained AADT for the major and minor roads from the GIS data made available by the NCDOT GIS Unit. The shapefiles used consisted of two types of files. First was a line layer of the road network that had one AADT value and year for each segment. Second was a group of point layers that represented traffic volume count points around the state. The researchers used the point layer to estimate AADT if there was not a value available in the line layer.

Crash data collection

The researchers obtained crash data from NCDOT. Mr. Brian Murphy ran queries on the TEAAS database to obtain the crash data for 2009-2015 for the segments and intersections.

Crash proportion tables

The researchers used HSIS North Carolina data from 2014 to prepare the crash proportion tables for rural two-lane roads, rural four-lane divided roads, urban arterials, and freeway segments. HSIS staff used data from the entire state to calculate the various proportions indicated in the HSM and proposed HSM chapters. Note that HSIS staff took care to exclude intersection related crashes for the segment crash proportion tables. The researchers prepared the intersection crash proportion tables using crash data from the sites selected for this effort. This was necessary because there is no statewide intersection crash database available in HSIS.

Step 4 – Apply the applicable Part C predictive model to predict total crash frequency for each site during the calibration period as a whole

The researchers applied the predictive models for each facility type following the HSM predictive method and also updated the previously developed Microsoft Excel™ spreadsheets to run the predictive models for the entire group of sample sites. These spreadsheets will be delivered with this report to allow NCDOT to develop new calibration factors in future years.

Step 5 – Compute calibration factors for use in Part C predictive model

The researchers calculated the calibration factor for each facility type as indicated in the HSM, by the following method:

$$Calibration\ Factor = \frac{observed\ crashes_{all\ sites}}{predicted\ crashes_{all\ sites}}$$

Calibration Factor versus Calibration Function

In using a calibration factor, the implicit assumption is that the base condition SPF and the CMFs are applicable to any state/jurisdiction, and the calibration factor accounts for differences in crash reporting thresholds and crash reporting procedures. If that assumption is not valid, then a single calibration factor may not be appropriate. One way to assess whether a single calibration factor is appropriate to use cumulative residual plots. The procedure for developing

CURE plots is discussed in Hauer and Bamfo (1997). If the cumulative residual plots indicate that a single calibration factor is not appropriate, then a calibration function may be one option.

A calibration function is similar to an SPF and can take different forms. Calibration functions can take many forms. Table 3 shows the different types of calibration functions that were estimated in a recent study using data from rural two lane roads in Arizona (Srinivasan et al., 2016).

Table 3. Calibration Functions Developed for Arizona

Calibration Function Type	Calibration Function for $N_{predicted}$
1	$N_{predicted} = a \times (\boldsymbol{HSM\_Pred})^{b}$
2	$N_{predicted} = a \times \boldsymbol{L} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)^{\boldsymbol{b}} \times \prod_{i=1}^{12} \boldsymbol{CMF_i}$
3	$N_{predicted} = \boldsymbol{a} \times \boldsymbol{L^c} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)^{\boldsymbol{b}} \times \prod_{i=1}^{12} \boldsymbol{CMF_i}$
4	$N_{predicted} = \boldsymbol{a} \times \boldsymbol{L^c} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)^{\boldsymbol{b}} \times \boldsymbol{e}^{\boldsymbol{d} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)} \times \prod_{i=1}^{12} \boldsymbol{CMF_i}$
5	$N_{predicted} = \boldsymbol{a} \times \boldsymbol{L^c} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)^{\boldsymbol{b}} \times \left(\prod_{i=1}^{12} \boldsymbol{CMF_i}\right)^{\boldsymbol{d}}$
6	$N_{predicted} = \boldsymbol{a} \times \boldsymbol{L^c} \times \left(\frac{\boldsymbol{AADT}}{\boldsymbol{1000}}\right)^{\boldsymbol{b}}$

In Table 3, a, b, c, and d represent parameters to be estimated in a calibration function, L represents segment length, AADT represents average annual daily traffic, $\prod_{i=1}^{12} CMF_i$ represents the product of 12 CMFs (i.e., $CMF_1 \times CMF_2 \times CMF_3 \times CMF_4 \times CMF_5 \times CMF_6 \times CMF_7 \times CMF_8 \times CMF_9 \times CMF_{10} \times CMF_{11} \times CMF_{12}$) that are used for the rural two lane chapter, and "HSM_Pred" is the total number of predicted crashes based on the HSM procedure (product of the base model with the CMFs) .

In this study, the researchers explored calibration functions for rural two lane roads as a test case and these are discussed in Appendix A.

Findings and Conclusions

Table 4, Table 5, and Table 6 show the calibration factors for segments and intersection models. Factors that are based on the HSM desired sample size of at least 100 observed crashes per year are indicated in ***bold italics***. It should be noted that data was collected for large samples of rural two-lane undivided and rural four-lane divided roadways in an effort to follow the sample size guidance in the NCHRP Calibration Guide. However, after removing sites for various reasons, these samples were still not quite large enough to meet the criteria specified in the guide. Appendix B presents more detailed tables, including data for the observed and predicted values for each calibration factor.

For rural two-lane undivided segments, the six year average calibration factor indicates that the HSM model predicted crashes fairly close to the observed values in North Carolina for the whole State (1.09), over-predicted crashes for the Mountain region (0.78) and under-predicted crashes for the Coast and Piedmont regions (1.78 and 1.21, respectively).

For rural four-lane divided segments, the six year average calibration factor indicates that the HSM model predicted crashes fairly close to the observed values in North Carolina for the whole State (0.93), over-predicted crashes for the Mountain and Piedmont regions (0.78 and 0.83, respectively), and under-predicted crashes for the Coast region (1.27).

For urban arterials, the six year average calibration factor indicates that the HSM model under-predicted crashes for all facility types. This was also the case in the results reported in NCDOT 2010-09.

For freeway segments, the SPFs are broken down into four categories: multiple-vehicle fatal and injury (MV,FI), single-vehicle fatal and injury (SV,FI), multiple-vehicle PDO (MV,PDO), and single-vehicle PDO (SV,PDO) for each of the freeway facility types. The six year average calibration factor indicates that the HSM model over-predicted crashes for all freeway facility types except:

- Rural 4 lane MV,FI (1.29)
- Rural 4 lane MV,PDO (1.57)
- Rural 4 lane SV, PDO (1.48)
- Urban 6 lane, SV, PDO (1.16)

Table 4. Calibration Factors for Segment Models

Segment Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 2U – Coast	***1.93***	***1.81***	***1.66***	***1.77***	***1.80***	***1.73***	***1.78***
Rural 2U – Mountain	***0.79***	***0.67***	***0.82***	***0.82***	***0.80***	***0.80***	***0.78***
Rural 2U – Piedmont	***1.34***	***1.09***	***1.31***	***1.19***	***1.16***	***1.17***	***1.21***
Rural 2U – Total	***1.15***	***0.99***	***1.11***	***1.10***	***1.09***	***1.08***	***1.09***

Segment Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 4D – Coast	***1.36***	***1.26***	***1.10***	***1.40***	***1.34***	***1.17***	***1.27***
Rural 4D – Mountain	***0.83***	***0.67***	***0.72***	***0.82***	***0.83***	***0.79***	***0.78***
Rural 4D – Piedmont	***0.93***	***0.73***	***0.76***	***0.97***	***0.74***	***0.86***	***0.83***
Rural 4D – Total	***1.02***	***0.86***	***0.84***	***0.97***	***0.95***	***0.93***	***0.93***
Urban 2U	1.21	1.07	1.19	1.03	1.20	***1.34***	1.17
Urban 3T	1.56	1.31	***1.62***	1.48	***1.75***	***1.56***	1.55
Urban 4U	2.66	1.60	2.43	2.09	2.01	2.73	2.25
Urban 4D	1.69	1.58	***2.01***	***2.41***	***2.54***	***2.63***	***2.14***
Urban 5T	***1.37***	***1.46***	***1.29***	***1.63***	***1.35***	***1.30***	***1.40***
Rural Frwy – 4ln MV,FI	***1.20***	***1.48***	***1.21***	***0.99***	***1.18***	***1.67***	***1.29***
Rural Frwy – 4ln SV,FI	***0.77***	***0.87***	***0.58***	***0.70***	***0.34***	***0.64***	***0.65***
Rural Frwy – 4ln MV,PDO	***1.49***	***2.05***	***1.42***	***1.98***	***1.02***	***1.45***	***1.57***
Rural Frwy – 4ln SV,PDO	***1.91***	***1.54***	***1.33***	***1.26***	***1.58***	***1.30***	***1.48***
Urban Frwy – 4ln MV,FI	0.79	1.19	0.36	0.78	0.88	***0.75***	0.79
Urban Frwy – 4ln SV,FI	0.73	0.49	0.43	0.43	0.55	***0.91***	0.59
Urban Frwy – 4ln MV,PDO	0.64	0.75	0.79	0.76	1.00	***1.10***	0.84
Urban Frwy – 4ln SV,PDO	0.71	0.61	0.59	0.59	0.63	***1.01***	0.69
Urban Frwy – 6ln MV,FI	***0.51***	***0.71***	***0.85***	***0.85***	***0.52***	***1.22***	***0.78***

Segment Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Urban Frwy – 6ln SV,FI	***0.85***	***0.48***	***0.96***	***0.76***	***0.92***	***1.08***	***0.84***
Urban Frwy – 6ln MV,PDO	***0.74***	***0.70***	***0.64***	***0.68***	***0.65***	***1.30***	***0.78***
Urban Frwy – 6ln SV,PDO	***0.88***	***0.92***	***1.20***	***1.27***	***1.20***	***1.51***	***1.16***
Urban Frwy – 8ln MV,FI	***0.97***	0.72	0.31	0.46	0.51	***0.56***	0.59
Urban Frwy – 8ln SV,FI	***1.07***	0.66	0.24	0.57	0.48	***0.88***	0.65
Urban Frwy – 8ln MV,PDO	***1.03***	0.65	0.45	0.41	0.84	***1.16***	0.76
Urban Frwy – 8ln SV,PDO	***1.15***	0.62	0.85	0.85	0.54	***1.11***	0.86

Table 5 shows that for rural two-lane intersection types, the six year average calibration factor indicates that the HSM model over-predicted crashes for all facility types in all regions with the exception of four-leg signalized intersections in the Coast region (0.99).

Table 5. Calibration Factors for Rural Two-Lane Intersections

Intersection Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 2U 3ST – Coast	0.41	0.51	0.42	0.45	0.64	0.61	0.51
Rural 2U 3ST – Mountain	0.61	0.76	0.77	0.60	0.61	0.80	0.69
Rural 2U 3ST – Piedmont	0.60	0.49	0.60	0.53	0.47	0.63	0.55
Rural 2U 3ST – Total	***0.58***	***0.56***	***0.61***	***0.53***	***0.53***	***0.67***	***0.58***
Rural 2U 4SG – Coast	0.85	0.86	0.87	1.03	***1.05***	***1.25***	0.99

Rural 2U 4SG – Mountain	0.62	0.75	0.63	0.60	0.52	0.67	0.63
Rural 2U 4SG – Piedmont	***0.68***	***0.67***	***0.60***	***0.71***	***0.73***	***0.86***	***0.71***
Rural 2U 4SG – Total	***0.71***	***0.73***	***0.68***	***0.78***	***0.78***	***0.93***	***0.77***
Rural 2U 4ST – Coast	0.53	0.58	0.58	0.73	0.67	***0.80***	0.65
Rural 2U 4ST – Mountain	0.63	0.59	0.59	0.34	0.49	0.39	0.50
Rural 2U 4ST – Piedmont	***0.70***	0.59	0.60	0.62	0.66	***0.85***	0.67
Rural 2U 4ST – Total	***0.62***	***0.58***	***0.59***	***0.61***	***0.63***	***0.75***	***0.63***

Table 6 shows that for rural multilane intersection types, the six year average calibration factor indicates that the HSM model over-predicted crashes for three-leg minor road stop-controlled intersections and four-leg signalized intersections (0.36 and 0.41, respectively). Crashes were under-predicted for four-leg minor road stop-controlled intersections (1.44). It should be noted that the sample sizes for three- and four-leg minor road stop-controlled intersections were very small. It was difficult to identify intersections of these types that had both major and minor road AADT as required for calibration factor calculations.

For urban arterial intersection types, the six year average calibration factor indicates that the HSM model under-predicted crashes for all facility types. The highest six year average calibration factor (four-leg signalized intersections, 3.07) is supported by a sample of sites that contained greater than 100 crashes.

Table 6. Calibration Factors for Rural Multilane and Urban Arterial Intersections

Intersection Facility Types	2010	2011	2012	2013	2014	2015	6 yr avg
Rural 4-lane – 3ST	0.19	0.20	0.42	0.31	0.56	0.47	0.36
Rural 4-lane – 4SG	***0.34***	***0.45***	***0.36***	***0.41***	***0.42***	***0.45***	***0.41***
Rural 4-lane – 4ST	1.32	1.38	1.30	1.37	1.84	1.45	1.44
Urban – 3ST	1.88	1.67	1.81	1.46	1.27	1.56	1.61
Urban – 3SG	***2.03***	***2.11***	***2.06***	***2.13***	***2.17***	***2.53***	***2.17***
Urban – 4ST	1.79	1.98	1.60	1.50	1.81	***2.06***	1.79
Urban – 4SG	***3.03***	***2.98***	***2.92***	***2.93***	***3.10***	***3.46***	***3.07***

Special note about calibration of pedestrian collision model

It should be noted that the calibration of urban signalized intersection models was based on vehicle-vehicle and vehicle-bicycle crashes only. The process did not involve pedestrian crashes in the calibration. This was for two reasons. One, the models to predict pedestrian crashes required detailed data on the number of bus stops, schools, and alcohol sales establishments within 1,000 feet of the intersection. The labor to acquire this data would have been extensive. Two, the HSM models to predict pedestrian crashes were developed by an NCHRP project that used Charlotte and Toronto data. During the course of the NCHRP project, the City of Charlotte provided researchers with GIS files that indicated the locations of bus stops, schools, and alcohol sales establishments; these data were subsequently used in the development of the predictive model. Thus, since the pedestrian models were developed using North Carolina data, the need to calibrate these models was minimal compared to the rest of the calibration effort.

Recommendations

In order to be able to use the advanced tools in the HSM, it is necessary for each jurisdiction to employ crash prediction models (also called safety performance functions, SPFs) that relate crash frequency and severity to roadway characteristics for different types of facilities. The HSM does not recommend using the SPFs directly from the HSM without calibration because the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including climate, driver populations, animal populations, accident reporting thresholds, and crash report system procedures. Therefore, the HSM recommends that calibration factors be updated every three years.

Alternatively, as the recommended three year update from the HSM is not based on statistical research, NCDOT could wait to update the calibration factors developed in this effort until the second edition of the HSM comes out. The HSM Second Edition is expected to be published in 2019 or 2020. If NCDOT holds off an updating of the calibration factors until 2020, they would see the following advantages:

1. The amount of time between the end of this calibration effort and the beginning of the next one would be consistent with the recommended period of time between updates (four years – 2016 to 2019).
2. The next calibration effort could encompass the new SPFs that will be included in the HSM Second Edition, such as new intersection types, six and eight lane arterials, one way roads, roundabouts, and many models specific to individual crash types and severities.

NCDOT could also prioritize updating calibration factors for roadway and intersection types that have lower sample sizes. Additionally, NCDOT could explore a collaborative effort for updating or developing calibration factors and SPFs with neighboring States, specifically South Carolina and Virginia.

NCDOT could also explore the possibility of estimating calibration functions for the different roadway and intersection types. In this study, calibration functions were estimated for rural two lane roads as a test case. The level of effort for estimating calibration functions will depend on the number of different functions that may need to be investigated for a particular facility type. As a rough estimate, between 8 and 16 hours from a statistical analyst may be needed to estimate calibration functions for a particular facility type.

NCHRP Project 17-62 is in the process of developing prediction models for the second edition of the HSM, and developing further guidance on calibration including a possible suggestion that agencies consider developing calibration functions in addition to calibration factors.

Implementation and Technology Transfer Plan

The authors provide the following input to the steering committee members regarding the implementation and technology transfer plan.

- Identification of research products:
  - Calibration factors using data from North Carolina for seven of the roadway types and all ten of the intersection types that have prediction models in the HSM. Additionally, calibration factors were developed for four of the freeway models presented in NCHRP 17-45 and slated to be part of the HSM Second Edition.
  - Crash proportion tables using data from North Carolina for seven of the roadway types and all ten of the intersection types that have prediction models in the HSM. Additionally, crash proportion tables were developed for four of the freeway models presented in NCHRP 17-45 and slated to be part of the HSM Second Edition.
  - Calibration function(s) for rural two-lane undivided roadways.
  - Example of how calibration functions can be used.
- Suggestions for who in the Department would use the results of this effort and how the results can be used:
  - **Application to processes (e.g. design):** The results of this effort can be used by various NCDOT staff, specifically those in the Traffic Safety Unit, for the purposes of evaluating engineering treatments.
  - **Application to projects:** NCDOT staff in all units can more accurately consider safety in the decision making process at the project level.
  - **Anticipated benefits:** In order to achieve the greatest return on the investment of limited budgets, it is imperative that decisions are made based on the best information regarding the safety implications of various design alternatives and engineering treatments. The products from this research will help the department make decisions based on the best information available hence saving money and enhancing safety.
- Recommendations for any training needed for implementation:
  - **How R&D Unit can participate:** Recommend using calibration factors for SPFs in future research efforts; particularly evaluation studies.

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Appendix A – Calibration Functions

Overview of Calibration Factors

This Appendix shows the calibration functions that were estimated for rural two lane roads as a test case. In addition, an example for using the calibration function is shown.

The notion of using calibration functions is still a point of debate in the safety research community. We hope the functions estimated in this project will contribute to this debate.

One way to represent a calibration function for segments is the following:

$$N_{predicted} = f(L) \times g(AADT) \times h(\prod_{i=1}^{n} CMF_i)$$

Where, L is the length of the segment in miles, AADT is the Annual Average Daily Traffic (AADT), $\prod_{i=1}^{n} CMF_i$ represents the product of the crash modification factors that are included as part of the HSM predictive equations, and f, g, and h represent functions. In this effort, the calibration functions were estimated using negative binomial regression.

Instead of a calibration function, if a calibration factor is used, then equation above can be written as follows:

$$N_{predicted} = c \times HSM\_pred$$

Where, c is the calibration factor and HSM_Pred is number of predicted crashes based on the HSM procedure (product of the base model with the CMFs).

In both calibration factors and calibration functions, the right hand side (RHS) of the equation is called as the fitted value. Based on the observed crash counts and the fitted value for each site, it is possible to make an assessment of the validity and reliability of the calibration factor or function.

Assessment of Calibration Factors and Functions

There are many ways to assess calibration factors and functions. FHWA has developed a SPF calibration and assessment tool that can be used to assess different types of calibration factors and functions (Lyon et al., 2017). This tool suggests the following goodness of fit measures to assess calibration factors and functions:

- Mean absolute deviation (MAD) – lower the MAD, better the fit
- Modified R^2 – higher the modified R2, better the fit
- Cumulative residual plots - The plot of the cumulative residuals with the fitted value is called the CURE plot for fitted value. The data in the CURE plot are expected to oscillate around the value 0. If the cumulative residuals are consistently drifting upward within a particular range of fitted values, then it would imply that there were more observed than predicted crashes. On the other hand, if the cumulative residuals are consistently

drifting downward within a particular range of fitted values, then it would imply that there were fewer observed than predicted crashes. Vertical lines in the CURE plot usually imply the presence of outliers. Hauer and Bamfo (1997) also derived confidence limits for the plot ($\pm 2\sigma$) beyond which the plot should go only rarely. There are two measures to assess the CURE plot:

- Maximum absolute CURE deviation – this has to be as low as possible
- Percentage of CURE deviation – this represents the percentage of observations where the CURE plot is beyond the confidence limits. This has to be as low as possible

Calibration Factors and Functions for Rural Two Lane Roads

This section provides the assessment of the calibration factors and the calibration functions for coast, mountain, and piedmont regions in North Carolina. The calibration functions documented in this section provide the prediction for a six year period. So, to estimate the prediction for one year, the prediction from the calibration functions should be divided by 6.

Coast

For the coastal region, apart from the calibration factor, only one calibration function was considered, since it provided a good fit. The calibration factor was 1.78. So the equation corresponding to the calibration factor can be written as follows:

$$N_{predicted} = 1.78 \times HSM\_pred$$

The calibration function (option 1) was the following:

$$N_{predicted} = 0.965 \times e^{-3.1953} \times L \times \prod_{i=1}^{12} CMF_i \times AADT^{0.6496}; \text{ k}^{1} = 0.16/\text{L}$$

The CURE plots for the calibration factor and option 1 of the calibration function are provided below:

[1] k is the overdispersion parameter

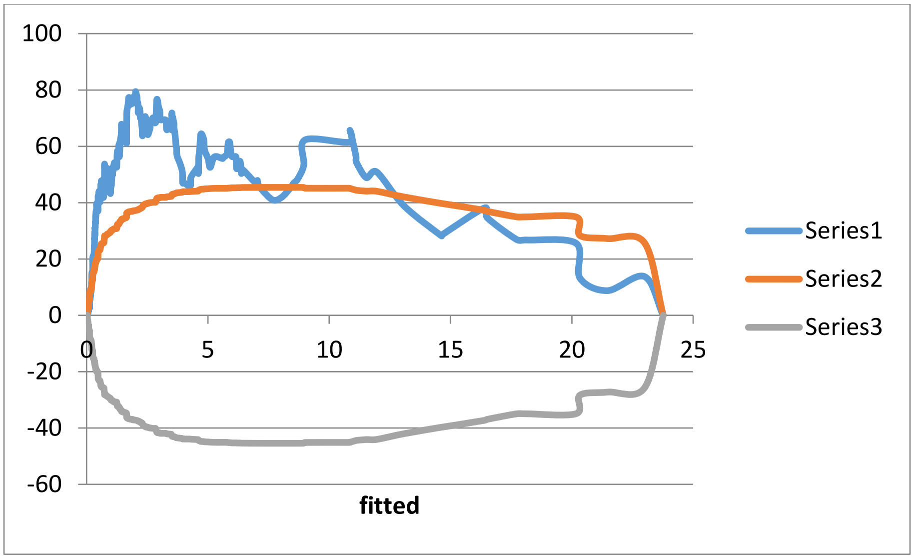

Figure 2. CURE Plot for Calibration Factor (Coastal)

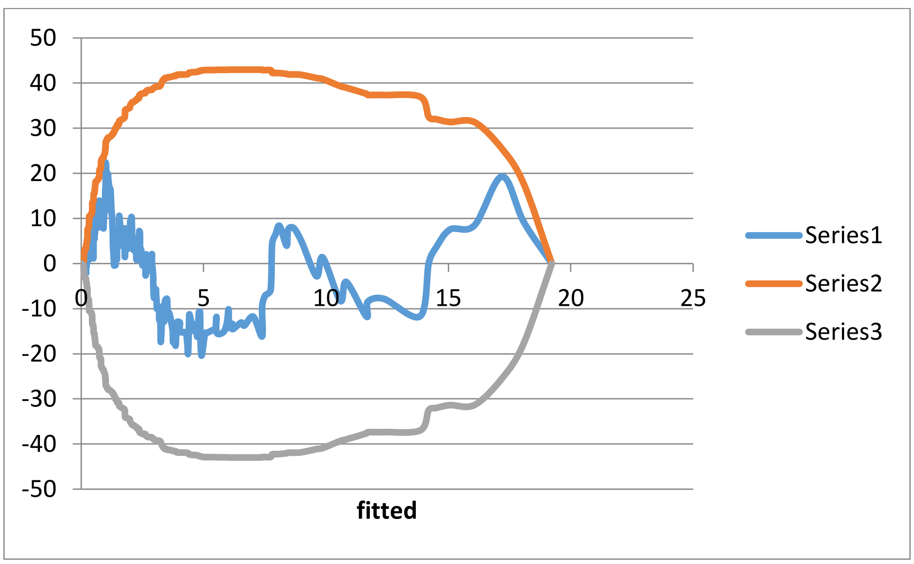

Figure 3. CURE Plot for Calibration Function (Option 1) (Coastal)

Table 7 shows the goodness of fit statistics for these two options:

Table 7. Goodness of Fit Statistics for Coastal Calibration Factors and Functions

Calibration Factor or Function	Modified R^2	MAD	Maximum absolute CURE deviation	% CURE deviation
Calibration factor	0.72	1.33	79.41	79%
Option 1 Calibration Function	0.77	1.33	22.40	2%

Based on Table 7, the Modified R^2 is slightly higher for the calibration function, but the MAD values are the same. However, the CURE plot is much better with the calibration function, and that is reflected in lower values of the maximum absolute CURE deviation and the % CURE deviation. It is clear that the calibration function provides a better fit for the data.

Mountain

The calibration factor was 0.78. So the equation corresponding to the calibration factor can be written as follows:

$$N_{predicted} = 0.78 \times HSM\_pred$$

Three different options were considered for calibration functions.

Option 1 calibration function was the following:

$$N_{predicted} = 0.76 \times e^{-6.5110} \times L \times AADT^{1.0129} \times \prod_{i=1}^{12} CMF_i; \text{ k = 0.13/L}$$

Option 2 calibration function was the following:

$$N_{predicted} = 0.97 \times e^{-3.7294} \times L \times \left(AADT \times \prod_{i=1}^{12} CMF_i\right)^{0.6808}; \text{ k = 0.11/L}$$

Option 3 calibration function was the following:

$$N_{predicted} = 1.02 \times e^{-0.1832} \times (HSM\_Pred)^{0.8512}; \text{ k = 1.16}$$

The CURE plots for the calibration factor and the three calibration functions are shown below.

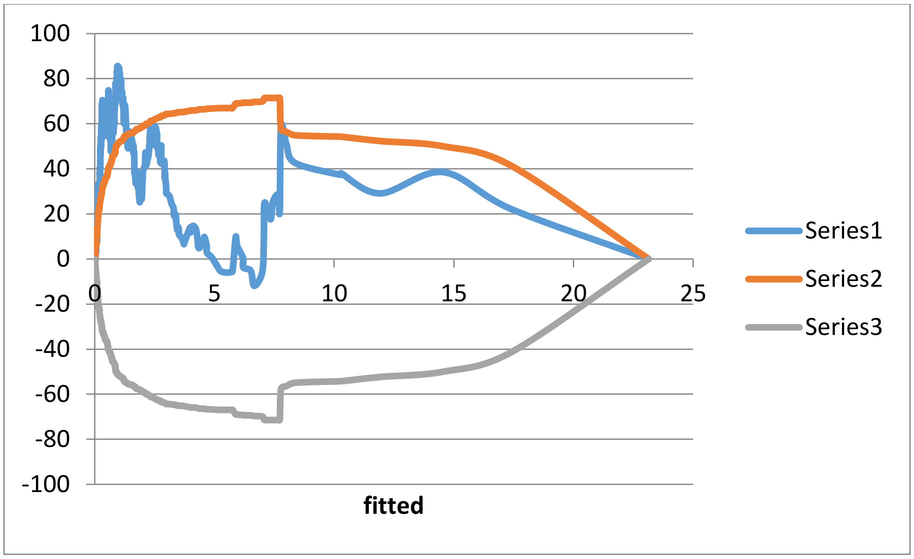

Figure 4. CURE Plot for Calibration Factor (Mountain)

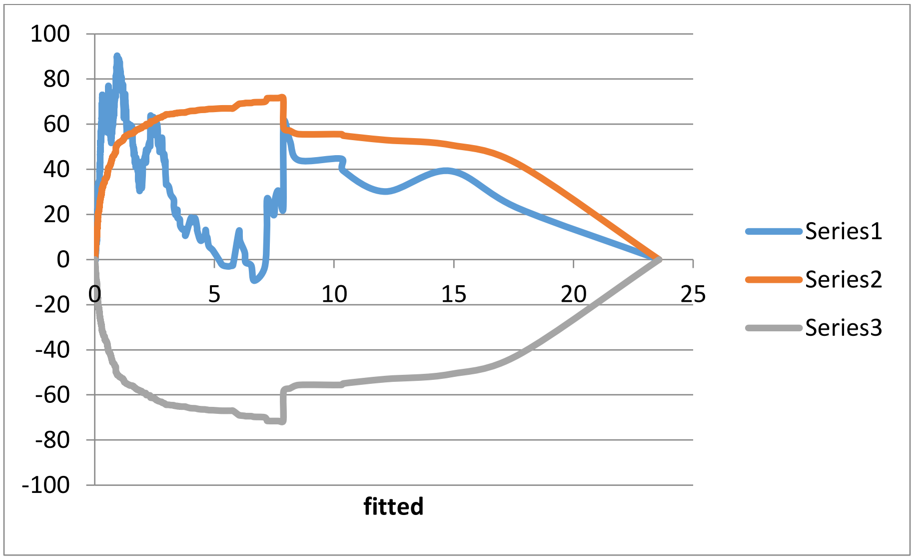

Figure 5. CURE Plot for Option 1 Calibration Function (Mountain)

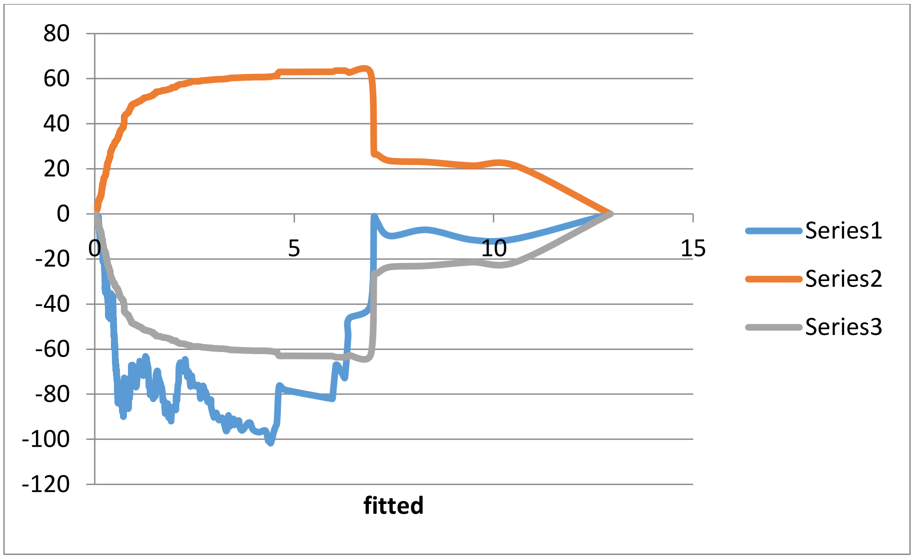

Figure 6. CURE Plot for Option 2 Calibration Function (Mountain)

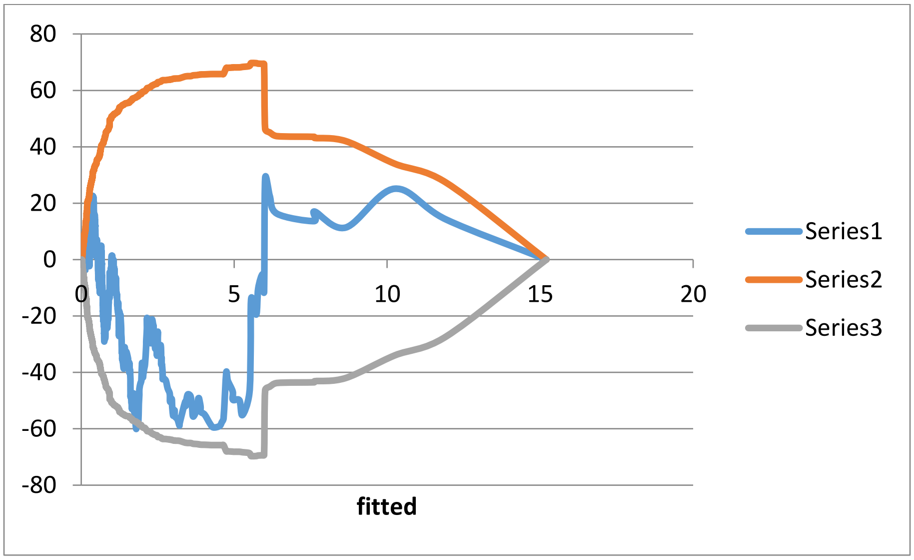

Figure 7. CURE Plot for Option 3 Calibration Function (Mountain)

Table 8 shows the goodness of fit statistics for factors and functions for the Mountain region.

Table 8. Goodness of Fit Statistics for Mountain Calibration Factors and Functions

Calibration Factor or Function	Modified R^2	MAD	Maximum absolute CURE deviation	% CURE deviation
Calibration factor	0.28	0.71	85.64	71%
Option 1 Calibration Function	0.28	0.70	90.37	73%
Option 2 Calibration Function	0.47	0.66	101.63	89%
Option 3 Calibration Function	0.32	0.72	59.97	5%

Based on Table 8, the performance of the Option 1 calibration function is very similar to that of the calibration factor. Option 2 has a better modified R^2 and MAD, but the CURE plot is worse compared to the calibration factor and the Option 1 calibration function. Option 3 has the best CURE plot, but does not as well as Option 2 with respect to the Modified R^2 and the MAD. Since Option 1 does not provide any advantages compared to the calibration factor, the choice is between Options 2 and 3. We prefer Option 3, but some could make the case for Option 2.

Piedmont

The calibration factor was 1.21. So the equation corresponding to the calibration factor can be written as follows:

$$N_{predicted} = 1.21 \times HSM\_pred$$

Two options were considered for calibration functions.

Option 1 calibration function was the following:

$$N_{predicted} = 0.92 \times e^{-5.0530} \times L \times AADT^{0.8546} \times \prod_{i=1}^{12} CMF_i; \text{ k = 0.11/L}$$

Option 2 calibration function was the following:

$$N_{predicted} = 0.99 \times e^{-3.6892} \times L \times \left(AADT \times \prod_{i=1}^{12} CMF_i\right)^{0.6949}; \text{ k = 0.09/L}$$

The CURE plots are show below.

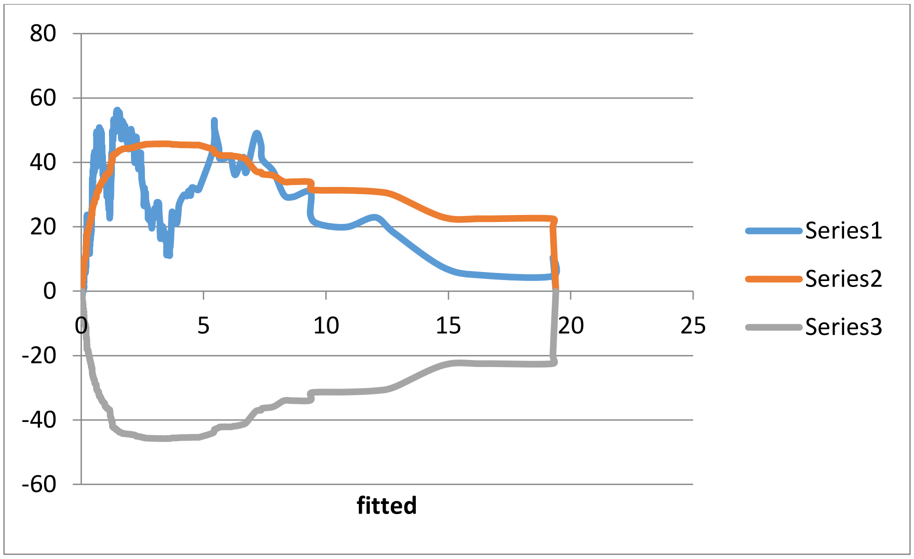

Figure 8. CURE Plot for Calibration Factor (Piedmont)

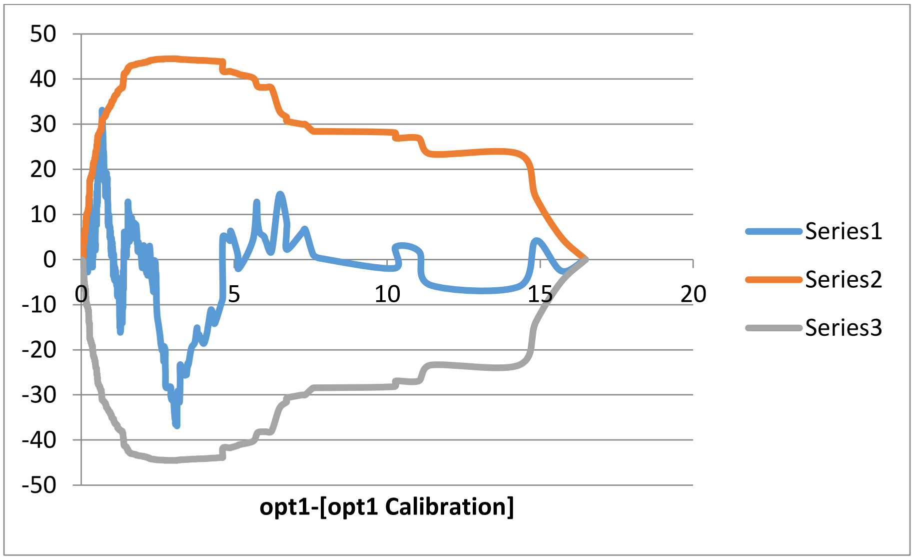

Figure 9. CURE Plot for Option 1 Calibration Function (Piedmont)

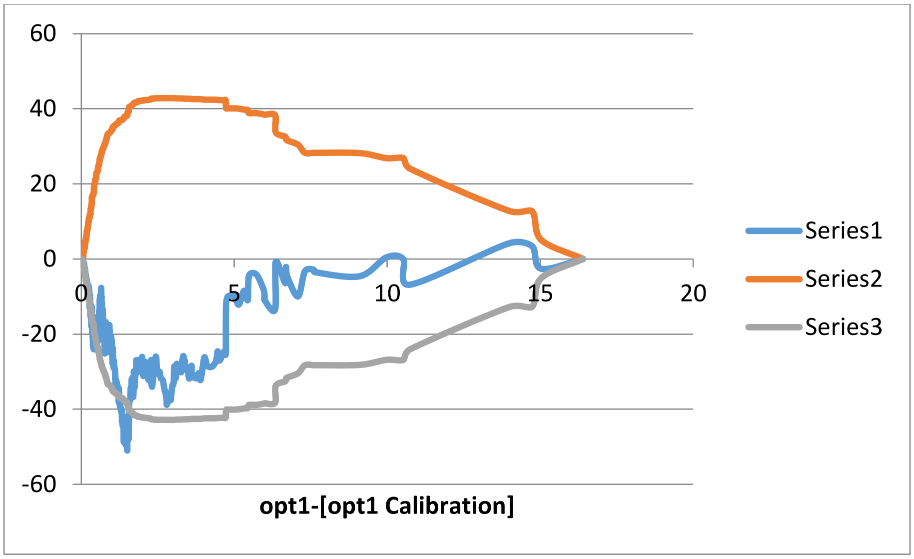

Figure 10. CURE Plot for Option 2 Calibration Function (Piedmont)

Table 9. Goodness of Fit Statistics for Piedmont Calibration Factors and Functions

Calibration Factor or Function	Modified R^2	MAD	Maximum absolute CURE deviation	% CURE deviation
Calibration factor	0.67	0.82	56.26	46%
Option 1 Calibration Function	0.70	0.83	36.88	6%
Option 2 Calibration Function	0.74	0.80	51.00	28%

Based on Table 9, Option 1 has the best CURE plot, but has a lower Modified R^2 and a higher MAD compared to Option 2. Based on the CURE plot, we prefer Option 1.

Example Application of Calibration Functions

Following is an example that illustrates the application of the calibration function that was estimated for the coastal region, using data for a section from that region. Here are the data from that section:

- AADT = 4200
- Length = 1.47 miles
- Lane width = 12 feet

- Left shoulder width = 6 feet
- Right shoulder width = 6 feet
- Left shoulder type = turf
- Right shoulder type = turf
- Alignment = tangent section
- Grade (assumed) = $\leq$ 3%
- Driveway density = 10.2 driveways per mile
- Centerline rumble strips = not present
- TWLTL = not present
- Passing lanes = not present
- Roadside hazard rating = 3 (default)
- Lighting = not present
- Automated speed enforcement = not present
- Total number of crashes = 6 in one year

Based on the first edition of the HSM, the following are the CMFs based on these site characteristics:

- CMF for lane width = 1.0
- CMF for shoulder width and type = 1.04
- CMF for horizontal alignment including radius and superelevation = 1.0
- CMF for grade = 1.0
- CMF for driveway density = 1.12
- CMF for Centerline rumble strips = 1.0
- CMF for TWLTL = 1.0
- CMF for Passing lanes = 1.0
- CMF for Roadside = 1.0
- CMF for Lighting = 1.0
- CMF for Automated speed enforcement = 1.0
- The product of all the CMFs = 1.1648

The calibration function for the coastal region is the following:

$$N_{predicted} = 0.965 \times e^{-3.1953} \times L \times \prod_{i=1}^{12} CMF_i \times AADT^{0.6496}$$

Substituting the values, the predicted number of crashes based on the calibration function is the following:

$$N_{predicted} = 0.965 \times e^{-3.1953} \times 1.47 \times 1.1648 \times 4200^{0.6496}$$
$$= 15.278 \text{ } crashes \text{ } over \text{ } 6 \text{ } years$$

Appendix B – Detailed Calibration Factor Tables

The tables below present the annual calibration factors for each facility type (by region where applicable). The observed and predicted crashes are shown to provide an indication of the sample size used for each calibration factor. Calibration factors with sample sizes greater than 100 per year are shown in bold italics.

Rural two-lane undivided roads

Year	Coast (n=144 miles)			Mountain (n=160 miles)			Piedmont (n=172 miles)			Total (n=476 miles)		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	***1.93***	153	79.32	***0.79***	198	249.29	***1.34***	179	133.76	***1.15***	530	462.37
2011	***1.81***	141	77.79	***0.67***	164	244.87	***1.09***	146	133.60	***0.99***	451	456.25
2012	***1.66***	134	80.63	***0.82***	196	239.15	***1.31***	175	133.91	***1.11***	505	453.70
2013	***1.77***	143	80.63	***0.82***	197	239.15	***1.19***	160	134.51	***1.10***	500	454.30
2014	***1.80***	146	81.17	***0.80***	189	235.86	***1.16***	156	134.77	***1.09***	491	451.79
2015	***1.73***	141	81.71	***0.80***	185	232.39	***1.17***	158	135.02	***1.08***	484	449.11

Rural four-lane divided roads

Year	Coast (n=64 miles)			Mountain (n=78 miles)			Piedmont (n=60 miles)			Total (n=202 miles)		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	***1.36***	182	133.7	***0.83***	152	182.2	***0.93***	138	148.8	***1.02***	472	464.7
2011	***1.26***	169	134.5	***0.67***	119	177.4	***0.73***	113	154.3	***0.86***	401	466.2
2012	***1.10***	151	137.6	***0.72***	128	177.8	***0.76***	116	153.1	***0.84***	395	468.5
2013	***1.40***	192	137.6	***0.82***	146	177.8	***0.76***	117	153.1	***0.97***	455	468.5
2014	***1.34***	186	139.0	***0.83***	146	176.5	***0.74***	114	154.3	***0.95***	446	469.8
2015	***1.17***	165	140.5	***0.79***	138	175.3	***0.86***	134	155.5	***0.93***	437	471.3

Urban arterial segments: two-lane undivided (2U) (n=30 miles)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.21	96	79.43
2011	1.07	84	78.45
2012	1.19	95	79.69
2013	1.03	83	80.465
2014	1.2	99	82.47
2015	***1.34***	112	83.44

Urban arterial segments: two-lane with TWLTL (3T) (n=15 miles)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.56	99	63.65
2011	1.31	82	62.42
2012	***1.62***	103	63.7
2013	1.48	94	63.695
2014	***1.75***	112	63.89
2015	***1.56***	100	64.1

Urban arterial segments: four-lane undivided (4U) (n=4 miles)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	2.66	63	23.64
2011	1.6	37	23.06
2012	2.43	57	23.45
2013	2.09	49	23.448
2014	2.01	47	23.44
2015	2.73	64	23.44

Urban arterial segments: four-lane divided (4D) (n=11 miles)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.69	96	56.78
2011	1.58	89	56.35
2012	***2.01***	111	55.27
2013	***2.41***	133	55.293
2014	***2.54***	139	54.79
2015	***2.63***	143	54.28

Urban arterial segments: four-lane with TWLTL (5T) (n=11 miles)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	***1.37***	183	133.11
2011	***1.46***	194	133.08
2012	***1.29***	174	135.18
2013	***1.63***	220	135.18
2014	***1.35***	183	136.05
2015	***1.30***	178	137.05

Rural four-lane freeways (n=28 miles)

Year	Multi-vehicle, FI			Single-vehicle, FI			Multi-vehicle, PDO			Single-vehicle, PDO		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	***1.20***	10	8.36	***0.77***	19	24.63	***1.49***	22	14.74	***1.91***	96	50.37
2011	***1.48***	13	8.78	***0.87***	22	25.23	***2.05***	32	15.63	***1.54***	80	52.01
2012	***1.21***	11	9.06	***0.58***	15	25.80	***1.42***	23	16.17	***1.33***	71	53.37
2013	***0.99***	9	9.06	***0.70***	18	25.80	***1.98***	32	16.17	***1.26***	67	53.37
2014	***1.18***	11	9.31	***0.34***	9	26.21	***1.02***	17	16.71	***1.58***	86	54.44
2015	***1.67***	16	9.57	***0.64***	17	26.61	***1.45***	25	17.27	***1.30***	72	55.49

Urban four-lane freeways (n=13 miles)

Year	Multi-vehicle, FI			Single-vehicle, FI			Multi-vehicle, PDO			Single-vehicle, PDO		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	0.79	13	16.44	0.73	12	16.51	0.64	19	29.53	0.71	29	40.83
2011	1.19	20	16.76	0.49	8	16.36	0.75	23	30.53	0.61	25	40.86
2012	0.36	6	16.68	0.43	7	16.21	0.79	24	30.43	0.59	24	40.66
2013	0.78	13	16.68	0.43	7	16.21	0.76	23	30.43	0.59	24	40.66
2014	0.88	15	16.96	0.55	9	16.33	1.00	31	31.15	0.63	26	41.04
2015	***0.75***	13	17.25	***0.91***	15	16.44	***1.10***	35	31.89	***1.01***	42	41.42

Urban six-lane freeways (n=14 miles)

Year	Multi-vehicle, FI			Single-vehicle, FI			Multi-vehicle, PDO			Single-vehicle, PDO		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	***0.51***	18	35.51	***0.85***	21	24.67	***0.74***	53	72.10	***0.88***	50	56.74
2011	***0.71***	26	36.38	***0.48***	12	24.88	***0.70***	52	74.48	***0.92***	53	57.47
2012	***0.85***	31	36.38	***0.96***	24	24.88	***0.64***	48	74.62	***1.20***	69	57.38
2013	***0.85***	31	36.38	***0.76***	19	24.88	***0.68***	51	74.62	***1.27***	73	57.38
2014	***0.52***	19	36.65	***0.92***	23	24.94	***0.65***	49	75.45	***1.20***	69	57.56
2015	***1.22***	45	36.93	***1.08***	27	25.00	***1.30***	99	76.31	***1.51***	87	57.74

Urban eight-lane freeways (n=5 miles)

Year	Multi-vehicle, FI			Single-vehicle, FI			Multi-vehicle, PDO			Single-vehicle, PDO		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	***0.97***	24	24.83	***1.07***	13	12.20	***1.03***	52	50.28	***1.15***	37	32.08
2011	0.72	18	24.93	0.66	8	12.17	0.65	33	50.68	0.62	20	32.02
2012	0.31	8	26.02	0.24	3	12.38	0.45	24	53.59	0.85	28	32.76
2013	0.46	12	26.02	0.57	7	12.38	0.41	22	53.59	0.85	28	32.76
2014	0.51	14	27.34	0.48	6	12.59	0.84	48	57.41	0.54	18	33.64
2015	***0.56***	15	26.96	***0.88***	11	12.53	***1.16***	65	56.27	***1.11***	37	33.31

Rural two-lane undivided roadway intersections – 3ST

Year	Coast (n=35)			Mountain (n=37)			Piedmont (n=101)			Total		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	0.41	11	26.82	0.61	30	49.09	0.60	77	128.81	***0.58***	118	204.73
2011	0.51	13	25.52	0.76	37	48.97	0.49	62	125.86	***0.56***	112	200.35
2012	0.42	11	26.22	0.77	37	48.34	0.60	76	127.15	***0.61***	124	201.71
2013	0.45	12	26.47	0.60	28	46.71	0.53	70	132.56	***0.53***	110	205.74
2014	0.64	17	26.37	0.61	28	45.83	0.47	63	133.41	***0.53***	108	205.60
2015	0.61	16	26.23	0.80	36	44.86	0.63	85	134.14	***0.67***	137	205.23

Rural two-lane undivided roadway intersections – 4ST

Year	Coast (n=91)			Mountain (n=28)			Piedmont (n=84)			Total		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	0.53	65	121.62	0.63	39	62.06	***0.70***	101	144.41	***0.62***	205	328.10
2011	0.58	69	118.92	0.59	35	59.74	0.59	84	143.52	***0.58***	188	322.18
2012	0.58	71	121.37	0.59	35	59.73	0.60	87	144.86	***0.59***	193	325.97
2013	0.73	91	125.10	0.34	20	58.44	0.62	88	142.64	***0.61***	199	326.18
2014	0.67	84	126.24	0.49	28	57.34	0.66	94	141.96	***0.63***	206	325.55
2015	***0.80***	102	127.29	0.39	22	56.25	***0.85***	120	140.98	***0.75***	244	324.51

Rural two-lane undivided roadway intersections – 4SG

Year	Coast (n=26)			Mountain (n=14)			Piedmont (n=45)			Total		
	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes	Calib Factor	Obs Crashes	Pred Crashes
2010	0.85	77	90.79	0.62	37	59.46	***0.68***	134	198.30	***0.71***	248	348.56
2011	0.86	79	91.64	0.75	44	58.72	***0.67***	133	199.21	***0.73***	256	349.57
2012	0.87	81	92.67	0.63	38	60.80	***0.60***	120	199.40	***0.68***	239	352.86
2013	1.03	97	94.18	0.60	37	61.22	***0.71***	143	200.85	***0.78***	277	356.26
2014	***1.05***	100	95.05	0.52	32	61.89	***0.73***	146	201.34	***0.78***	278	358.28
2015	***1.25***	120	95.75	0.67	42	62.51	***0.86***	174	201.67	***0.93***	336	359.94

Rural multilane three-leg with minor road stop-control intersections – 3ST (n=15)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	0.19	2	10.65
2011	0.2	2	9.85
2012	0.42	4	9.52
2013	0.31	3	9.54
2014	0.56	5	8.88
2015	0.47	4	8.52

*Note that the sample sizes for three-leg minor road stop-controlled intersections were very small. It was difficult to identify intersections of this type that had both major and minor road AADT as required for calibration factor calculations.

Rural multilane four-leg with minor road stop-control intersections – 4ST (n=22)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.32	26	19.7
2011	1.38	25	18.09
2012	1.3	24	18.5
2013	1.37	24	17.56
2014	1.84	33	17.98
2015	1.45	26	17.91

*Note that the sample sizes for four-leg minor road stop-controlled intersections were very small. It was difficult to identify intersections of this type that had both major and minor road AADT as required for calibration factor calculations.

Rural multilane four-leg signalized intersections – 4SG (n=27)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	***0.34***	130	376.89
2011	***0.45***	168	375.47
2012	***0.36***	138	380.29
2013	***0.41***	161	388.52
2014	***0.42***	163	383.67
2015	***0.45***	175	385.25

Urban arterial three-leg stop-controlled intersections – 3ST (n=52)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.88	59	31.32
2011	1.67	54	32.36
2012	1.81	60	33.20
2013	1.46	50	34.27
2014	1.27	43	33.83
2015	1.56	54	34.53

Urban arterial three-leg signalized intersections – 3SG (n=33)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	***2.03***	129	63.53
2011	***2.11***	137	64.91
2012	***2.06***	138	67.08
2013	***2.13***	144	67.60
2014	***2.17***	146	67.37
2015	***2.53***	173	68.45

Urban arterial four-leg stop-controlled intersections – 4ST (n=56)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	1.79	86	48.03
2011	1.98	96	48.50
2012	1.60	79	49.49
2013	1.50	75	50.10
2014	1.81	92	50.87
2015	***2.06***	***106***	***51.56***

Urban arterial four-leg signalized intersections – 4SG (n=102)

Year	Calibration Factor	Observed Crashes	Predicted Crashes
2010	***3.03***	1002	330.68
2011	***2.98***	1002	336.08
2012	***2.92***	970	331.97
2013	***2.93***	992	338.10
2014	***3.10***	1044	337.05
2015	***3.46***	1171	337.99