RESEARCH & DEVELOPMENT

Updated and Regional Calibration Factors for Highway Safety Manual Crash Prediction Models (2016-2019)

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NCDOT Project 2020-27
FHWA/NC/2020-27
June 2021

<u>FINAL REPORT</u>

Updated and Regional Calibration Factors for Highway Safety Manual Crash Prediction Models (2016-2019)

NCDOT Research Project No. 2020-27

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Submitted to North Carolina Department of Transportation
June 2021

Technical Report Documentation Page

<table>
<tr><td>1. Report No.
FHWA/NC/2020-27</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Updated and Regional Calibration Factors for Highway Safety Manual Crash Prediction Models (2016-2019)</td><td colspan="2">5. Report Date
June 30, 2021</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
Taha Saleem, Raghavan Srinivasan, and Mike Vann</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Highway Safety Research Center
University of North Carolina at Chapel Hill
730 Martin Luther King, Jr. Blvd, CB #3430
Chapel Hill, NC 27599-3430</td><td colspan="2">10. Work Unit No. (TRAIS)</td></tr>
<tr><td colspan="2">11. Contract or Grant No.</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
North Carolina Department of Transportation</td><td colspan="2">13. Type of Report and Period Covered
Final Report
August 1, 2019 to June 30, 2021</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
NCDOT 2020-27</td></tr>
<tr><td colspan="4">15. Supplementary Notes:</td></tr>
<tr><td colspan="4">16. Abstract
The overall objective of this effort 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 four years (2016 – 2019) 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.</td></tr>
<tr><td colspan="2">17. Key Words
Highway Safety Manual; Calibration; Calibration Factor; Safety Performance Function</td><td colspan="2">18. Distribution Statement</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
50</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

DISCLAIMER

ACKNOWLEDGEMENTS

The authors would like to thank the North Carolina Department of Transportation for funding this effort. The authors thank the members of the Steering and Implementation Committee for their guidance through the process:

- Carrie Simpson
- Brian Murphy
- Daniel Carter
- Timothy Nye
- Daniell Bagley
- Matthew Cowhig

The authors would also like to thank Cesar Reyes, Clay Ashford, Duncan Richey, and Rachel O'Reilly, research assistants who worked diligently to compile the data from aerial photographs and GIS files that were necessary for the calibration.

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Executive Summary

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. 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.

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. Four previous NCDOT projects (2009-06, 2009-07, 2010-09 and 2016-09) produced North Carolina-specific calibration factors for the prediction models from Part C 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 F&I represents multiple-vehicle fatal and injury, SV F&I 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.

Rural Segment Calibration Factors

Site Type	Region	2016	2017	2018	2019	2016-2019
Rur2U	All	***1.29***	***1.30***	***1.25***	***1.30***	***1.29***
Rur2U	Coast	***1.57***	***1.54***	***1.63***	***1.46***	***1.55***
Rur2U	Mountain	***1.12***	***1.25***	***1.19***	***1.30***	***1.21***
Rur2U	Piedmont	***1.32***	***1.23***	***1.10***	***1.21***	***1.21***
Rur4D	All	***1.25***	***1.45***	***1.45***	***1.41***	***1.39***
Rur4D	Coast	***1.53***	***1.78***	***1.47***	***1.36***	***1.53***
Rur4D	Mountain	***1.09***	***1.33***	***1.52***	***1.39***	***1.33***
Rur4D	Piedmont	***1.17***	***1.29***	***1.36***	***1.46***	***1.32***

Urban Segment Calibration Factors

Site Type	2016	2017	2018	2019	2016-2019
Urb2U	***1.62***	***1.58***	***1.61***	***1.37***	***1.54***
Urb3T	***2.06***	***2.11***	***2.01***	***1.85***	***2.02***
Urb4U	***2.27***	***2.10***	***2.14***	***1.83***	***2.08***
Urb4D	1.88	1.56	1.79	1.45	1.67
Urb5T	***1.12***	***1.36***	***1.27***	***1.15***	***1.22***

Freeway Calibration Factors

Site type	Crash Type	2016	2017	2018	2019	2016-2019
Rur4Ln-FrWy	MV F&I Crashes	1.02*	1.21*	1.33*	1.30*	1.23*
Rur4Ln-FrWy	MV PDO Crashes	1.97	1.29	1.11	1.57	1.48
Rur4Ln-FrWy	SV F&I Crashes	1.04	0.58*	0.64*	0.67*	0.73*
Rur4Ln-FrWy	SV PDO Crashes	1.23	1.11	0.91	1.13	1.09
Urb4Ln-FrWy	MV F&I Crashes	1.19	1.24	1.23	1.12	1.20
Urb4Ln-FrWy	MV PDO Crashes	1.68	***1.67***	***1.76***	***1.83***	***1.74***
Urb4Ln-FrWy	SV F&I Crashes	0.86	1.11	0.60*	0.48*	0.76*
Urb4Ln-FrWy	SV PDO Crashes	1.03	0.72	1.02	0.79	0.89
Urb6Ln-FrWy	MV F&I Crashes	1.15	1.18	1.21	1.23	1.19
Urb6Ln-FrWy	MV PDO Crashes	***1.27***	***1.33***	***1.38***	***1.77***	***1.44***
Urb6Ln-FrWy	SV F&I Crashes	0.65	0.62	1.09	0.74	0.78
Urb6Ln-FrWy	SV PDO Crashes	0.82	0.87	***1.24***	***0.96***	***0.98***
Urb8Ln-FrWy	MV F&I Crashes	0.97	0.91	1.14	1.23	1.06
Urb8Ln-FrWy	MV PDO Crashes	***1.24***	***1.19***	***1.43***	***1.86***	***1.42***
Urb8Ln-FrWy	SV F&I Crashes	0.66	0.53	0.79	0.64	0.66
Urb8Ln-FrWy	SV PDO Crashes	0.69	0.69	1.05	0.89	0.83

**Calibration factors based on less than 20 observed crashes per year*

Rural 2-Lane Intersection Calibration Factors

Intersection Type	*Region*	*2016*	*2017*	*2018*	*2019*	*2016-2019*
Rur2L-3ST	All	***0.63***	***0.69***	***0.66***	***0.71***	***0.67***
Rur2L-3ST	Coast	0.65	0.63	0.71	0.54	0.63
Rur2L-3ST	Mountain	0.53	0.66	0.58	0.80	0.64
Rur2L-3ST	Piedmont	***0.68***	***0.72***	***0.69***	***0.71***	***0.70***
Rur2L-4SG	All	***0.87***	***0.87***	***0.88***	***0.86***	***0.87***
Rur2L-4SG	Coast	***1.04***	***1.15***	***1.25***	***1.25***	***1.17***
Rur2L-4SG	Mountain	0.58	0.59	0.67	0.57	0.60
Rur2L-4SG	Piedmont	***0.89***	***0.85***	***0.80***	***0.80***	***0.83***
Rur2L-4ST	All	***0.80***	***0.69***	***0.70***	***0.75***	***0.73***
Rur2L-4ST	Coast	***0.88***	***0.91***	***0.70***	***0.97***	***0.86***
Rur2L-4ST	Mountain	0.64	0.35	0.71	0.61	0.58
Rur2L-4ST	Piedmont	***0.81***	***0.65***	***0.70***	***0.64***	***0.69***

Rural 4-Lane Intersection Calibration Factors

Intersection Type	*2016*	*2017*	*2018*	*2019*	*2016-2019*
RurML-3ST	0.35*	0.35*	0.62*	0.99*	0.58*
RurML-4SG	***0.28***	***0.37***	***0.36***	***0.28***	***0.32***
RurML-4ST	1.12	1.10	1.22	1.19	1.15

**Calibration factors based on less than 20 observed crashes per year*

Urban Arterial Intersection Calibration Factors

Intersection Type	*2016*	*2017*	*2018*	*2019*	*2016-2019*
UrbArt-3SG	1.89	2.63	2.43	2.07	2.26
UrbArt-3ST	1.91	2.41	2.62	2.60	2.40
UrbArt-4SG	***3.27***	***3.24***	***3.25***	***3.16***	***3.23***
UrbArt-4ST	1.01	1.30	1.59	1.34	1.31

1. Introduction

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. 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.

1.1. Purpose and Scope

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.

Four previous NCDOT projects (2009-06, 2009-07, 2010-09 and 2016-09) produced North Carolina-specific calibration factors for the prediction models from Part C of the HSM. These calibration factors have been extensively used by the NCDOT Traffic Safety Unit as part of their decision-making process. The HSM recommends that these calibration factors be updated every three years. The 2016-09 effort also estimated separate calibration factors for three different regions in North Carolina (Western, Piedmont, and Coastal) to properly account for significant differences in terrain, climate, and roadway characteristics.

This effort aimed to update the calibration factors from these previous efforts as well as include new models which have not yet had calibration factors estimated.

1.2. Research Objectives

The overall objective of this effort was to estimate calibration factors for all prediction models in Part C of the HSM (that are of interest to NCDOT) based on the latest available four years (2016

– 2019) of roadway, traffic, and crash data from North Carolina. Separate calibration factors were also developed for the three different regions in North Carolina (Western, Piedmont, and Coastal). Along with these calibration factors, the project also produced state-specific crash type proportions to be used along with the calibration factors. Ultimately, it is expected that the outcomes of this study will help NCDOT assess projects from a safety perspective by promoting data-driven decisions.

1.3. Report Organization

This chapter provides a brief introduction of the purpose and scope of this effort along with the research objectives.

Chapter 2 presents a brief literature review followed by a summary of previous NCDOT projects where various researchers produced North Carolina-specific calibration factors.

Chapter 3 gives an overview of the HSM prediction methodology, and how it was applied to calculate the calibration factors.

Chapter 4 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.

Chapter 5 provides an overview of recommendations for future efforts.

2. Review of Literature and Current State Practices

2.1. 1st edition of the HSM

The 1st edition of 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, SPFs, 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 segments, 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, SPFs 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 SPFs 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 state-maintained roads in North Carolina.

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 must 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.

2.2. Supplement to the 1st edition of the HSM

NCHRP 17-45 (Bonneson, et al., 2012) developed SPFs for freeway and interchanges for inclusion in the 2nd edition of the HSM. Two proposed chapters are included in the appendices of the NCHRP 17-45 final report. The SPFs were estimated using data from California, Washington, and Maine. The first chapter 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)

The second chapter 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

2.3. 2nd edition of the HSM

AASHTO is in the process of compiling materials for the 2nd edition of the HSM. The 2nd edition of the HSM was originally scheduled for publication in 2019 but has been hit with delays and the final publication date is yet to be finalized. The 2nd edition of the HSM will have many more SPFs for the same facility types included in the 1st edition, and SPFs for other facility types that were not included in the 1st edition. UNC's Highway Safety Research Center (HSRC) has been involved in developing some of the SPFs for the Chapter 12 of the 2nd edition of the HSM as part of recently completed NCHRP Project 17-62. In addition, as part of NCHRP Project 17-72, HSRC is developing CMFs (to be called SPF adjustment factors) to be used with the prediction models in Part C of the 2nd edition of the HSM.

In the 1st edition of the HSM, many chapters included one SPF for total crashes for a particular facility type and recommended that a state agency use proportions of crash type and severity to predict the number of crashes for a particular combination of crash type and severity. In the 2nd edition, some of the facility types include SPFs for specific combinations of crash type and severity. In other words, there are more SPFs that replace the use of agency proportions of crash type and severity in some cases. In addition, many of these SPFs are being calibrated to a common state before they are published in the HSM. HSRC, as part of NCHRP 17-72, is calibrating various of these models using Ohio and North Carolina data. In addition, an ongoing research project (NCHRP 17-84) is estimating SPFs for pedestrian and bicycle crashes.

2.4. SPF Calibration Efforts Using North Carolina Data

There have been four previous efforts (NCDOT 2009-06, NCDOT 2009-07, NCDOT 2010-09, and NCDOT 2016-09) that undertook SPF calibration using North Carolina Data.

2.3.1. NCDOT 2009-06

NCDOT 2009-06 "Superstreet Benefits and Capacities" (Hummer et al., 2010a) 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.

2.3.2. NCDOT 2009-07

NCDOT 2009-07 "Procedure for Curve Warning Signing, Delineation and Advisory Speeds for Horizontal Curves" (Hummer et al., 2010b) 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.

2.3.3. 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.

2.3.4. NCDOT 2016-09

NCDOT 2016-09 "Updated and Regional Calibration Factors for Highway Safety Manual Crash Prediction Models" (Smith et al., 2017) developed North Carolina specific calibration factors for the following facility types:

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)
- Rural 2-lane, minor road stop-controlled 4-leg intersections (4ST)
- Rural 2-lane, signalized 4-leg intersections (4SG)
- 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)

2.5. SPF Calibration Efforts in Other States

Many other states have developed calibration factors for the HSM SPFs. 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.

The research team also conducted an online survey of transportation agencies (including NCDOT) as part of NCHRP 17-93 (led by HSRC), to learn about their experiences with regards to applying and calibrating HSM and other non-local SPFs.

2.5.1. State DOT Survey Results

Following is a summary of State DOT responses to the survey questions.

- 57.5% of agencies apply SPFs that are not developed by them (e.g., SPFs in the HSM or those developed using non-local data)
- 40% of agencies do no calibrate SPFs to local conditions, while about 53% use calibration factors as defined in the HSM.
- 75% of agencies do not maintain and update the database(s) that can be used to calibrate the SPFs regularly.

    - Of these 75%, maintaining and updating database is not a priority for two-thirds of the respondents, while the remaining one-third do not do it because of the intensive effort needed.
- None of the respondent agencies have specific policies in place for how often to calibrate.

Based on the responses received, it can be seen that (a) majority of State DOTs do not maintain a calibration database, and (b) majority of State DOTs do not have a set frequency/timeline for calibration.

3. Methodology

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.

3.1. 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:

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

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.

3.2. 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 as the "ratio of observed crashes to predicted crashes".

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

3.2.1. 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. Following discussions with NCDOT, 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.

3.2.1.1 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)

3.2.1.2. 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)

3.2.2. 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.

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 2016-09. 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.

3.2.3. 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, and 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 Elements

Facility Type	*Data Element*	*Source*
All	Segment length	HSIS, NCDOT GIS
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/Streetview imagery
Rural 2U and 4D	Shoulder type	HSIS, Aerial/Streetview imagery
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 2016-09 Data, NCDOT GIS
Rural 2U, Freeways	Radii of horizontal curves	NCDOT 2016-09 Data, NCDOT GIS
Urban arterials and freeways	Number of through traffic lanes	HSIS, Aerial/Streetview imagery
Rural 2U	Presence of spiral transition for horizontal curves	n/a – used "Not Present" as default
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, Aerial/Streetview imagery (measured)
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	n/a – used default values in HSM for Medium-High Pedestrian activity
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	Aerial/Streetview imagery
Urban arterials	Presence of schools within 1,000 ft	Aerial/Streetview imagery
Urban arterials	Presence of alcohol sales establishments within 1,000 ft	Aerial/Streetview imagery

3.2.3.1. Data Collection Process

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 2016 (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. When confirming segment end points, it was often the case that the beginning or ending milepost of a segment had to be redefined because 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.

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 Aerial and Streetview imagery. 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.

Crash data were obtained from NCDOT. NCDOT staff ran queries on the TEAAS database to obtain the crash data for 2016-2019 for the segments and intersections.

3.2.4. 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 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 be used as reference when developing new calibration factors in future years.

3.2.5. 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:

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

4. Calibration Results

The following sections show the calibration factors for segments and intersection models, including detailed tables, including data for the observed and predicted values for each calibration factor.

4.1. Calibration Factors for Segment Models

Table 3 summarizes the segment length (by type/region) used for calculating calibration factors.

Table 3. Segment Lengths (by type/region) Used for Calibration

Segment Type	*Segment Length (miles)*
Rur2U - All	732.74
Rur2U - Coast	193.78
Rur2U - Mountain	277.88
Rur2U - Piedmont	261.08
Rur4D - All	197.27
Rur4D - Coast	60.21
Rur4D - Mountain	77.28
Rur4D - Piedmont	59.78
Urb2U	42.01
Urb3T	19.16
Urb4U	7.51
Urb4D	4.17
Urb5T	15.71
Rur4Ln-FrWy	30.12
Urb4Ln-FrWy	19.79
Urb6Ln-FrWy	18.84
Urb8Ln-FrWy	12.52

4.1.1. Rural Segments

For rural two-lane undivided segments (Table 4 and Table 5), the four-year average calibration factor indicates that the HSM model under-predicted crashes for the whole State (1.29) as well as the three regions: Coast (1.55), Mountain (1.21), and Piedmont (1.21).

Table 4. Rural 2-lane Undivided Segments (2U)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2U - All	2016	715	555.48	**1.29**
Rur2U - All	2017	735	564.31	**1.30**
Rur2U - All	2018	717	572.13	**1.25**
Rur2U - All	2019	756	580.00	**1.30**
Rur2U - All	2016 - 2019	2923	2271.92	**1.29**

Table 5. Rural 2-Lane Undivided Segments (2U) - by region

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2U - Coast	2016	186	118.271	**1.57**
Rur2U - Coast	2017	185	120.061	**1.54**
Rur2U - Coast	2018	206	126.768	**1.63**
Rur2U - Coast	2019	195	133.536	**1.46**
Rur2U - Coast	2016 - 2019	772	498.635	**1.55**
Rur2U - Mountain	2016	266	237.67	**1.12**
Rur2U - Mountain	2017	304	243.76	**1.25**
Rur2U - Mountain	2018	289	243.11	**1.19**
Rur2U - Mountain	2019	314	242.47	**1.30**
Rur2U - Mountain	2016 - 2019	1173	967.01	**1.21**
Rur2U - Piedmont	2016	263	199.55	**1.32**
Rur2U - Piedmont	2017	246	200.49	**1.23**
Rur2U - Piedmont	2018	222	202.24	**1.10**
Rur2U - Piedmont	2019	247	203.99	**1.21**
Rur2U - Piedmont	2016 - 2019	978	806.28	**1.21**

Table 6. Rural 4-Lane Divided Segments (4D)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur4D - All	2016	646	516.92	**1.25**
Rur4D - All	2017	745	515.52	**1.45**
Rur4D - All	2018	762	526.62	**1.45**
Rur4D - All	2019	758	538.04	**1.41**
Rur4D - All	2016 - 2019	2911	2096.51	**1.39**

Table 7. Rural 4-Lane Divided Segments (4D) - by region

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur4D - Coast	2016	237	154.823	**1.53**
Rur4D - Coast	2017	264	148.622	**1.78**
Rur4D - Coast	2018	227	153.966	**1.47**
Rur4D - Coast	2019	217	159.380	**1.36**
Rur4D - Coast	2016 - 2019	945	616.676	**1.53**
Rur4D - Mountain	2016	199	183.23	**1.09**
Rur4D - Mountain	2017	250	187.95	**1.33**
Rur4D - Mountain	2018	282	186.13	**1.52**
Rur4D - Mountain	2019	257	184.37	**1.39**
Rur4D - Mountain	2016 - 2019	988	741.56	**1.33**
Rur4D - Piedmont	2016	210	178.86	**1.17**
Rur4D - Piedmont	2017	231	178.95	**1.29**
Rur4D - Piedmont	2018	253	186.53	**1.36**
Rur4D - Piedmont	2019	284	194.29	**1.46**
Rur4D - Piedmont	2016 - 2019	978	738.27	**1.32**

For rural four-lane divided segments (Table 6 and Table 7), the four-year average calibration factor indicates, that similar to the rural two-lane undivided segments, the HSM model under-predicted crashes for the whole State (1.39) as well as the three regions: Coast (1.53), Mountain (1.33), and Piedmont (1.32).

4.1.2. Urban Segments

For urban arterials, the four-year average calibration factor indicates that the HSM model under-predicted crashes for all facility types.

Table 8. Urban 2-Lane Undivided Segments (2U)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb2U	2016	170	104.98	**1.62**
Urb2U	2017	170	107.92	**1.58**
Urb2U	2018	181	112.40	**1.61**
Urb2U	2019	160	117.12	**1.37**
Urb2U	2016 - 2019	681	441.95	**1.54**

Table 9. Urban 2-Lane with TWLTL Segments (3T)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb3T	2016	163	78.94	**2.06**
Urb3T	2017	163	77.34	**2.11**
Urb3T	2018	154	76.52	**2.01**
Urb3T	2019	141	76.12	**1.85**
Urb3T	2016 - 2019	621	307.93	**2.02**

Table 10. Urban 4-Lane Undivided Segments (4U)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb4U	2016	196	86.51	**2.27**
Urb4U	2017	188	89.46	**2.10**
Urb4U	2018	198	92.48	**2.14**
Urb4U	2019	175	95.55	**1.83**
Urb4U	2016 - 2019	757	363.85	**2.08**

Table 11. Urban 4-Lane Divided Segments (4D)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb4D	2016	63	33.57	**1.88**
Urb4D	2017	53	33.88	**1.56**
Urb4D	2018	61	34.14	**1.79**
Urb4D	2019	50	34.42	**1.45**
Urb4D	2016 - 2019	227	135.97	**1.67**

Table 12. Urban 4-Lane with TWLTL Segments (5T)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb5T	2016	205	183.63	**1.12**
Urb5T	2017	255	187.77	**1.36**
Urb5T	2018	244	191.72	**1.27**
Urb5T	2019	225	195.73	**1.15**
Urb5T	2016 - 2019	929	758.69	**1.22**

4.1.3. Freeways

For freeway segments, the SPFs are broken down into four categories: multiple-vehicle fatal and injury (MV F&I), single-vehicle fatal and injury (SV F&I), multiple-vehicle PDO (MV PDO), and single-vehicle PDO (SV PDO) for each of the freeway facility types.

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 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 to exclude 0.5 miles on either side of a ramp (measuring from the taper point).

The lack of availability of some other data elements also led the researchers to assume base case scenarios for some CMFs, e.g., CMF for high volume (needed hourly AADT) and CMF for clear zone (clear zone width was not available for all segments).

The four-year average calibration factor indicates that for most part, the HSM model over-predicted single vehicle crashes and under predicted multiple vehicle crashes.

Table 13. Rural Freeways (4 through lanes)

Site Type	*Crash Type*	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur4Ln-FrWy	MV F&I	2016	12	11.72	**1.02**
Rur4Ln-FrWy	MV F&I	2017	16	13.24	**1.21**
Rur4Ln-FrWy	MV F&I	2018	18	13.51	**1.33**
Rur4Ln-FrWy	MV F&I	2019	18	13.87	**1.30**
Rur4Ln-FrWy	MV F&I	2016 - 2019	64	52.19	**1.23**
Rur4Ln-FrWy	MV PDO	2016	45	22.84	**1.97**
Rur4Ln-FrWy	MV PDO	2017	34	26.31	**1.29**
Rur4Ln-FrWy	MV PDO	2018	30	26.95	**1.11**
Rur4Ln-FrWy	MV PDO	2019	44	27.99	**1.57**
Rur4Ln-FrWy	MV PDO	2016 - 2019	153	103.41	**1.48**
Rur4Ln-FrWy	SV F&I	2016	27	26.04	**1.04**
Rur4Ln-FrWy	SV F&I	2017	16	27.64	**0.58**
Rur4Ln-FrWy	SV F&I	2018	18	28.08	**0.64**

Rur4Ln-FrWy	SV F&I	2019	19	28.45	**0.67**
Rur4Ln-FrWy	SV F&I	2016 - 2019	80	110.34	**0.73**
Rur4Ln-FrWy	SV PDO	2016	74	59.99	**1.23**
Rur4Ln-FrWy	SV PDO	2017	72	65.04	**1.11**
Rur4Ln-FrWy	SV PDO	2018	60	66.09	**0.91**
Rur4Ln-FrWy	SV PDO	2019	76	67.07	**1.13**
Rur4Ln-FrWy	SV PDO	2016 - 2019	282	258.31	**1.09**

Table 14. Urban Freeways (4 through lanes)

Site Type	*Crash Type*	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb4Ln-FrWy	MV F&I	2016	35	29.37	**1.19**
Urb4Ln-FrWy	MV F&I	2017	39	31.55	**1.24**
Urb4Ln-FrWy	MV F&I	2018	38	30.92	**1.23**
Urb4Ln-FrWy	MV F&I	2019	34	30.38	**1.12**
Urb4Ln-FrWy	MV F&I	2016 - 2019	146	122.06	**1.20**
Urb4Ln-FrWy	MV PDO	2016	96	57.25	**1.68**
Urb4Ln-FrWy	MV PDO	2017	105	62.71	**1.67**
Urb4Ln-FrWy	MV PDO	2018	107	60.91	**1.76**
Urb4Ln-FrWy	MV PDO	2019	109	59.57	**1.83**
Urb4Ln-FrWy	MV PDO	2016 - 2019	417	239.76	**1.74**
Urb4Ln-FrWy	SV F&I	2016	21	24.43	**0.86**
Urb4Ln-FrWy	SV F&I	2017	28	25.22	**1.11**
Urb4Ln-FrWy	SV F&I	2018	15	25.04	**0.60**
Urb4Ln-FrWy	SV F&I	2019	12	24.84	**0.48**
Urb4Ln-FrWy	SV F&I	2016 - 2019	76	99.57	**0.76**
Urb4Ln-FrWy	SV PDO	2016	70	68.23	**1.03**
Urb4Ln-FrWy	SV PDO	2017	51	71.24	**0.72**
Urb4Ln-FrWy	SV PDO	2018	72	70.50	**1.02**
Urb4Ln-FrWy	SV PDO	2019	55	69.72	**0.79**
Urb4Ln-FrWy	SV PDO	2016 - 2019	248	279.74	**0.89**

Table 15. Urban Freeways (6 through lanes)

Site Type	*Crash Type*	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb6Ln-FrWy	MV F&I	2016	70	61.04	**1.15**
Urb6Ln-FrWy	MV F&I	2017	75	63.44	**1.18**
Urb6Ln-FrWy	MV F&I	2018	77	63.81	**1.21**
Urb6Ln-FrWy	MV F&I	2019	79	64.33	**1.23**
Urb6Ln-FrWy	MV F&I	2016 - 2019	301	252.41	**1.19**
Urb6Ln-FrWy	MV PDO	2016	174	137.15	**1.27**
Urb6Ln-FrWy	MV PDO	2017	192	144.58	**1.33**
Urb6Ln-FrWy	MV PDO	2018	200	144.93	**1.38**
Urb6Ln-FrWy	MV PDO	2019	259	145.97	**1.77**
Urb6Ln-FrWy	MV PDO	2016 - 2019	825	571.51	**1.44**
Urb6Ln-FrWy	SV F&I	2016	24	36.72	**0.65**

Urb6Ln-FrWy	SV F&I	2017	23	37.21	**0.62**
Urb6Ln-FrWy	SV F&I	2018	41	37.52	**1.09**
Urb6Ln-FrWy	SV F&I	2019	28	37.79	**0.74**
Urb6Ln-FrWy	SV F&I	2016 - 2019	116	149.29	**0.78**
Urb6Ln-FrWy	SV PDO	2016	86	104.38	**0.82**
Urb6Ln-FrWy	SV PDO	2017	93	106.55	**0.87**
Urb6Ln-FrWy	SV PDO	2018	133	107.36	**1.24**
Urb6Ln-FrWy	SV PDO	2019	104	108.12	**0.96**
Urb6Ln-FrWy	SV PDO	2016 - 2019	416	426.47	**0.98**

Table 16. Urban Freeways (8 through lanes)

Site Type	*Crash Type*	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Urb8Ln-FrWy	MV F&I	2016	63	64.67	**0.97**
Urb8Ln-FrWy	MV F&I	2017	61	67.01	**0.91**
Urb8Ln-FrWy	MV F&I	2018	73	63.87	**1.14**
Urb8Ln-FrWy	MV F&I	2019	75	60.84	**1.23**
Urb8Ln-FrWy	MV F&I	2016 - 2019	272	256.25	**1.06**
Urb8Ln-FrWy	MV PDO	2016	178	143.76	**1.24**
Urb8Ln-FrWy	MV PDO	2017	179	150.43	**1.19**
Urb8Ln-FrWy	MV PDO	2018	202	140.80	**1.43**
Urb8Ln-FrWy	MV PDO	2019	245	131.77	**1.86**
Urb8Ln-FrWy	MV PDO	2016 - 2019	804	566.07	**1.42**
Urb8Ln-FrWy	SV F&I	2016	21	31.59	**0.66**
Urb8Ln-FrWy	SV F&I	2017	17	32.08	**0.53**
Urb8Ln-FrWy	SV F&I	2018	25	31.57	**0.79**
Urb8Ln-FrWy	SV F&I	2019	20	31.04	**0.64**
Urb8Ln-FrWy	SV F&I	2016 - 2019	83	126.30	**0.66**
Urb8Ln-FrWy	SV PDO	2016	64	92.40	**0.69**
Urb8Ln-FrWy	SV PDO	2017	65	94.39	**0.69**
Urb8Ln-FrWy	SV PDO	2018	97	92.12	**1.05**
Urb8Ln-FrWy	SV PDO	2019	80	89.81	**0.89**
Urb8Ln-FrWy	SV PDO	2016 - 2019	306	368.76	**0.83**

4.2. Calibration Factors for Intersection Models

Table 17 summarizes the number of intersections (by type/region) used for calculating calibration factors.

Table 17. Number of Intersections (by type/region) Used for Calibration

Intersection Type	*No. of Intersections*
Rur2L-3ST - All	208
Rur2L-3ST - Coast	47
Rur2L-3ST - Mountain	51
Rur2L-3ST - Piedmont	110
Rur2L-4SG - All	105
Rur2L-4SG - Coast	28
Rur2L-4SG - Mountain	18
Rur2L-4SG - Piedmont	59
Rur2L-4ST - All	234
Rur2L-4ST - Coast	103
Rur2L-4ST - Mountain	32
Rur2L-4ST - Piedmont	99
RurML-3ST	14
RurML-4SG	28
RurML-4ST	21
UrbArt-3SG	7
UrbArt-3ST	53
UrbArt-4SG	117
UrbArt-4ST	18

4.2.1. Rural Intersections

For rural two-lane intersection types, the four-year average calibration factor indicates that the HSM model over-predicted crashes for all facility types in all regions except for four-leg signalized intersections in the Coast region (1.17).

Table 18. Rural 2-Lane, Minor Road Stop-Controlled 3-Leg Intersections (3ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2L-3ST - All	2016	166	262.29	**0.63**
Rur2L-3ST - All	2017	182	263.72	**0.69**
Rur2L-3ST - All	2018	179	269.30	**0.66**
Rur2L-3ST - All	2019	195	274.78	**0.71**
Rur2L-3ST - All	2016 - 2019	722	1073.25	**0.67**

Table 19. Rural 2-Lane, Minor Road Stop-Controlled 3-Leg Intersections (3ST) – by region

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2L-3ST - Coast	2016	26	39.89	**0.65**
Rur2L-3ST - Coast	2017	25	39.43	**0.63**
Rur2L-3ST - Coast	2018	28	39.39	**0.71**
Rur2L-3ST - Coast	2019	21	39.02	**0.54**
Rur2L-3ST - Coast	2016 - 2019	100	158.20	**0.63**
Rur2L-3ST - Mountain	2016	39	74.22	**0.53**
Rur2L-3ST - Mountain	2017	50	75.91	**0.66**
Rur2L-3ST - Mountain	2018	46	78.74	**0.58**
Rur2L-3ST - Mountain	2019	65	81.35	**0.80**
Rur2L-3ST - Mountain	2016 - 2019	200	310.88	**0.64**
Rur2L-3ST - Piedmont	2016	101	148.18	**0.68**
Rur2L-3ST - Piedmont	2017	107	148.38	**0.72**
Rur2L-3ST - Piedmont	2018	105	151.17	**0.69**
Rur2L-3ST - Piedmont	2019	109	154.42	**0.71**
Rur2L-3ST - Piedmont	2016 - 2019	422	604.16	**0.70**

Table 20. Rural 2-Lane, Signalized 4-Leg Intersections (4SG) – by region

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2L-4SG - Coast	2016	120	115.85	**1.04**
Rur2L-4SG - Coast	2017	133	115.24	**1.15**
Rur2L-4SG - Coast	2018	144	115.32	**1.25**
Rur2L-4SG - Coast	2019	145	115.74	**1.25**
Rur2L-4SG - Coast	2016 - 2019	542	463.33	**1.17**
Rur2L-4SG - Mountain	2016	51	87.65	**0.58**
Rur2L-4SG - Mountain	2017	52	88.22	**0.59**
Rur2L-4SG - Mountain	2018	60	89.21	**0.67**
Rur2L-4SG - Mountain	2019	51	89.88	**0.57**
Rur2L-4SG - Mountain	2016 - 2019	214	355.69	**0.60**
Rur2L-4SG - Piedmont	2016	258	289.03	**0.89**
Rur2L-4SG - Piedmont	2017	253	297.71	**0.85**
Rur2L-4SG - Piedmont	2018	246	306.27	**0.80**
Rur2L-4SG - Piedmont	2019	251	313.90	**0.80**
Rur2L-4SG - Piedmont	2016 - 2019	1008	1209.11	**0.83**

Table 21. Rural 2-Lane, Minor Road Stop-Controlled 4-Leg Intersections (4ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2L-4ST - All	2016	290	360.88	**0.80**
Rur2L-4ST - All	2017	260	376.48	**0.69**
Rur2L-4ST - All	2018	276	394.36	**0.70**
Rur2L-4ST - All	2019	309	410.57	**0.75**
Rur2L-4ST - All	2016 - 2019	1135	1546.68	**0.73**

Table 22. Rural 2-Lane, Minor Road Stop-Controlled 4-Leg Intersections (4ST) – by region

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
Rur2L-4ST - Coast	2016	115	131.27	**0.88**
Rur2L-4ST - Coast	2017	124	136.66	**0.91**
Rur2L-4ST - Coast	2018	100	143.18	**0.70**
Rur2L-4ST - Coast	2019	144	149.01	**0.97**
Rur2L-4ST - Coast	2016 - 2019	483	562.39	**0.86**
Rur2L-4ST - Mountain	2016	40	62.43	**0.64**
Rur2L-4ST - Mountain	2017	22	63.32	**0.35**
Rur2L-4ST - Mountain	2018	46	64.72	**0.71**
Rur2L-4ST - Mountain	2019	40	65.68	**0.61**
Rur2L-4ST - Mountain	2016 - 2019	148	256.92	**0.58**
Rur2L-4ST - Piedmont	2016	135	167.18	**0.81**
Rur2L-4ST - Piedmont	2017	114	176.50	**0.65**
Rur2L-4ST - Piedmont	2018	130	186.46	**0.70**
Rur2L-4ST - Piedmont	2019	125	195.88	**0.64**
Rur2L-4ST - Piedmont	2016 - 2019	504	727.37	**0.69**

For rural multilane intersection types, the four-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 (0.58 and 0.32, respectively). Crashes were under-predicted for four-leg minor road stop-controlled intersections (1.15).

Table 23. Rural 4-Lane, Minor Road Stop-Controlled 3-Leg Intersections (3ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
RurML-3ST	2016	4	11.28	**0.35**
RurML-3ST	2017	4	11.41	**0.35**
RurML-3ST	2018	7	11.23	**0.62**
RurML-3ST	2019	11	11.08	**0.99**
RurML-3ST	2016 - 2019	26	44.94	**0.58**

Table 24. Rural 4-Lane, Signalized 4-Leg Intersections (4SG)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
RurML-4SG	2016	126	443.47	**0.28**
RurML-4SG	2017	163	442.39	**0.37**
RurML-4SG	2018	160	439.02	**0.36**
RurML-4SG	2019	125	441.82	**0.28**
RurML-4SG	2016 - 2019	574	1778.20	**0.32**

Table 25. Rural 4-Lane, Minor Road Stop-Controlled 4-Leg Intersections (4ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
RurML-4ST	2016	27	24.13	**1.12**
RurML-4ST	2017	28	25.35	**1.10**
RurML-4ST	2018	32	26.19	**1.22**
RurML-4ST	2019	32	26.83	**1.19**
RurML-4ST	2016 - 2019	119	103.19	**1.15**

4.2.2. Urban Arterial Intersections

For urban arterial intersection types, the four-year average calibration factor indicates that the HSM model under-predicted crashes for all facility types. The highest four-year average calibration factor (four-leg signalized intersections, 3.23) is supported by a sample of sites that contained greater than 1000 crashes/year.

Table 26. Urban Arterial, Signalized 3-Leg Intersections (3SG)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-3SG	2016	35	18.57	**1.89**
UrbArt-3SG	2017	50	18.98	**2.63**
UrbArt-3SG	2018	47	19.38	**2.43**
UrbArt-3SG	2019	41	19.77	**2.07**
UrbArt-3SG	2016 - 2019	173	76.72	**2.26**

Table 27. Urban Arterial, Stop-Controlled 3-Leg Intersections (3ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-3ST	2016	55	28.81	**1.91**
UrbArt-3ST	2017	72	29.83	**2.41**
UrbArt-3ST	2018	81	30.86	**2.62**
UrbArt-3ST	2019	83	31.90	**2.60**
UrbArt-3ST	2016 - 2019	291	121.41	**2.40**

Table 28. Urban Arterial, Signalized 4-Leg Intersections (4SG)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-4SG	2016	1503	460.08	**3.27**
UrbArt-4SG	2017	1509	465.16	**3.24**
UrbArt-4SG	2018	1527	470.10	**3.25**
UrbArt-4SG	2019	1499	474.35	**3.16**
UrbArt-4SG	2016 - 2019	6038	1871.28	**3.23**

Table 29. Urban Arterial, Stop-Controlled 4-Leg Intersections (4ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-4ST	2016	31	30.64	**1.01**
UrbArt-4ST	2017	41	31.53	**1.30**
UrbArt-4ST	2018	51	32.16	**1.59**
UrbArt-4ST	2019	44	32.72	**1.34**
UrbArt-4ST	2016 - 2019	167	127.20	**1.31**

4.3. Quick Reference Tables

Tables 31 – 36 are quick reference tables showing 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***.

Table 30. Rural Segments Quick Reference Table

Site Type	***Region***	***2016***	***2017***	***2018***	***2019***	***2016-2019***
Rur2U	All	***1.29***	***1.30***	***1.25***	***1.30***	***1.29***
Rur2U	Coast	***1.57***	***1.54***	***1.63***	***1.46***	***1.55***
Rur2U	Mountain	***1.12***	***1.25***	***1.19***	***1.30***	***1.21***
Rur2U	Piedmont	***1.32***	***1.23***	***1.10***	***1.21***	***1.21***
Rur4D	All	***1.25***	***1.45***	***1.45***	***1.41***	***1.39***
Rur4D	Coast	***1.53***	***1.78***	***1.47***	***1.36***	***1.53***
Rur4D	Mountain	***1.09***	***1.33***	***1.52***	***1.39***	***1.33***
Rur4D	Piedmont	***1.17***	***1.29***	***1.36***	***1.46***	***1.32***

Table 31. Urban Segments Quick Reference Table

Site Type	***2016***	***2017***	***2018***	***2019***	***2016-2019***
Urb2U	***1.62***	***1.58***	***1.61***	***1.37***	***1.54***
Urb3T	***2.06***	***2.11***	***2.01***	***1.85***	***2.02***
Urb4U	***2.27***	***2.10***	***2.14***	***1.83***	***2.08***
Urb4D	1.88	1.56	1.79	1.45	1.67
Urb5T	***1.12***	***1.36***	***1.27***	***1.15***	***1.22***

Table 32. Freeways Quick Reference Table

Site type	*Crash Type*	*2016*	*2017*	*2018*	*2019*	*2016-2019*
Rur4Ln-FrWy	MV F&I Crashes	1.02*	1.21*	1.33*	1.30*	1.23*
Rur4Ln-FrWy	MV PDO Crashes	1.97	1.29	1.11	1.57	1.48
Rur4Ln-FrWy	SV F&I Crashes	1.04	0.58*	0.64*	0.67*	0.73*
Rur4Ln-FrWy	SV PDO Crashes	1.23	1.11	0.91	1.13	1.09
Urb4Ln-FrWy	MV F&I Crashes	1.19	1.24	1.23	1.12	1.20
Urb4Ln-FrWy	MV PDO Crashes	1.68	***1.67***	***1.76***	***1.83***	***1.74***
Urb4Ln-FrWy	SV F&I Crashes	0.86	1.11	0.60*	0.48*	0.76*
Urb4Ln-FrWy	SV PDO Crashes	1.03	0.72	1.02	0.79	0.89
Urb6Ln-FrWy	MV F&I Crashes	1.15	1.18	1.21	1.23	1.19
Urb6Ln-FrWy	MV PDO Crashes	***1.27***	***1.33***	***1.38***	***1.77***	***1.44***
Urb6Ln-FrWy	SV F&I Crashes	0.65	0.62	1.09	0.74	0.78
Urb6Ln-FrWy	SV PDO Crashes	0.82	0.87	***1.24***	***0.96***	***0.98***
Urb8Ln-FrWy	MV F&I Crashes	0.97	0.91	1.14	1.23	1.06
Urb8Ln-FrWy	MV PDO Crashes	***1.24***	***1.19***	***1.43***	***1.86***	***1.42***
Urb8Ln-FrWy	SV F&I Crashes	0.66	0.53	0.79	0.64	0.66
Urb8Ln-FrWy	SV PDO Crashes	0.69	0.69	1.05	0.89	0.83

**Calibration factors based on less than 20 observed crashes per year*

Table 33. Rural 2-Lane Intersections Quick Reference Table

Intersection Type	*Region*	*2016*	*2017*	*2018*	*2019*	*2016-2019*
Rur2L-3ST	All	***0.63***	***0.69***	***0.66***	***0.71***	***0.67***
Rur2L-3ST	Coast	0.65	0.63	0.71	0.54	0.63
Rur2L-3ST	Mountain	0.53	0.66	0.58	0.80	0.64
Rur2L-3ST	Piedmont	***0.68***	***0.72***	***0.69***	***0.71***	***0.70***
Rur2L-4SG	All	***0.87***	***0.87***	***0.88***	***0.86***	***0.87***
Rur2L-4SG	Coast	***1.04***	***1.15***	***1.25***	***1.25***	***1.17***
Rur2L-4SG	Mountain	0.58	0.59	0.67	0.57	0.60
Rur2L-4SG	Piedmont	***0.89***	***0.85***	***0.80***	***0.80***	***0.83***
Rur2L-4ST	All	***0.80***	***0.69***	***0.70***	***0.75***	***0.73***
Rur2L-4ST	Coast	***0.88***	***0.91***	***0.70***	***0.97***	***0.86***
Rur2L-4ST	Mountain	0.64	0.35	0.71	0.61	0.58
Rur2L-4ST	Piedmont	***0.81***	***0.65***	***0.70***	***0.64***	***0.69***

Table 34. Rural 4-Lane Intersections Quick Reference Table

Intersection Type	*2016*	*2017*	*2018*	*2019*	*2016-2019*
RurML-3ST	0.35*	0.35*	0.62*	0.99*	0.58*
RurML-4SG	***0.28***	***0.37***	***0.36***	***0.28***	***0.32***
RurML-4ST	1.12	1.10	1.22	1.19	1.15

**Calibration factors based on less than 20 observed crashes per year*

Table 35. Urban Arterial Intersections Quick Reference Table

Intersection Type	*2016*	*2017*	*2018*	*2019*	*2016-2019*
UrbArt-3SG	1.89	2.63	2.43	2.07	2.26
UrbArt-3ST	1.91	2.41	2.62	2.60	2.40
UrbArt-4SG	***3.27***	***3.24***	***3.25***	***3.16***	***3.23***
UrbArt-4ST	1.01	1.30	1.59	1.34	1.31

5. Recommendations

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.

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. 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.

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References

Bahar, G., (2014), User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors, NCHRP 20-07 Task 332, National Cooperative Highway Research Program, Transportation Research Board.

Bonneson, J., S. Geedipally, M. Pratt, and D. Lord, (2012), NCHRP 17-45: Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges, NCHRP 17-45, National Cooperative Highway Research Program, Transportation Research Board.

Hauer, E. and J. Bamfo (1997), Two Tools for Finding What Function Links the Dependent Variable to the Explanatory Variables, *Presented at the ICTCT Conference*, Lund, Sweden.

HSM (2010), Highway Safety Manual, AASHTO.

Hummer, J., R. Haley, S. Ott, R. Foyle, and C. Cunningham, (2010a), Superstreet Benefits and Capacities, Report FHWA/NC/2009-06, North Carolina Department of Transportation.

Hummer, J., W. Rasdorf, D. Findley, C. Zegeer, and C. Sundstrom, (2010b), Procedure for curve warning signing, delineation, and advisory speeds for horizontal curves, Report FHWA/NC/2009-07, North Carolina Department of Transportation.

Smith, S., D. Carter, and R. Srinivasan (2017), Updated and Regional Calibration Factors For Highway Safety Manual Crash Prediction Models, Report FHWA/NC/2016-09, North Carolina Department of Transportation.

Srinivasan, R. and D. Carter (2011), Development of Safety Performance Functions for North Carolina, Report FHWA/NC/2010-09, North Carolina Department of Transportation.

Srinivasan, R., B. Lan, and D. Carter, (2014), Safety Evaluation of Signal Installation With and Without Left Turn Lanes on Two Lane Roads in Rural and Suburban Areas, FHWA/NC/2013-11, North Carolina Department of Transportation.

R. Srinivasan, M. Colety, G. Bahar, B. Crowther, and M. Farmen (2016), Estimation of Calibration Functions for Predicting Crashes on Rural Two Lane Roads in Arizona, *Transportation Research Record: Journal of the Transportation Research Board* 2583, pp. 17-24, Washington, D.C.

Appendix A. Missing Minor Road AADTs (Urban Arterial Intersections)

For some of urban arterial intersections, minor road AADTs were not available. Only using urban arterial intersections with minor road AADTs diminishes the sample used for calibration for these intersection types. The calibration factors reported in Chapter 4 of this report are based only on urban arterial intersections for which minor road AADTs were available. As can be seen from Table A-1, this leads to 40 intersections being excluded from calibration factor calculations.

Table A-1: Number of Urban Arterial Intersections (with/without Minor Road AADTs)

Intersection Type	***No. of Intersections (with Minor Road AADTs)***	***No. of Intersections (with/without Minor Road AADTs)***
UrbArt-3SG	7	9
UrbArt-3ST	53	72
UrbArt-4SG	117	129
UrbArt-4ST	18	25

To include all intersections in the calibration procedure, the research team interpolated the missing minor road AADTs using the following steps:

1. Calculate the minimum, maximum, average, and the standard deviation of the available minor road AADTs as a percentage of major road AADT by intersection type.
2. Use Microsoft Excel's uniform random number generator to randomly generate the missing minor road AADTs as percentage of major road AADT with upper and lower bounds defined as the average percentage of the available minor road AADTs ±1 standard deviation.

The research team conduced a sensitivity analysis to determine the effect of minor road AADTs on the calibration factors and found variations in calibration factors to be in the ±2% range for the various randomly generated minor road AADT samples.

Tables A-2 to A-6 present updated calibration factors for urban arterial intersection types including both sites with available minor road AADTs and sites with minor road AADTs interpolated using the procedure described above.

Table A-2. Urban Arterial, Signalized 3-Leg Intersections (3SG)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-3SG	2016	46	22.80	**2.02**
UrbArt-3SG	2017	70	23.45	**2.99**
UrbArt-3SG	2018	59	24.08	**2.45**
UrbArt-3SG	2019	58	24.72	**2.35**
UrbArt-3SG	2016 - 2019	233	95.06	**2.45**

Table A-3. Urban Arterial, Stop-Controlled 3-Leg Intersections (3ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-3ST	2016	100	66.95	**1.49**
UrbArt-3ST	2017	116	71.94	**1.61**
UrbArt-3ST	2018	131	77.16	**1.70**
UrbArt-3ST	2019	122	82.57	**1.48**
UrbArt-3ST	2016 - 2019	469	298.13	**1.57**

Table A-436. Urban Arterial, Signalized 4-Leg Intersections (4SG)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-4SG	2016	1596	509.63	**3.13**
UrbArt-4SG	2017	1577	516.21	**3.05**
UrbArt-4SG	2018	1602	522.73	**3.06**
UrbArt-4SG	2019	1578	528.62	**2.99**
UrbArt-4SG	2016 - 2019	6353	2078.61	**3.06**

Table A-5. Urban Arterial, Stop-Controlled 4-Leg Intersections (4ST)

Site Type	*Year*	*Obs. Crashes*	*Pred. Crashes*	*Calib. Factor*
UrbArt-4ST	2016	57	46.37	**1.23**
UrbArt-4ST	2017	57	48.54	**1.17**
UrbArt-4ST	2018	64	50.46	**1.27**
UrbArt-4ST	2019	56	52.32	**1.07**
UrbArt-4ST	2016 - 2019	234	197.82	**1.18**

Table A-6. Urban Arterial Intersections (Updated Quick Reference Table)

Intersection Type	***2016***	***2017***	***2018***	***2019***	***2016-2019***
UrbArt-3SG	2.02	2.99	2.45	2.35	2.45
UrbArt-3ST	***1.49***	***1.61***	***1.70***	***1.48***	***1.57***
UrbArt-4SG	***3.13***	***3.05***	***3.06***	***2.99***	***3.06***
UrbArt-4ST	1.23	1.17	1.27	1.07	1.18

The four-year average calibration factors still indicate that the HSM models under-predicted crashes for all urban arterial intersection types. However, the increased sample led to the calibration factor for three-leg, stop-controlled intersections to be based on the HSM desired sample size of at least 100 observed crashes per year.

Appendix B. Crash Proportion Tables

2016 – 2019 North Carolina crash data from the sites selected for this effort were used to prepare the crash proportion tables for rural two-lane roads, rural four-lane divided roads, urban arterials, and freeway segments.

The table numbering is being kept consistent with HSM for easy reference.

Table 10-3: Distribution for Crash Severity Level on Rural Two-Lane, Two-Way Roadway Segments

Crash Severity Level	Percentage of Total Roadway Segment Crashes
Fatal	0.82
Incapacitating Injury	2.73
Non-incapacitating Injury	10.15
Possible injury	17.15
Total fatal plus injury	30.85
Property damage only	66.35
Unknown	2.80
Total (should sum to 100)	100.00

Table 10-4: Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Roadway Segments

Collision Type	Percentage of Total Roadway Segment Crashes by Crash Severity Level		
	Total Fatal and Injury	Property Damage Only	Total (All Severity Levels Combined)
SINGLE-VEHICLE CRASHES			
Collision with animal	4.03	36.06	25.97
Collision with bicycle	0.65	0.05	0.24
Collision with pedestrian	0.87	0.10	0.34
Overturned	7.52	2.16	3.85
Ran off road	45.69	28.13	33.67
Other single-vehicle crash	2.51	3.31	3.06
Total single-vehicle crashes	61.29	69.81	67.12
MULTIPLE-VEHICLE CRASHES			
Angle collision	3.60	2.41	2.78
Head-on collision	3.82	0.50	1.55
Rear-end collision	13.52	11.33	12.02
Sideswipe collision	6.00	6.02	6.01
Other multiple-vehicle collision	11.78	9.93	10.51
Total multiple-vehicle crashes	38.71	30.19	32.88
Total Crashes (should sum to 100)	100.00	100.00	100.00

Table 10-12: Nighttime Crash Proportions for Rural Unlighted Roadway Segments

Roadway Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury	PDO	
Rural Two-Lane, Two-Way	0.270	0.730	0.448

Table 10-5: Distribution for Crash Severity Level at Rural Two-Lane, Two-Way Intersections

	Percentage of Total Intersection Crashes		
Crash Severity Level	**Three-Leg Stop-Controlled Intersections**	**Four-Leg Stop-Controlled Intersections**	**Four-Leg Signalized Intersections**
Fatal	0.27	2.02	0.17
Incapacitating Injury	2.12	3.16	1.16
Non-incapacitating Injury	11.16	16.23	7.72
Possible injury	19.65	23.95	20.23
Total fatal plus injury	33.20	45.35	29.27
Property damage only	64.54	53.51	70.07
Unknown	2.26	1.14	0.66
Total (should sum to 100)	100	100	100

Table 10-6: Distribution by Collision Type and Manner of Collision at Rural Two-Lane, Two-Way Intersections

Collision Type	Percentage of Total Crashes by Collision Type								
	Three-Leg Stop-Controlled Intersections			Four-Leg Stop-Controlled Intersections			Four-Leg Signalized Intersections		
	Fatal and Injury	Property Damage Only	Total	Fatal and Injury	Property Damage Only	Total	Fatal and Injury	Property Damage Only	Total
SINGLE-VEHICLE CRASHES									
Collision with animal	1.60	7.20	5.30	0.00	5.74	3.11	0.19	1.97	1.44
Collision with bicycle	1.20	0.00	0.41	0.39	0.00	0.18	0.00	0.08	0.06
Collision with pedestrian	0.00	0.00	0.00	0.77	0.00	0.35	1.13	0.08	0.39
Overturned	2.40	0.82	1.36	0.97	0.82	0.89	0.38	0.08	0.17
Ran off road	26.80	18.31	21.20	5.42	11.48	8.70	4.52	6.53	5.94
Other single-vehicle crash	0.40	0.41	0.41	0.58	0.00	0.27	0.19	0.00	0.06
Total single-vehicle crashes	32.40	26.75	28.67	8.12	18.03	13.49	6.40	8.73	8.05
MULTIPLE-VEHICLE CRASHES									
Angle collision	2.80	5.56	4.62	61.90	37.54	48.71	25.61	12.12	16.09
Head-on collision	2.80	0.41	1.22	1.35	0.33	0.80	0.94	0.47	0.61
Rear-end collision	26.80	37.45	33.83	12.19	16.23	14.37	32.02	41.54	38.73
Sideswipe collision	4.40	5.14	4.89	0.97	2.79	1.95	2.64	8.10	6.49
Other multiple-vehicle	30.80	24.69	26.77	15.47	25.08	20.67	32.39	29.03	30.02
Total multiple-vehicle crashes	67.60	73.25	71.33	91.88	81.97	86.51	93.60	91.27	91.95
Total Crashes (should sum to 100)	100	100	100	100	100	100	100	100	100

Table 10-15: Nighttime Crash Proportions for Rural Two-Way, Two-Lane Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
Three-Leg Stop-Controlled	0.235
Four-Leg Stop-Controlled	0.193
Four-Leg Signalized	0.124

Table 11-6: Distribution of Crashes by Collision Type and Crash Severity Level for Rural 4-Lane Divided Roadway Segments

	Proportion of Crashes by Collision Type and Crash Severity Level			
	Severity Level			
Collision Type	Total	Fatal and Injury (KABC)	Fatal and Injury (KAB only)	PDO
Head-on	0.003	0.007	0.009	0.001
Sideswipe	0.088	0.055	0.017	0.102
Rear-end	0.147	0.216	0.107	0.116
Angle	0.060	0.130	0.106	0.029
Single	0.599	0.454	0.668	0.664
Other	0.104	0.139	0.095	0.088
Total (should sum to 1)	1.000	1.000	1.000	1.000
Single (without Animal)	0.376	0.428	0.659	0.353

Table 11-19: Nighttime Crash Proportions for Rural Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		
Roadway Type	Fatal and Injury	PDO	Proportion of Crashes that Occur at Night
Rural 4-Lane Divided	0.253	0.747	0.414

Table 11-9: Distribution of Rural 4-Lane Intersection Crashes by Collision Type and Crash Severity

Proportion of Crashes by Collision Type and Crash Severity Level				
	Three-Leg Intersections with Minor-Road Stop Control			
Collision Type	**Total**	**Fatal and Injury (KABC)**	**Fatal and Injury (KAB only)**	**PDO**
Head-on	0.000	0.000	--	0.000
Sideswipe	0.107	0.000	--	0.150
Rear-end	0.429	0.375	--	0.450
Angle	0.071	0.250	--	0.000
Single	0.250	0.125	--	0.300
Other	0.143	0.250	--	0.100
Total (should sum to 1)	1.000	1.000	--	1.000
	Four-Leg Intersections with Minor-Road Stop Control			
Collision Type	**Total**	**Fatal and Injury (KABC)**	**Fatal and Injury (KAB only)**	**PDO**
Head-on	0.008	0.016	--	0.000
Sideswipe	0.050	0.016	--	0.086
Rear-end	0.025	0.000	--	0.052
Angle	0.508	0.710	--	0.293
Single	0.142	0.048	--	0.241
Other	0.267	0.210	--	0.328
Total (should sum to 1)	1.000	1.000	--	1.000
	Three-Leg Signalized Intersections			
Collision Type	**Total**	**Fatal and Injury (KABC)**	**Fatal and Injury (KAB only)**	**PDO**
Head-on	--	--	--	--
Sideswipe	--	--	--	--
Rear-end	--	--	--	--
Angle	--	--	--	--
Single	--	--	--	--
Other	--	--	--	--
Total (should sum to 1)	--	--	--	--
	Four-Leg Signalized Intersections			
Collision Type	**Total**	**Fatal and Injury (KABC)**	**Fatal and Injury (KAB only)**	**PDO**
Head-on	0.014	0.027	--	0.008
Sideswipe	0.103	0.021	--	0.142
Rear-end	0.395	0.314	--	0.435
Angle	0.214	0.367	--	0.140
Single	0.054	0.043	--	0.060
Other	0.220	0.229	--	0.215
Total (should sum to 1)	1.000	1.000	--	1.000

Table 11-24: Nighttime Crash Proportions for Rural 4-Lane Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
3-leg stop controlled with minor road stop control	0.200
4-leg stop controlled with minor road stop control	0.176

Table 12-4: Distribution of Multiple-Vehicle Nondriveway Collisions for Urban Roadway Segments by Manner of Collision Type

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.624	0.639	0.530	0.490	0.418	0.438	0.401	0.443	0.343	0.364
Head-on collision	0.021	0.009	0.045	0.003	0.018	0.002	0.019	0.007	0.025	0.003
Angle collision	0.085	0.093	0.164	0.176	0.227	0.135	0.273	0.176	0.267	0.169
Sideswipe, same direction	0.014	0.056	0.037	0.092	0.045	0.235	0.067	0.215	0.055	0.215
Sideswipe, opposite direction	0.057	0.043	0.000	0.028	0.009	0.009	0.019	0.010	0.021	0.022
Other multiple-vehicle collisions	0.199	0.160	0.224	0.210	0.282	0.181	0.221	0.149	0.288	0.227
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 12-6: Distribution of Single-Vehicle Crashes for Urban Roadway Segments by Collision Type

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with animal	0.051	0.284	0.029	0.294	0.000	0.132	0.000	0.385	0.023	0.314
Collision with fixed object	0.017	0.090	0.029	0.059	0.000	0.053	0.000	0.103	0.023	0.039
Collision with other object	0.119	0.224	0.143	0.235	0.057	0.263	0.086	0.154	0.182	0.235
Other single-vehicle collision	0.814	0.403	0.800	0.412	0.943	0.553	0.914	0.359	0.773	0.412
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B-1: Total Crash Proportions for Collision Types Presented in Table 12-4

Collision Type	Proportion of Total Crashes for Specific Road Types				
	2U	3T	4U	4D	5T
	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)
Rear-end collision	0.632	0.510	0.428	0.422	0.354
Head-on collision	0.015	0.024	0.010	0.013	0.014
Angle collision	0.089	0.170	0.181	0.225	0.218
Sideswipe, same direction	0.035	0.065	0.140	0.141	0.135
Sideswipe, opposite direction	0.050	0.014	0.009	0.014	0.022
Other multiple-vehicle collisions	0.180	0.217	0.232	0.185	0.257
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000

Table B-2: Total Crash Proportions for Collision Types Presented in Table 12-6

Collision Type	Proportion of Total Crashes for Specific Road Types				
	2U	3T	4U	4D	5T
	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)
Collision with animal	0.167	0.161	0.066	0.192	0.168
Collision with fixed object	0.053	0.044	0.026	0.051	0.031
Collision with other object	0.171	0.189	0.160	0.120	0.209
Other single-vehicle collision	0.608	0.606	0.748	0.637	0.592
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000

Table 12-21: Proportion of Urban Fixed-Object Crashes

Road Type	Proportion of Fixed-Object Collisions
2-lane undivided	0.056
2-lane with TWLTL	0.041
4-lane undivided	0.016
4-lane divided	0.012
4-lane with TWLTL	0.022

Table 12-23: Nighttime Crash Proportions for Urban Unlighted Roadway Segments

Roadway Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury	PDO	
2-lane undivided	0.286	0.714	0.125
2-lane with TWLTL	0.305	0.695	0.005
4-lane undivided	0.382	0.618	0.074
4-lane divided	0.444	0.556	0.018
4-lane with TWLTL	0.390	0.610	0.030

Table 12-11: Distribution of Multiple-Vehicle Collisions for Urban Intersections by Collision Type

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types							
	3-leg stop control with minor road stop control		3-leg signalized		4-leg stop controlled with minor road stop control		4-leg signalized	
	Fatal and Injury	PDO	Fatal and Injury	PDO	Fatal and Injury	PDO	Fatal and Injury	PDO
Rear-end collision	0.421	0.391	0.421	0.459	0.147	0.248	0.412	0.448
Head-on collision	0.041	0.000	0.018	0.000	0.027	0.008	0.033	0.009
Angle collision	0.223	0.210	0.263	0.145	0.587	0.376	0.287	0.179
Sideswipe	0.058	0.192	0.000	0.195	0.013	0.143	0.059	0.175
Other multiple-vehicle collisions	0.256	0.207	0.298	0.201	0.227	0.226	0.208	0.189
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B-3: Total Crash Proportions for Collision Types Presented in Table 12-11

Collision Type	Proportion of Total Crashes for Specific Road Types			
	3-leg stop control with minor road stop control	3-leg signalized	4-leg stop controlled with minor road stop control	4-leg signalized
	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)
Rear-end collision	0.406	0.440	0.197	0.430
Head-on collision	0.021	0.009	0.017	0.021
Angle collision	0.217	0.204	0.481	0.233
Sideswipe	0.125	0.097	0.078	0.117
Other multiple-vehicle collisions	0.231	0.250	0.226	0.199
Total (should sum to 1)	1.000	1.000	1.000	1.000

Table 12-13: Distribution of Single-Vehicle Crashes for Urban Intersections by Collision Type

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types							
	3-leg stop control with minor road stop control		3-leg signalized		4-leg stop controlled with minor road stop control		4-leg signalized	
	Fatal and Injury	PDO	Fatal and Injury	PDO	Fatal and Injury	PDO	Fatal and Injury	PDO
Collision with parked vehicle	0.000	0.030	0.200	0.000	0.000	0.091	0.014	0.020
Collision with animal	0.036	0.182	0.000	0.286	0.000	0.182	0.014	0.095
Collision with fixed object	0.107	0.152	0.000	0.143	0.222	0.182	0.106	0.250
Collision with other object	0.000	0.061	0.000	0.000	0.000	0.000	0.000	0.075
Other single-vehicle collision	0.857	0.515	0.800	0.571	0.667	0.545	0.782	0.445
Non Collision	0.000	0.061	0.000	0.000	0.111	0.000	0.085	0.115
Total (should sum to 1)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B-4: Total Crash Proportions for Collision Types Presented in Table 12-13

Collision Type	Proportion of Total Crashes for Specific Road Types			
	3-leg stop control with minor road stop control	3-leg signalized	4-leg stop controlled with minor road stop control	4-leg signalized
	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)	Total (FI + PDO)
Collision with parked vehicle	0.015	0.100	0.045	0.017
Collision with animal	0.109	0.143	0.091	0.055
Collision with fixed object	0.129	0.071	0.202	0.178
Collision with other object	0.030	0.000	0.000	0.038
Other single-vehicle collision	0.686	0.686	0.606	0.613
Non Collision	0.030	0.000	0.056	0.100
Total (should sum to 1)	1.000	1.000	1.000	1.000

Table 12-27: Nighttime Crash Proportions for Urban Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night
3-leg stop controlled with minor road stop control	0.093
4-leg stop controlled with minor road stop control	0.065
3- and 4-leg signalized	0.024

Table 18-6: Distribution of Multiple-Vehicle Crashes by Crash Type for Freeway Segments

Area Type	Crash Type Category	Proportion of Crashes by Severity	
		Fatal and Injury	PDO
Rural	Head-on	0.017	0.008
	Right-angle	0.000	0.000
	Rear-end	0.759	0.492
	Sideswipe	0.207	0.469
	Other multiple-vehicle crashes	0.017	0.031
	Total (should sum to 1)	1.000	1.000
Urban	Head-on	0.011	0.003
	Right-angle	0.021	0.013
	Rear-end	0.686	0.578
	Sideswipe	0.224	0.367
	Other multiple-vehicle crashes	0.057	0.039
	Total (should sum to 1)	1.000	1.000

Table B-5: Total Crash Proportions for Collision Types Presented in Table 18-6

Area Type	Crash Type Category	Proportion of Total Crashes
		Total (FI + PDO)
Rural	Head-on	0.013
	Right-angle	0.000
	Rear-end	0.625
	Sideswipe	0.338
	Other multiple-vehicle crashes	0.024
	Total (should sum to 1)	1.000
Urban	Head-on	0.007
	Right-angle	0.017
	Rear-end	0.632
	Sideswipe	0.296
	Other multiple-vehicle crashes	0.048
	Total (should sum to 1)	1.000

Table 18-8: Distribution of Single-Vehicle Crashes by Crash Type for Freeway Segments

Area Type	Crash Type Category	Proportion of Crashes by Severity	
		Fatal and Injury	PDO
Rural	Crash with animal	0.077	0.238
	Crash with fixed object	0.667	0.534
	Crash with other object	0.038	0.146
	Crash with parked vehicle	0.000	0.000
	Other single-vehicle crashes	0.218	0.082
	Total (should sum to 1)	1.000	1.000
Urban	Crash with animal	0.020	0.109
	Crash with fixed object	0.614	0.492
	Crash with other object	0.034	0.223
	Crash with parked vehicle	0.000	0.000
	Other single-vehicle crashes	0.332	0.175
	Total (should sum to 1)	1.000	1.000

Table B-6: Total Crash Proportions for Collision Types Presented in Table 18-8

Area Type	Crash Type Category	Proportion of Total Crashes
		Total (FI + PDO)
Rural	Crash with animal	0.158
	Crash with fixed object	0.600
	Crash with other object	0.092
	Crash with parked vehicle	0.000
	Other single-vehicle crashes	0.150
	Total (should sum to 1)	1.000
Urban	Crash with animal	0.065
	Crash with fixed object	0.553
	Crash with other object	0.128
	Crash with parked vehicle	0.000
	Other single-vehicle crashes	0.254
	Total (should sum to 1)	1.000