**NCHRP 17-93: Updating Safety Performance Functions for Data-Driven Safety Analysis**

**Working White Paper: Guidelines on the Use of Combined Calibration for Similar Site Types, or Crash Types and Severity Categories of Interest**

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Introduction

Practitioners are often faced with the decision on whether to combine calibration data for similar site types, or crash types and severity categories of interest. There are two issues to consider here:

* To offset the increase in the number of models to be calibrated, can prediction models developed for some site types be calibrated using a common database including different site types?
* To offset the increases in the number of models to be calibrated and the size of the calibration database, can a calibration factor for a prediction model that represents total crashes be used to obtain reliable estimates when this factor is used with a prediction model for predicting specific crash types, severity categories, or both?

The rest of this document is structured as follows. The next two sections provide a background of both these issues and a summary of the approach discussed by Bahar (2014) for addressing the two issues mentioned above. This is followed by a brief overview of the prediction models from the 1st edition of the HSM (HSM, 2010) for rural roads and urban arterials. An overview of the data that were collected is discussed next. This is followed by a summary of the results based on the approach described in Bahar (2014) and the resulting guidance.

Background

Combined Calibration Data for Similar Site Types

Crash prediction models (also known as safety performance functions (SPFs)) are increasing in number in response to the need to address more of the various site types that exist on roadways. This increase allows analysts to evaluate a wider range of site types, but it also increases the number of models that need to be calibrated and updated.

* Facility Type of Interest

The facility type designation is used to categorize roadways into categories with distinctly different speed environments, access functions, and design criteria. These characteristics tend to have a significant influence on traveler safety. It is rationalized that SPF reliability will be improved when it is developed for a specific facility type. Facility type descriptors typically include area type (i.e., urban, or rural) and road class (e.g., freeway, highway, arterial street). The facility types recognized in Part C of the 1st edition of HSM include:

* Rural, two-lane roads,
* Rural multilane highways,
* Urban and suburban arterial streets,
* Rural and urban freeways, and
* Rural and urban interchange ramps.

The facility type of interest is used to identify the SPFs to be calibrated. Documentation describing the development of each candidate SPF should be consulted to determine whether it is a match to the facility type of interest.

* Site Types of Interest

Each SPF is developed for application to a specific site type. There are two main site type categories: segment and intersection. Within the segment category, a site type can be designated by its area type (i.e., urban, or rural), number of through lanes, and functional classification. Within the intersection category, a site type can be designated by its area type, number of legs, traffic control type (e.g., signal), and design configuration (e.g., conventional intersection, roundabout).

For safety evaluation, a facility is considered to consist of one or more sites. For this reason, there is some overlap in the facility-type and site-type designations such that some site-type categories are predetermined once the facility type of interest is identified. For example, “area type” is both a facility-type category and a site-type category. If the facility type of interest is designated to include only urban facilities, then the site type of interest is also designated as urban.

The site type of interest is used to identify the SPF to be calibrated. Documentation describing the development of the candidate SPF should be consulted to determine whether it is a match to the site type of interest. This documentation should be reviewed to identify the specific definition and criteria used to define the site type represented by the candidate SPF. The HSM Part C chapters describe the definition and segmentation criteria used to identify each site type category associated with a HSM SPF.

In an effort to offset the increase in the number of models to be calibrated, this research attempts to determine if the SPFs for some site types can be calibrated using a common database. That is, one calibration database is assembled to include a mix of the site types of interest (e.g., urban street segments with divided or undivided cross sections) and is then used to compute one calibration factor for all site types represented in the database. The approach makes the calibration process more efficient because the minimum site sample size is not increased by the presence of two or more site types in the database.

Reliability of Extrapolating Calibration Factor Across Crash Type and Severity Categories

SPFs are increasing in number in response to the need to address unique combinations of crash type and severity category. This increase allows analysts to reliably estimate specific types and categories, but it also increases the number of models that need to be calibrated and updated. It can also increase the minimum site sample size when the crash type and severity category of interest represents a relatively rare crash event.

Each SPF is developed to predict a specific crash type and severity category. Some of the crash types represented by SPFs in the HSM include:

* All crash types combined,
* Single-vehicle crashes,
* Multiple-vehicle crashes,
* Vehicle-pedestrian crashes and
* Vehicle-bicycle crashes.

Similarly, several different crash severity categories have been used. Some of those represented by CPMs in the HSM include:

* All severities combined,
* Fatal-and-injury combined (i.e., K, A, B, or C severity designation), and
* KAB combined.

If the SPF is developed to predict crashes of all types and severity categories, then it is considered to predict “total” crashes.

The crash type and severity category of interest is referred to hereafter as the “target crashes.” The target crashes are used to identify the SPF to be calibrated. Documentation describing the development of the candidate CPM should be consulted to determine whether it is a match to the target crashes. The HSM Part C chapters describe the target crashes associated with a HSM SPF.

In an effort to offset the resulting increase in the number of models to be calibrated and the size of the calibration database, this research attempts to determine if the calibration factor for a SPF that represents total crashes can be used to obtain reliable estimates when this factor is used with a SPF for predicting specific crash types, severity categories, or both. In other words, can the calibration factor for total crashes be computed and used as the calibration factor for a SPF that predicts a specific crash type and severity category (e.g., single-vehicle fatal-and-injury crashes)?

Overview of Approach Discussed by Bahar (2014)

Bahar (2014) presented an approach developed by Dr. Ezra Hauer to determine how many crashes are needed to estimate a calibration factor to a given accuracy. This approach determined the accuracy of the calibration factor estimate depending on the number of observed crashes and/or the number of (representative) sites.

 denotes the unadjusted predicted crashes based on the SPF and CMFs which are in the HSM for calibration factor () of 1 (i.e., the base conditions). The purpose of is to adapt the to a different location and time.

The in the equation above is an estimate of the number of crashes expected on an average unit of specified type, with a certain length and traffic volume using the base condition SPF in the HSM. When is multiplied by it makes the which is the number of crashes expected on an average unit of a certain type, length, traffic volume and traits pertaining to the time and place where it is to be used.

The HSM suggests estimating using the following equation:

The summation in the equation above represents the overall sites in the sample which represents the population of interest. The question is how many crashes must be in the numerator of this equation or, equivalently, how many sites must be in the sample, for the estimate of to be sufficiently accurate.

The variance of calibration factor , one can assume that the numerator of the above equation is a random variable and source of variance, and that the denominator is a constant. Thus, it can be justly assumed that the observed crashes at one site are statistically independent of the crashes observed at every other site.

The variances in the right-hand-side of above equation are computed around the , the number of crashes expected on an average unit. With the usual Poisson-Gamma assumptions leading to the negative binomial distribution, and denoting the overdispersion parameter for by , as in the HSM, yields to:

As such, with information about the segment length, AADT, and crash counts, variance and standard error of the calibration factor can be estimated using the following equations:

Overview of Base Prediction Models in 1st Edition of the HSM

Following sections provide an overview of the base condition SPFs from the 1st edition of the HSM for rural two-lane roads, rural multi-lane divided roads, and urban arterials.

Rural Two-Lane Roads

The base condition SPF for predicted average crash frequency for rural two-lane, two-way roadway segments is as follows:

Where, is the average annual daily traffic volume, and is the length of the roadway segment in miles. In other words, the relationship between between AADT is linear.

The overdispersion parameter () is estimated as a function of the length of the roadway segment:

Rural Four-Lane Divided Roads

The base condition SPF for predicted average crash frequency for rural four-lane divided road segments is as follows:

Where, is the average annual daily traffic volume, is the length of the roadway segment in miles, and and are regression coefficients.

The overdispersion parameter () is estimated as a function of the length of the roadway segment:

Where, is the regression coefficient used to determine the overdispersion parameter.

For total crashes, the regression coefficients are as follows:

Unlike the prediction model for rural two-lane roads, the relationship between and AADT is not linear. However, with b (the power for AADT) = 1.049, the relationship is quite close to being linear (if b = 1.0, then the relationship is linear as in the case of rural two-lane roads).

Urban Arterials

The base condition SPF for predicted average crash frequency for urban arterials is as follows:

Where, is the predicted average crash frequency of multiple-vehicle non-driveway collisions for base conditions, is the predicted average crash frequency of single vehicle crashes for base conditions, and is the predicted average crash frequency of multiple-vehicle driveway related collisions.

The SPF for multiple-vehicle non-driveway collisions is applied as follows:

Where, is the average annual daily traffic volume, is the length of the roadway segment in miles, and and are regression coefficients.

For total crashes, fatal & injury crashes, and property damage only crashes, the regression coefficients are as follows, respectively:

* Urban 2U
* Urban 3T
* Urban 4U
* Urban 4D
* Urban 5T

The SPF for single-vehicle crashes is applied as follows:

Where, is the average annual daily traffic volume, is the length of the roadway segment in miles, and and are regression coefficients.

For total crashes, fatal & injury crashes, and property damage only crashes, the regression coefficients are as follows, respectively:

* Urban 2U
* Urban 3T
* Urban 4U
* Urban 4D
* Urban 5T

The total number of multiple-vehicle driveway related crashes are determined as follows:

Where, is the number of driveway-related collisions per driveway per year for driveway type ,is number of driveways within roadway segment of driveway type including all driveways on both sides of the road, and is the regression coefficient for traffic volume adjustment ( for urban two-lane undivided arterials).

Seven specific driveway types are considered for the modeling - major commercial driveways, minor commercial driveways, major industrial/institutional driveways, minor industrial/institutional driveways, major residential driveways, minor residential driveways, and other driveways. values for each of these driveways are presented in the HSM.

Summary of Data

Recent data from North Carolina (2016 – 2019) were compiled as part of two recent projects (NCHRP Project 17-72: Update of Crash Modification Factors for the Highway Safety Manual, and NCDOT Project 2020-27: Updated and Regional Calibration Factors for Highway Safety Manual Prediction Models 2016-2019). 2013 – 2017 data for urban arterials was also obtained from Ohio.

Table 1 shows the sum of mileage and the average AADT (by roadway type). Note that in the Tables, rural two-lane roads are denoted by Rural 2U, rural four-lane divided roads are denoted by Rural 4D, urban two-lane undivided arterials are denoted by Urban 2U, urban three-lane arterials including a center two-way left-turn lane are denoted by Urban 3T, urban four-lane undivided arterials are denoted by Urban 4U, urban four-lane divided arterials are denoted by Urban 4D, and urban five-lane arterials including a center two-way left-turn lane are denoted by Urban 5T

Table . Sum of Mileage (by Roadway Type)

|  |  |  |  |
| --- | --- | --- | --- |
| **Roadway Type** | **State** | **Sum of Mileage** | **Average AADT** |
| Rural 2U | North Carolina | 732.74 | 2030.55 |
| Rural 4D | North Carolina | 197.27 | 14395.03 |
| Urban 2U | North Carolina | 42.01 | 8425.16 |
| Urban 2U | Ohio | 1827.76 | 7539.06 |
| Urban 3T | North Carolina | 19.16 | 10876.39 |
| Urban 3T | Ohio | 172.65 | 10984.34 |
| Urban 4U | North Carolina | 7.52 | 17506.31 |
| Urban 4U | Ohio | 602.89 | 14939.83 |
| Urban 4D | North Carolina | 4.17 | 22769.71 |
| Urban 4D | Ohio | 311.93 | 15710.49 |
| Urban 5T | North Carolina | 15.71 | 20602.69 |
| Urban 5T | Ohio | 319.12 | 19160.58 |

Results

This section summarizes the results based on the approach described in Bahar (2014) and uses the base condition SPFs from the 1st edition of the HSM (without accounting for the CMFs, i.e., adjustment factors) – the approach described by Bahar (2014) used the unadjusted predicted crashes based on the base conditions. Tables 2 – 8 show the observed total crashes, HSM predicted total crashes (without the adjustment factors), the calibration factors, and the standard errors of the calibration factors (by site type and crash type/severity) (the standard errors were estimated based on the procedure in Bahar (2014)). Note that these calculations are based on using North Carolina data. Data from Ohio was not used as further crash coding is needed to place crashes in appropriate bins. We plan to use this data when refining the draft guidelines presented here in Phase 2.

Table . Calibration Factors for Total Crashes (Rural 2U and Rural 4D)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Rural 2U | North Carolina | 2923 | 2240.46 | 1.305 | 0.092 |
| Rural 4D | North Carolina | 2911 | 2089.85 | 1.393 | 0.145 |

Table . Calibration Factors for Total Multiple-Vehicle Non-Driveway Collisions (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 460 | 184.16 | 2.498 | 0.389 |
| Urban 3T | North Carolina | 450 | 160.41 | 2.805 | 0.309 |
| Urban 4U | North Carolina | 639 | 122.58 | 5.213 | 0.951 |
| Urban 4D | North Carolina | 192 | 71.69 | 2.678 | 0.947 |
| Urban 5T | North Carolina | 776 | 376.09 | 2.063 | 0.266 |

Table . Calibration Factors for Fatal and Injury Multiple-Vehicle Non-Driveway Collisions (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 137 | 56.11 | 2.442 | 0.405 |
| Urban 3T | North Carolina | 118 | 37.47 | 3.149 | 0.433 |
| Urban 4U | North Carolina | 204 | 35.50 | 5.746 | 1.170 |
| Urban 4D | North Carolina | 49 | 20.76 | 2.360 | 1.095 |
| Urban 5T | North Carolina | 214 | 106.10 | 2.017 | 0.276 |

Table . Calibration Factors for Property Damage Only Multiple-Vehicle Non-Driveway Collisions (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 323 | 135.66 | 2.381 | 0.393 |
| Urban 3T | North Carolina | 332 | 118.32 | 2.806 | 0.321 |
| Urban 4U | North Carolina | 435 | 81.64 | 5.328 | 1.019 |
| Urban 4D | North Carolina | 143 | 54.99 | 2.600 | 0.934 |
| Urban 5T | North Carolina | 562 | 287.09 | 1.958 | 0.274 |

Table . Calibration Factors for Total Single-Vehicle Crashes (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 207 | 100.79 | 2.054 | 0.262 |
| Urban 3T | North Carolina | 125 | 36.19 | 3.454 | 0.599 |
| Urban 4U | North Carolina | 75 | 27.96 | 2.682 | 0.596 |
| Urban 4D | North Carolina | 34 | 12.03 | 2.826 | 0.992 |
| Urban 5T | North Carolina | 90 | 99.09 | 0.908 | 0.145 |

Table . Calibration Factors for Fatal and Injury Single-Vehicle Crashes (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 58 | 23.97 | 2.420 | 0.425 |
| Urban 3T | North Carolina | 35 | 10.06 | 3.479 | 0.904 |
| Urban 4U | North Carolina | 34 | 7.31 | 4.651 | 1.176 |
| Urban 4D | North Carolina | 10 | 2.13 | 4.695 | 1.754 |
| Urban 5T | North Carolina | 41 | 22.75 | 1.802 | 0.357 |

Table . Calibration Factors for Property Damage Only Single-Vehicle Crashes (Urban Arterials)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **State** | ***Observed Crashes*** | ***HSM Predicted Crashes (w/o Adjustment Factors)*** | **Calibration Factor** | **Standard Error of Calibration Factor** |
| Urban 2U | North Carolina | 149 | 73.40 | 2.030 | 0.294 |
| Urban 3T | North Carolina | 90 | 25.15 | 3.579 | 0.782 |
| Urban 4U | North Carolina | 41 | 22.54 | 1.819 | 0.489 |
| Urban 4D | North Carolina | 24 | 9.93 | 2.417 | 0.976 |
| Urban 5T | North Carolina | 49 | 71.77 | 0.683 | 0.134 |

Combined Calibration Data for Similar Site Types

Using the calibration factors and their standard errors, 95% confidence intervals were calculated for total crashes for each site type. The lower and upper limits of the 95% confidence interval were calculated as follows:

 and

Tables 9 – 15 summarize the 95% confidence intervals and also present the relative calibration factor differences to a specific roadway type, for each crash type/severity combination.

As an example, the following equation can be used to find the relative calibration factor difference for Rural 4D compared to Rural 2U.

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Total Crashes on Rural Roads

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Rural 2U** | **Rural 4D** |
| Rural 2U | North Carolina | 732.74 | 1.305 | 1.124 - 1.485 | - | **-6.3%** |
| Rural 4D | North Carolina | 197.27 | 1.393 | 1.109 - 1.677 | **6.8%** | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Total Multiple Vehicle Non-Driveway Collisions on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.498 | 1.735 - 3.260 | - | -**11.0%** | -52.1% | **-6.7%** | 21.1% |
| Urban 3T | North Carolina | 19.16 | 2.805 | 2.200 - 3.411 | **12.3%** | - | -46.2% | **4.7%** | 36.0% |
| Urban 4U | North Carolina | 7.52 | 5.213 | 3.349 - 7.077 | 108.7% | 85.8% | - | 94.6% | 152.6% |
| Urban 4D | North Carolina | 4.17 | 2.678 | 0.822 - 4.534 | **7.2%** | **-4.5%** | -48.6% | - | 29.8% |
| Urban 5T | North Carolina | 15.71 | 2.063 | 1.542 - 2.585 | **-17.4%** | -26.4% | -60.4% | -23.0% | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Fatal & Injury Multiple Vehicle Non-Driveway Collisions on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.442 | 1.648 - 3.235 | - | -22.5% | -57.5% | **3.4%** | 21.1% |
| Urban 3T | North Carolina | 19.16 | 3.149 | 2.301 - 3.998 | 29.0% | - | -45.2% | 33.4% | 56.1% |
| Urban 4U | North Carolina | 7.52 | 5.746 | 3.453 - 8.040 | 135.4% | 82.5% | - | 143.5% | 184.9% |
| Urban 4D | North Carolina | 4.17 | 2.360 | 0.214 - 4.507 | **-3.3%** | -25.1% | -58.9% | - | **17.0%** |
| Urban 5T | North Carolina | 15.71 | 2.017 | 1.476 - 2.558 | -**17.4%** | -36.0% | -64.9% | **-14.5%** | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Property Damage Only Multiple Vehicle Non-Driveway Collisions on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.381 | 1.611 - 3.151 | - | **-15.1%** | -55.3% | **-8.4%** | 21.6% |
| Urban 3T | North Carolina | 19.16 | 2.806 | 2.177 - 3.435 | **17.8%** | - | -47.3% | **7.9%** | 43.3% |
| Urban 4U | North Carolina | 7.52 | 5.328 | 3.331 - 7.326 | 123.8% | 89.9% | - | 104.9% | 172.2% |
| Urban 4D | North Carolina | 4.17 | 2.600 | 0.770 - 4.431 | **9.2%** | **-7.3%** | -51.2% | - | 32.8% |
| Urban 5T | North Carolina | 15.71 | 1.958 | 1.421 - 2.495 | **-17.8%** | -30.2% | -63.3% | -24.7% | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Total Single Vehicle Crashes on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.054 | 1.540 - 2.567 | - | -40.5% | -23.4% | -27.3% | 126.1% |
| Urban 3T | North Carolina | 19.16 | 3.454 | 2.280 - 4.628 | 68.2% | - | 28.8% | 22.2% | 280.3% |
| Urban 4U | North Carolina | 7.52 | 2.682 | 1.514 - 3.851 | 30.6% | -22.3% | - | **-5.1%** | 195.3% |
| Urban 4D | North Carolina | 4.17 | 2.826 | 0.882 - 4.771 | 37.6% | **-18.2%** | **5.4%** | - | 211.2% |
| Urban 5T | North Carolina | 15.71 | 0.908 | 0.624 - 1.192 | -55.8% | -73.7% | -66.1% | -67.9% | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Fatal & Injury Single Vehicle Crashes on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.420 | 1.584 - 3.253 | - | -30.5% | -48.0% | -48.5% | 34.3% |
| Urban 3T | North Carolina | 19.16 | 3.479 | 1.707 - 5.251 | 43.8% | - | -25.2% | -25.9% | 93.0% |
| Urban 4U | North Carolina | 7.52 | 4.651 | 2.346 - 6.956 | 92.2% | 33.7% | - | **-0.9%** | 158.1% |
| Urban 4D | North Carolina | 4.17 | 4.695 | 1.257 - 8.133 | 94.0% | 34.9% | **0.9%** | - | 160.5% |
| Urban 5T | North Carolina | 15.71 | 1.802 | 1.102 - 2.502 | -25.5% | -48.2% | -61.3% | -61.6% | - |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences for Property Damage Only Single Vehicle Crashes on Urban Arterials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | North Carolina | 42.01 | 2.030 | 1.454 - 2.606 | - | -43.3% | **11.6%** | **-16.0%** | 197.3% |
| Urban 3T | North Carolina | 19.16 | 3.579 | 2.046 - 5.111 | 76.3% | - | 96.7% | 48.1% | 424.1% |
| Urban 4U | North Carolina | 7.52 | 1.819 | 0.861 - 2.777 | **-10.4%** | -49.2% | - | -24.7% | 166.4% |
| Urban 4D | North Carolina | 4.17 | 2.417 | 0.504 - 4.330 | **19.1%** | -32.5% | 32.9% | - | 254.0% |
| Urban 5T | North Carolina | 15.71 | 0.683 | 0.420 - 0.945 | -66.4% | -80.9% | -62.5% | -71.8% | - |

Reliability of Extrapolating Calibration Factor Across Crash Type and Severity Categories

Tables 16 – 20 summarize the 95% confidence intervals and also present the relative calibration factor differences to a total crash calibration factor, for each roadway type.

As an example, the following equation can be used to find the relative calibration factor difference for fatal & injury crashers compared to total crashes.

Note that in the following tables fatal & injury crashes are referred to as KABC crashes, and property damage only crashes are referred to as PDO crashes.

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences to Total Crashes for Urban 2U

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **Crash Type/Severity** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Relative Differences to Total Crash Cr** |
| Urban 2U | MV Total | North Carolina | 42.01 | 2.498 | 1.735 - 3.260 | - |
| Urban 2U | MV KABC | North Carolina | 42.01 | 2.442 | 1.648 - 3.235 | **-2.2%** |
| Urban 2U | MV PDO | North Carolina | 42.01 | 2.381 | 1.611 - 3.151 | **-4.7%** |
|   |   |   |   |   |   |   |
| Urban 2U | SV Total | North Carolina | 42.01 | 2.054 | 1.540 - 2.567 | - |
| Urban 2U | SV KABC | North Carolina | 42.01 | 2.420 | 1.584 - 3.253 | **17.8%** |
| Urban 2U | SV PDO | North Carolina | 42.01 | 2.030 | 1.454 - 2.606 | **-1.2%** |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences to Total Crashes for Urban 3T

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **Crash Type/Severity** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Relative Differences to Total Crash Cr** |
| Urban 3T | MV Total | North Carolina | 19.16 | 2.805 | 2.200 - 3.411 | - |
| Urban 3T | MV KABC | North Carolina | 19.16 | 3.149 | 2.301 - 3.998 | **12.3%** |
| Urban 3T | MV PDO | North Carolina | 19.16 | 2.806 | 2.177 - 3.435 | **0.0%** |
|   |   |   |   |   |   |   |
| Urban 3T | SV Total | North Carolina | 19.16 | 3.454 | 2.280 - 4.628 | - |
| Urban 3T | SV KABC | North Carolina | 19.16 | 3.479 | 1.707 - 5.251 | **0.7%** |
| Urban 3T | SV PDO | North Carolina | 19.16 | 3.579 | 2.046 - 5.111 | **3.6%** |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences to Total Crashes for Urban 4U

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **Crash Type/Severity** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Relative Differences to Total Crash Cr** |
| Urban 4U | MV Total | North Carolina | 7.52 | 5.213 | 3.349 - 7.077 | - |
| Urban 4U | MV KABC | North Carolina | 7.52 | 5.746 | 3.453 - 8.040 | **10.2%** |
| Urban 4U | MV PDO | North Carolina | 7.52 | 5.328 | 3.331 - 7.326 | **2.2%** |
|   |   |   |   |   |   |   |
| Urban 4U | SV Total | North Carolina | 7.52 | 2.682 | 1.514 - 3.851 | - |
| Urban 4U | SV KABC | North Carolina | 7.52 | 4.651 | 2.346 - 6.956 | 73.4% |
| Urban 4U | SV PDO | North Carolina | 7.52 | 1.819 | 0.861 - 2.777 | -32.2% |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences to Total Crashes for Urban 4D

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Roadway Type** | **Crash Type/Severity** | **State** | **Mileage** | **Calibration Factors** | **95% Confidence Interval** | **Relative Differences to Total Crash Cr** |
| Urban 4D | MV Total | North Carolina | 4.17 | 2.678 | 0.822 - 4.534 | - |
| Urban 4D | MV KABC | North Carolina | 4.17 | 2.360 | 0.214 - 4.507 | **-11.9%** |
| Urban 4D | MV PDO | North Carolina | 4.17 | 2.600 | 0.770 - 4.431 | **-2.9%** |
|   |   |   |   |   |   |   |
| Urban 4D | SV Total | North Carolina | 4.17 | 2.826 | 0.882 - 4.771 | - |
| Urban 4D | SV KABC | North Carolina | 4.17 | 4.695 | 1.257 - 8.133 | 66.1% |
| Urban 4D | SV PDO | North Carolina | 4.17 | 2.417 | 0.504 - 4.330 | **-14.5%** |

Table . Calibration Factor, 95% Confidence Intervals, and Relative Differences to Total Crashes for Urban 5T

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Roadway Type | Crash Type/Severity | State | Mileage | Calibration Factors | 95% Confidence Interval | Relative Differences to Total Crash Cr |
| Urban 5T | MV Total | North Carolina | 15.71 | 2.063 | 1.542 - 2.585 | - |
| Urban 5T | MV KABC | North Carolina | 15.71 | 2.017 | 1.476 - 2.558 | **-2.2%** |
| Urban 5T | MV PDO | North Carolina | 15.71 | 1.958 | 1.421 - 2.495 | **-5.1%** |
|   |   |   |   |   |   |   |
| Urban 5T | SV Total | North Carolina | 15.71 | 0.908 | 0.624 - 1.192 | - |
| Urban 5T | SV KABC | North Carolina | 15.71 | 1.802 | 1.102 - 2.502 | 98.4% |
| Urban 5T | SV PDO | North Carolina | 15.71 | 0.683 | 0.420 - 0.945 | -24.8% |

Discussion and Recommended Guidance

Combined Calibration Data for Similar Site Types

The results from Tables 9 through 15 indicate that for Rural 2U and Rural 4D, there is very little difference between the calibration factors (and the relative calibration factor differences). The 95% confidence interval ranges for the calibration factors for these two roadway types are also very similar. However, for Urban Arterials, there are various instances where the relative differences between the calibration factors are high (more so for single vehicle crashes compared to multiple vehicle collisions) and the 95% confidence interval ranges for the calibration factors exhibit fairly wide ranges (due to the small sample size available for this analysis). This leads to situations where there is some overlap between the confidence intervals for different roadway types merely due to the fact that the confidence intervals exhibiting a wide range.

Based on these results, the following guidance is recommended for practitioners when identifying if prediction models developed for some roadway types be calibrated using a common database including different site types:

* The 95% confidence intervals for the calibration factors for the site types in consideration should present some overlap.
* The relative difference between the calibration factors for the different site types should be less than 20% (this would help in filtering out site types exhibiting a wide range for the 95% confidence intervals).

Based on this guidance and the results presented in Tables 9 through 15 (based on the data from North Carolina), data for the following roadway types can be combined to estimate a common calibration factor (it should be noted that for Urban Arterials, the HSM presents separate models for multiple vehicle and single vehicle crashes, as shown earlier in the overview of HSM models):

* Rural Roads
	+ **Total Crashes**
		- *Rural 2U and Rural 4D*
* Urban Arterials
	+ **Multiple Vehicle Total Crashes**
		- *Urban 2U, Urban 3T, Urban 4D, and Urban 5T*
	+ **Multiple Vehicle Fatal & Injury Collisions**
		- *Urban 2U, Urban 4D, and Urban 5T*
	+ **Multiple Vehicle Property Damage Only Collisions**
		- *Urban 2U, Urban 3T, Urban 4D, and Urban 5T*
	+ **Single Vehicle Total Crashes**
		- *Urban 3T, Urban 4U, and Urban 4D*
	+ **Single Vehicle Fatal & Injury Crashes**
		- *Urban 4U and Urban 4D*
	+ **Single Vehicle Property Damage Only Crashes**
		- *Urban 2U, Urban 4U, and Urban 4D*

The results presented above are based off calculations requiring the availability of segment length, AADT, and crash counts for all segments used for calibration. This method can alternatively be simplified to not account for the standard errors of the calibration factors and only use the calibration factors for the various roadway types developed under various effort by the state DOTs. Thus, using the relative difference between the calibration factors for the different site types of less than 20% as the only condition to determine if prediction models developed for some roadway types be calibrated using a common database including different site types.

Tables 21 – 23 demonstrate the use of this simplified methodology using calibration factors developed by state DOT efforts in Florida[[1]](#footnote-2), Maryland[[2]](#footnote-3), and Oregon[[3]](#footnote-4).

Table . Calibration Factors and Relative Differences to Total Crashes for Florida Urban Arterials

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Calibration Factors** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | Florida | 1.025 | - | **-1.3%** | 40.6% | -37.0% | 53.2% |
| Urban 3T | Florida | 1.038 | **1.3%** | - | 42.4% | -36.2% | 55.2% |
| Urban 4U | Florida | 0.729 | -28.9% | -29.8% | - | -55.2% | **9.0%** |
| Urban 4D | Florida | 1.628 | 58.8% | 56.8% | 123.3% | - | 143.3% |
| Urban 5T | Florida | 0.669 | -34.7% | -35.5% | **-8.2%** | -58.9% | - |

Table . Calibration Factors and Relative Differences to Total Crashes for Maryland Urban Arterials

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  | ***Relative Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Calibration Factors** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | Maryland | 0.6814 | - | -36.8% | -22.5% | **-17.6%** | -42.7% |
| Urban 3T | Maryland | 1.0785 | 58.3% | - | 22.7% | 30.4% | **-9.3%** |
| Urban 4U | Maryland | 0.8788 | 29.0% | **-18.5%** | - | **6.3%** | -26.1% |
| Urban 4D | Maryland | 0.8269 | 21.4% | -23.3% | **-5.9%** | - | -30.5% |
| Urban 5T | Maryland | 1.1891 | 74.5% | **10.3%** | 35.3% | 43.8% | - |

Table . Calibration Factors and Relative Differences to Total Crashes for Oregon Urban Arterials

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  | ***Relative Cr Differences to Roadway Type*** |
| **Roadway Type** | **State** | **Calibration Factors** | **Urban 2U** | **Urban 3T** | **Urban 4U** | **Urban 4D** | **Urban 5T** |
| Urban 2U | Oregon | 0.620 | - | -23.5% | -56.1% | **-1.6%** | -3.1% |
| Urban 3T | Oregon | 0.810 | 30.6% | - | -42.6% | 28.6% | 26.6% |
| Urban 4U | Oregon | 1.411 | 127.6% | 74.2% | - | 124.0% | 120.5% |
| Urban 4D | Oregon | 0.630 | **1.6%** | -22.2% | -55.4% | - | **-1.6%** |
| Urban 5T | Oregon | 0.640 | **3.2%** | -21.0% | -54.6% | **1.6%** | - |

Using this simplified methodology has some limitations including the inability to identify a separate calibration factor for the different crash types that feed into the HSM total crash calculations for various Urban Arterials (this issue could be alleviated is the state DOTs derive calibration factor for various crash type and severity categories as opposed to just the overall total crashes, something we could not find in our literature review) and the inability to filter out site types exhibiting a wide range for the 95% confidence intervals.

Based on this simplified guidance and the results presented in Tables 21 through 23, data for the following roadway types can be combined to estimate a common calibration factor:

* Urban Arterials
	+ **Florida**
		- **Total Crashes**
			* *Urban 2U and Urban 3T*
			* *Urban 4U and Urban 5T*
	+ **Maryland**
		- **Total Crashes**
			* *Urban 2U, Urban 4U, and Urban 4D*
			* *Urban 3T, Urban 4U, and Urban 5T*
	+ **Oregon**
		- **Total Crashes**
			* *Urban 2U, Urban 4D, and Urban 5T*

Reliability of Extrapolating Calibration Factor Across Crash Type and Severity Categories

The results from Tables 16 through 20 indicate that for Urban Arterials, there are various instances where relative differences between the calibration factors are high for single vehicle fatal & injury and property damage only crashes compared to total single vehicle crashes, for the same roadway type. This also leads to the 95% confidence interval ranges for the single vehicle crashes exhibiting fairly wide ranges.

Based on these results, the following guidance is recommended for practitioners when identifying if calibration factor for a prediction model that represents total crashes be used to obtain reliable estimates when this factor is used with a prediction model for predicting specific crash types, severity categories, or both:

* The 95% confidence intervals for the calibration factors for the different crash type and severity categories in consideration should present some overlap.
* The relative difference between the calibration factors for the different crash type and severity categories compared to calibration factor for total crashes should be less than 20% (this would help in filtering out crash type and severity categories exhibiting a wide range for the 95% confidence intervals).

Based on this guidance and the results presented in Tables 16 through 20, calibration factor for a prediction model that represents total crashes be used to obtain reliable estimates when this factor is used with a prediction model for predicting the following specific crash types, severity categories, by roadway type:

* Urban 2U
	+ **Multiple Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Multiple Vehicle Fatal & Injury Collisions*
		- *Multiple Vehicle Property Damage Only Collisions*
	+ **Single Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Single Vehicle Fatal & Injury Crashes*
		- *Single Vehicle Property Damage Only Crashes*
* Urban 3T
	+ **Multiple Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Multiple Vehicle Fatal & Injury Collisions*
		- *Multiple Vehicle Property Damage Only Collisions*
	+ **Single Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Single Vehicle Fatal & Injury Crashes*
		- *Single Vehicle Property Damage Only Crashes*
* Urban 4U
	+ **Multiple Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Multiple Vehicle Fatal & Injury Collisions*
		- *Multiple Vehicle Property Damage Only Collisions*
* Urban 4D
	+ **Multiple Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Multiple Vehicle Fatal & Injury Collisions*
		- *Multiple Vehicle Property Damage Only Collisions*
	+ **Single Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Single Vehicle Property Damage Only Crashes*
* Urban 5T
	+ **Multiple Vehicle Total Crashes** prediction model can be used with a prediction model for predicting:
		- *Multiple Vehicle Fatal & Injury Collisions*
		- *Multiple Vehicle Property Damage Only Collisions*

References

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

HSM (2010). “Highway Safety Manual.” American Association of State Highway and Transportation Officials. Washington, D.C.

1. Development and Calibration of Highway Safety Manual Equations for Florida Conditions. Available at: <https://trid.trb.org/view.aspx?id=1133787>. [↑](#footnote-ref-2)
2. The Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland. Available at: <https://www.roads.maryland.gov/OPR_Research/MD-14-SP209B4J_Local-Calibration-Factors-for-HSM_Report.pdf>. [↑](#footnote-ref-3)
3. Calibrating the Future Highway Safety Manual Predictive Methods for Oregon State Highways. Available at: <https://rosap.ntl.bts.gov/view/dot/23994>. [↑](#footnote-ref-4)