National Cooperative Highway Research Program
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User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors

Requested by:

American Association of State Highway
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Prepared by:

Geni B. Bahar, P.E.
NAVIGATS Inc.
In association with Dr. Ezra Hauer

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Instructions to Panel Members

This project is being conducted at the request of the AASHTO Standing Committee on Highway Traffic Safety as part of National Cooperative Highway Research Program Project 20-07. The report will not go through the rigorous review process established and monitored by the Transportation Research Board Executive Committee or the Governing Board of the National Research Council, and should not be described as a "TRB Report." It should be described as a contractor's report requested by the AASHTO Standing Committee on Highway Traffic Safety and conducted as part of NCHRP Project 20-07.

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Glossary of Terms

The terms defined in this section are presented alphabetically. Most definitions are found in the HSM (2010) Glossary, Volume 1 and were copied here; while additional or modified definitions (noted with *) are included for completeness of this glossary.

Adjusted prediction model – predicted model that includes the calibration factor to adjust the SPF for local conditions

AADT - annual average daily traffic - the counted (or estimated) total traffic volume in one year divided by 365 days/year

ADT * - average daily traffic - the counted (or estimated) total traffic volume for a period of time (e.g., one week, two weeks, etc) divided by number of days included in the counting period

Approach - a lane or set of lanes at an intersection that accommodates all left-turn, through, and right-turn movements from a given direction

Auxiliary lane - a lane marked for use, but not assigned for use by through traffic

Base model * - a regression model for predicting the average crash frequency; in each HSM prediction procedure, a set of site characteristics or conditions is given (namely, data elements used during the development of the SPF). The base model, like all regression models, predicts the value of a dependent variable as a function of a set of independent variables (such as AADT).

Bayesian statistics - statistical method of analysis which bases statistical inference on a number of philosophical underpinnings that differ in principle from frequentist or classical statistical thought. First, this method incorporates knowledge from history of other similar sites. In other words, prior knowledge is formally incorporated to obtain the "best" estimation. Second, the method considers the likelihood of certain types of events as part of the analysis process. Third, it uses Bayes' theorem to translate probabilistic statements into degrees of belief instead of the classical confidence interval interpretation.

Calibration factor * - a factor to adjust crash frequency estimates produced from a safety prediction procedure to approximate for local conditions and temporal differences. The factor is computed by comparing existing crash data at the state, regional, or local level to estimates obtained from predictive models.

Collision type* – crashes grouped by impact type such as single-vehicle collision with animal, single-vehicle overturned, multiple-vehicle angle collision, multiple-vehicle sideswipe collision, etc

Crash estimation **-** any methodology used to forecast or predict the crash frequency of an existing roadway for existing conditions during a past period or future period; an existing roadway for alternative conditions during a past or future period; or a new roadway for given conditions for a future period.

Crash frequency - number of crashes occurring at a particular site, facility, or network in a one year period and is measured in number of crashes per year

Crash modification factor (CMF) **-** an index of how much crash experience is expected to change following a modification in design or traffic control. CMF is the ratio between the number of crashes per unit of time expected after a modification or measure is implemented and the number of crashes per unit of time estimated if the change does not take place.

Crash modification function (CMF)* – similarly to a crash modification factor, as defined above, extended to include additional elements in a function used to estimate the expected change in future number of crashes per unit of time. Additional elements can be AADT (e.g., CMFs for lane width), curve radius and length (e.g., CMFs for curve changes), among others.

Crash prediction – using an algorithm based on safety performance of similar sites (in terms of geometric and traffic conditions), an average crash frequency is predicted for a given traffic volume.

Crash prediction algorithm* **-** procedure used to predict average crash frequency, consisting of three elements. It has two analytical components: baseline models and crash modification factors or functions, as well as a third component: crash histories.

Crash rate **-** the number of crashes per unit of exposure. For an intersection, this is typically the number of crashes divided by the total entering AADT; for roadway segments, this is typically the number of crashes per million vehicle-miles traveled on the roadway segment.

Crash severity – the level of injury or property damage due to a crash, commonly divided into categories based on the KABCO scale. * In the HSM, levels of injury may be combined such as fatal + injury (without additional categories of injury explicitly).

Dependent variable - in a function given as Y = f(X1,…,Xn), it is customary to refer to X1,…,Xn as independent or explanatory variables, and Y a the dependent or response variable. In each crash frequency prediction procedure, the dependent variable estimated in the base model is the annual average crash frequency for a roadway segment or intersection.

Driveway density - the number of driveways per mile on both sides of the roadway combined

Empirical Bayes (EB) method* –the method used to combine observed crash frequency data for a given site with predicted crash frequency data from many similar sites to estimate its expected average crash frequency.

Expected average crash frequency - the estimate of long-term average crash frequency of a site, facility or network under a given set of geometric conditions and traffic volumes (AADT) in a given time period. In the EB methodology, this frequency is calculated from observed crash frequency at the site and predicted crash frequency which is based on crash frequency estimates at other similar sites.

Expected average crash frequency, change in - the difference between the expected average crash frequency in the absence of treatment and with the treatment in place

Expected crashes - an estimate of long range average number of crashes per year for a particular type of roadway or intersection

Facility - a length of highway that may consist of connected sections, roadway segments, and intersections

Homogeneous roadway segment - a portion of a roadway with similar average daily traffic volumes (veh/day), geometric design, and traffic control features

Independent variables - a variable which is used to explain (predict) the change in the value of another variable

Influence area (intersection) - functional area on each approach to an intersection consisting of three elements (1) perception-reaction distance, (2) maneuver distance, and (3) queue storage distance

Intersection - general area where two or more roadways or highways meet, including the roadway, and roadside facilities for pedestrian and bicycle movements within the area.

Intersection functional area - area extending upstream and downstream from the physical intersection area including any auxiliary lanes and their associated channelization

Intersection related crash – a crash that occurred at an intersection itself or a crash that occurred on an intersection approach within 250 ft (as defined in the HSM) of the intersection and is related to the presence of the intersection

KABCO - an injury scale developed by the National Safety Council to measure the observed injury severity for any person involved as determined by law enforcement at the scene of the crash: Fatal injury (K), Incapacitating Injury (A), Non-Incapacitating Injury (B), Possible Injury (C), and No Injury (O). The scale can also be applied to crashes: for example, a K crash would be a crash in which the most severe injury as a fatality, and so forth.

Lateral clearance - lateral distance from edge of traveled way to a roadside object or feature

Median - the portion of a divided highway separating the traveled ways from traffic in opposite directions

Median refuge island - an island in the center of a road that physically separates the directional flow of traffic and that provides pedestrians with a place of refuge and reduces the crossing distance of a crosswalk

Median width * – in the HSM (2010) Chapters 11 and 12, width is measured between the inside edges of the through travel lanes in the opposing direction of travel; the inside shoulder and turning lanes are included in the median width. This is consistent with the AASHTO Roadside Design Guide.

Minor street - the lower volume street controlled by stop signs at a two-way, or four-way stop-controlled intersection; also referred to as a side street. The lower volume street at a signalized intersection.

Model Inventory of Roadway Elements (MIRE)* - set of guidelines outlining the roadway information that should be included in a roadway database to be used for safety analysis

Model Minimum Uniform Crash Criteria (MMUCC) - set of guidelines outlining the minimum elements in crash, roadway, vehicle, and person data that should ideally be in an integrated crash database.

Motor vehicle crash - any incident in which bodily injury or damage to property is sustained as a result of the movement of a motor vehicle, or of its load while the motor vehicle is in motion.

Multilane highway - a highway with at least two lanes for the exclusive use of traffic in each direction, with no control, partial control, or full control of access, but that may have periodic interruptions to flow at signalized intersections.

Observed crash frequency or crash counts *- the number of crashes recorded for a given year for a site or facility of roadway network

Observed average crash frequency* – the crash frequency counted and recorded in historical datasets, usually presented as average crash frequency/year of a number of years of data gathered for analysis of a given site.

Offset - lateral distance from edge of traveled way to a roadside object or feature. Also known as lateral clearance.

Overdispersion parameter* - a parameter estimated during the statistical modeling procedure; when the results of modeling are used to estimate expected crash frequencies, it indicates how widely the crash counts are distributed around the estimated mean. This term is used interchangeably with dispersion parameter.

Predicted average crash frequency - the estimate of long-term average crash frequency which is forecast to occur at a site using a predictive model found in Part C of the HSM. The predictive models in the HSM involve the use of regression models, known as Safety Performance Functions, in combination with Crash Modification Factors and calibration factors to adjust the model to site specific and local conditions.

Predictive method * - the methodology in Part C of the HSM(2010), a 18-step procedure, used to estimate the expected average crash frequency of a site, facility, or roadway under given geometric conditions, traffic volume, and period of time.

Predictive model * - formed by a multiplication of the predicted average crash frequency (N_{spf}) determined for base conditions of the SPF for a given site type, crash modification factors (CMFs) specific to the SPF, and the calibration factor (C) to adjust the SPF to local and temporal conditions of the given site type.

Quantitative predictive analysis - methodology used to calculate an expected number of crashes based on the geometric and operational characteristics at the site for existing conditions, future conditions and/or roadway design alternatives.

Regression analysis - a collective name for statistical methods used to determine the interdependence of variables for the purpose of predicting expected average outcomes. These methods consist of values of a dependent variable and one or more independent variables (explanatory variables).

Regression-to-the-mean (RTM) - the tendency for the occurrence of crashes at a particular site to fluctuate up or down, over the long term, and to converge to a long-term average. This tendency introduces regression-to-the-mean bias into crash estimation and analysis, which can make treatments at sites with extremely high crash frequency appear to be more effective than they truly are (or sites be mistakenly selected for treatment due to their high crash short-term average)

Roadside - the area between the outside shoulder edge and the right-of-way limits. The area between roadways of a divided highway may also be considered roadside.

***Roadside hazard rating* (RHR)** - considers the clear zone in conjunction with the roadside slope, roadside surface roughness, recoverability of the roadside, and other elements beyond the clear zone such as barriers or trees. As the RHR increases from 1 to 7, the crash risk for frequency and/or severity increases.

Roadway - the portion of a highway, including shoulders, for vehicular use

Roadway cross-section elements - roadway travel lanes, medians, shoulders, and sideslopes

Roadway environment - a system, where the driver, the vehicle, and the roadway interact with each other

Roadway segment ***-** a portion of a road defined by two endpoints.

Rural areas **-** places outside the boundaries of urban growth boundary where the population is less than 5,000 inhabitants

Safety **-** the number of crashes, by severity, expected to occur on an entity per unit of time. An entity may be a signalized intersection, a road segment, a driver, a fleet of trucks, etc.

Safety performance function (SPF) ***-** an equation used to estimate or predict the expected average crash frequency per year at a location as a function of traffic volume (and length for road segments).

Segment - a portion of a facility on which a crash analysis is performed. A segment is defined by two endpoints. Also known as roadway segment.

Set of individual facilities* **–** consists of a contiguous set of individual intersections and roadway segments, each referred to as "sites."

Severity distribution – represents the distribution by collision type or by combination of collision types for specific crash severity levels on a given facility (such as rural two-lane, two-way roads). It is also known as crash proportions.

Shoulder **-** a portion of the roadway contiguous with the traveled way for accommodation of pedestrians, bicycles, stopped vehicles, emergency use, as well as lateral support of the sub base, base, and surface courses.

Site **-** project location consisting of, but not limited to, intersections, ramps, interchanges, at-grade rail crossings, roadway segments, etc.

Slope **-** the relative steepness of the terrain expressed as a ratio or percentage. Slopes may be categorized as positive (backslopes) or negative (foreslopes) and as parallel or cross slopes in relation to the direction of traffic.

Suburban environment **-** an area with a mixture of densities for housing and employment, where high-density nonresidential development is intended to serve the local community.

Superelevation - the banking of a roadway in a curve to counteract lateral acceleration.

Total entering volume - Sum of total major and minor street volumes approaching an intersection

Traveled way - lanes, excluding the shoulders.

Unadjusted predictive model – predicted model for which the SPF has not been adjusted by a calibration factor for local conditions and temporal differences.

Volume - the number of persons or vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often one hour, expressed in vehicles, bicycles, or persons per hour.

Volume, annual average daily traffic (AADT) - the average number of vehicles passing a point on a roadway in a day from both directions, for all days of the year, during a specified calendar year, expressed in vehicles per day.

Executive Summary

The Highway Safety Manual (HSM), published by AASHTO in 2010, documents predictive methods and analytical procedures to support the project development process (project planning, preliminary design, final design, and construction), and the roadway safety management process. The HSM comprises four parts, namely, Part A (Introduction; Human Factors; and Fundamentals), Part B (Roadway Safety Management Process: network screening, diagnosis, select countermeasures, prioritize projects, and safety effectiveness evaluation); Part C (Predictive Method for rural two-lane, two-way roads; rural multilane highways; and urban and suburban arterials); and Part D (Crash Modifications Factors: roadway segments; intersections; interchanges; special facilities and geometric situations; and road networks). Errata with significant corrections should be consulted at www.highwaysafetymanual.org.

This Guide is focused on the predictive method found in Part C of the HSM (2010). The predictive method is used to estimate the expected average crash frequency of an individual site. The expected average crash frequencies of individual sites can be combined to form an entire facility or road network. The expected average crash frequency of a site is based on the predicted average crash frequency determined using a predictive model appropriate for the individual site and, if applicable, on site's past crash frequency (also referred to as observed crash frequency) recorded for each year of a given time period. The Empirical Bayes (EB) method is used to combine the predicted average crash frequency with observed crash frequency for the given time period. During this time period, the site geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The predictive models were developed for three facility types, as noted above, and included in Part C of the HSM (2010).

Each predictive model is formed by a multiplication of the predicted average crash frequency (N_{spf}) determined for the base conditions of SPF for a given site type, crash modification factors (CMFs) specific to the SPF for the given site type, and the calibration factor (C) to adjust the SPF to local and temporal conditions of the given site type . The predictive model format can be shown as: $N_{predicted} = N_{spf} \times C \times (CMF_1 \times CMF_2 \times \ldots \times CMF_i)$. In the HSM (2010), the N_{spf} was developed using a given set of roadway, traffic and crash data and it is referred to as "base conditions." For example, the SPF for rural two-lane, two-way road segments corresponds to base conditions such as tangent, straight (no horizontal curves) and flat (0% grade) roadway segments with 12-feet lane, 6-feet paved shoulder, no illumination, no passing lanes, no rumble strips, no two-way left-turn lane (TWLTL), up to 5 driveways/mile, no automated speed enforcement, and a typical roadside hazard rating (RHR) of 3 (i.e., clear zone about 10 feet; sideslope about 1V:3H, marginally recoverable). When considering rural two-lane, two-way road segments that have attributes different than the base conditions, CMFs are selected and multiplied to adjust the N_{spf} accordingly. The adjusted model will be used to determine the predicted or expected average crash frequency for the conditions being analyzed. The versatility of this approach enables professionals (designers, planners, etc) to consider the safety impact of modifying roadway elements such as increasing curve radius, decreasing vertical grade, improving roadside traversability, etc.

The safety performance functions (SPFs) included in Chapters 10, 11, and 12 of the HSM Part C, were developed using crash, highway geometry, and exposure (traffic volumes) data collected for a number of states (such as Minnesota, Washington, Michigan, Texas, and California) and cities (such as City of Charlotte in North Carolina, and City of Toronto in Ontario) for given periods of time. These time periods, spanning between 1985 and 2003, were determined by the individual National Cooperative Highway Research Program's research studies carried out for the making of the HSM (2010). These SPFs are accompanied by crash severity and collision type distribution tables and adjustment factors; similarly, some CMFs are accompanied by tables of collision type proportions of total crashes. These HSM default tables and factors were created using given state data sources, as noted in the HSM Part C Chapters. Prior to the publication of the HSM (2010), the SPF coefficients, default crash severity and collision type distributions, and default nighttime crash proportions developed for Chapters 10, 11 and 12 were adjusted to a consistent basis using data from FHWA's Highway Safety Information System (HSIS). For roadway segments, five-year HSIS data (2002-2006) from Washington State; and for intersections, five-year HSIS data (2002-2006) from California State, were used for this adjustment.

The use of the predictive models in any jurisdiction calls for calibration of the HSM (2010) SPFs, and replacement of crash severity and collision type distribution tables and adjustment factors to local and current conditions. Different climate, driver populations, animal populations, crash reporting thresholds, crash reporting system procedures, time periods (i.e., different years) are some of the reasons for developing calibration factors for the SPFs and jurisdiction-specific distribution tables and factors toward more accurate local estimates of expected frequency and severity of crashes. Recent data are important in order to adjust for the reduction in crash occurrence and related injury levels that occurred in the past decade, nationwide. This Guide's aim is to support the development of calibration factors, and the adaptation of crash distribution tables and adjustment factors to local and current conditions.

The user of this Guide will need a copy of the HSM (2010) when consulting this Guide as references are made to chapters of the HSM. Basic description of the calibration procedures is found in Appendix A of Part C of the HSM (2010). The goal of this Guide is to expand Appendix A of Part C into a comprehensive and clear resource by providing guidance on four key aspects:

1. Why calibration is needed
2. How to implement the calibration process
3. How to assess the results of calibration
4. How to prepare for future calibration updates

This Guide complements two other Guides, namely: "Safety Performance Function Decision Guide: SPF Calibration vs SPF Development" and "Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs." These guidebooks have been completed and can be accessed for downloading at *http://safety.fhwa.dot.gov/rsdp/*

The development of calibration factors requires the integration of existing data on crashes, exposure (traffic volumes), and roadway elements, as well as the collection of missing required data. Three issues arise:

i. How to prioritize the facility types and predictive models for SPF calibration, assuming that the calibration effort will be phased based on monetary and human resource availability
ii. Identification of data available within jurisdiction-specific sources and their integration based on a common identifier (i.e., location), and feasibility of collecting missing data elements (by means of office tools such as GoogleMap Streetview, video-tapes, etc or field tools such as grade measurements, traffic counts, etc)

iii. Data preparation for calibration procedure and for data preservation toward re-calibration (yearly or multi-yearly) or SPF development

Data collection, gathering, and preparation comprise the greater part of the effort when developing calibration factors for the first time. The availability of data varies considerably among jurisdictions in general and for given facility types (e.g., AADTs for rural multilane highway signalized intersections may be counted annually as part of the annual traffic counting program while rural two-lane, two-way signalized intersections are counted every five years). Thus, it is difficult to estimate the cost and project duration as they are very dependent on the amount of data to be collected and human resources available to carry out the data collection and preparation. A few examples of effort and project costs are found in Section 4.

Required and desirable data are listed for each of the predictive models found in the HSM. Potential methods to gather specific data elements are briefly presented. The development of calibration factors does not entail a single-time effort since calibration needs to be repeated periodically with updated and current data. Thus, there is a vital need to create an on-going data capturing program to support the application of safety prediction methods. The data ought to be housed in a format and software application that allows for easy annual updates and expansion, as needed. These data could also be used for jurisdiction-specific SPF development in future.

As said earlier, the purpose of calibration is to provide better estimates for jurisdiction-specific conditions; the calibrated models are used to estimate the existing and future safety of project corridors / sites while considering potential engineering improvements. Consequently, it is recommended that calibration factors be estimated, whenever possible, for each HSM SPF by crash injury severity level (such as: calibration factors for rural multilane highway segments' SPF_{total} and $SPF_{fatal + injury}$; calibration factor for urban and suburban arterial segments' SPF_{total} and $SPF_{fatal + injury}$; calibration factor for urban and suburban arterial vehicle-pedestrian collision $SPF_{fatal + injury}$ at signalized intersection; etc). This recommendation is an expansion of the Appendix A of HSM Part C direction that a single calibration factor for each SPF_{total} is satisfactory. Furthermore, recommendations are also made, in the Guide, for further consideration of calibration factors that will account for differences in regional sub-sets of an agency's highway network, and account for different segment lengths, AADT volumes, etc., and the change with time The feasibility of assembling sufficient number of sites with observed crashes that meet the sample sizes required to develop calibration factors within the desired accuracy level will be the determinant factor.

Appendix A of HSM Part C presents the calibration procedure consisting of five steps. The 5-step calibration procedure commences with the decision by the agency to which facility type/s and HSM SPFs it wishes to have calibrated to jurisdiction-specific conditions (Step 1). This is followed by selecting a random sample of sites representing the given facility type and HSM SPFs (by crash severity level) till reaching a sample size that may provide a calibration factor within the desired accuracy level (Step 2). A statistical procedure is given for agencies to select the accuracy level of the calibration factors and respective sample size of sites to attain such an accuracy. Data elements are collated for each specific site selected to facilitate the estimation of unadjusted predicted crash frequency. (i.e., assuming calibration factor = 1, thus not adjusted for local conditions and temporal differences) (Step 3). The unadjusted predicted crash frequency for each group of sites relevant to a given SPF is calculated applying the necessary and jurisdiction-specific CMFs to the HSM SPF base model, as needed (Step 4). The sum of all unadjusted predicted crash frequencies for each group of sites (or sub-group of sites, such as for sites within a region of a jurisdiction, or for sites with AADT volumes higher than a given value, etc) is compared with the respective sum of crash frequencies observed at these sites for the same time period pertinent to the geometric and traffic data (Step 5). The ratio between the observed and unadjusted predicted crash frequencies is the estimated calibration factor.

1. Introduction

1.1 This Guide in the Context of the HSM

The Highway Safety Manual (HSM), published by AASHTO in 2010, documents predictive methods and analytical procedures to support the project development process (project planning, preliminary design, final design, and construction), and the roadway safety management process. The HSM comprises four parts, namely, Part A (Introduction; Human Factors; and Fundamentals), Part B (Roadway Safety Management Process: network screening, diagnosis, select countermeasures, prioritize projects, and safety effectiveness evaluation); Part C (Predictive Method for rural two-lane, two-way roads; rural multilane highways; and urban and suburban arterials); and Part D (Crash Modifications Factors: roadway segments; intersections; interchanges; special facilities and geometric situations; and road networks). Errata with significant corrections should be consulted at www.highwaysafetymanual.org.

This Guide is focused on the predictive method found in Part C of the HSM (2010). The predictive method is used to estimate the expected average crash frequency of an individual site. The expected average crash frequencies of individual sites can be combined to form an entire facility or road network. The expected average crash frequency of a site is based on the predicted average crash frequency determined using a predictive model appropriate for the individual site and, if applicable, on site's past crash frequency (also referred to as observed crash frequency) recorded for each year of a given time period. The Empirical Bayes (EB) method is used to combine the predicted average crash frequency with observed crash frequency for the given time period. During this time period, the site geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The predictive models were developed for three facility types, as noted above, and included in Part C of the HSM (2010). Future versions of the HSM will incorporate additional facilities, such as freeways, ramps, one-way streets, roundabouts, urban and suburban arterial streets with six or more lanes.

Predictive Method

The expected average crash frequency is based on:

- *i.* *the predicted average crash frequency determined using a predictive model appropriate for the individual site; and, if applicable,*
- *ii.* *the site's crash frequency recorded for each year of a given time period*

The safety performance functions (SPFs), that are the basis of the predictive models included in Chapters 10, 11, and 12 of the HSM Part C, were developed using crash, highway geometry, and exposure (traffic volumes) data collected for a number of states and cities for given periods of time. These time periods, spanning between 1985 and 2003, were determined by the individual National Cooperative Highway Research Program's research studies carried out for the making of the HSM (2010). Chapter 10 includes predictive models for rural two-lane, two-way roads developed using 1985-1995 state highway data extracted from existing databases found in Minnesota, Washington, Michigan, and California; Chapter 11 includes predictive models for rural multilane highways developed using 1991-1998 state highway data extracted from databases found in Texas, California, Minnesota, New York, and Washington; and Chapter 12 includes a) *roadway segment* predictive models for urban and suburban arterials developed using 1997-2003 data field collected or extracted from databases found in Minnesota DOT, Hennepin County & Ramsey County in Minnesota, Michigan DOT; Oakland County in Michigan, and Washington DOT; b) *intersection* predictive models using 1997-2003 data extracted from databases found in Minnesota DOT, City of Charlotte in North Carolina, and Florida DOT; and, c) *pedestrian* predictive models using data extracted from databases found in City of Toronto in Ontario, City of Charlotte in North Carolina, and two metro areas in Minnesota.

Time periods

HSM safety performance functions (SPFs) were developed with safety data related to different time periods as follows:

i. Rural two-lane, two-way roads: 1985-1995
ii. Rural multilane highways: 1991-1998
iii. Urban and suburban arterials: 1997-2003

All SPFs were later adjusted using state of Washington and state of California HSIS data (2002-2006)

Datasets

HSM SPFs were developed with safety data extracted from different transportation agencies:

i. Rural two-lane, two-way roads: Minnesota, Washington, Michigan, and California
ii. Rural multilane highways: Texas, California, Minnesota, New York, and Washington
iii. Urban and suburban arterials: Minnesota, Michigan; Washington, North Carolina, and Florida

SPFs need to be adjusted to local (and current) conditions prior to their use

Prior to the publication of the HSM (2010), the SPF coefficients, default crash severity and collision type distributions, and default nighttime crash proportions developed for Chapters 10, 11 and 12 were adjusted to a consistent basis using data from FHWA's Highway Safety Information System (HSIS). For roadway segments, five-year HSIS data (2002-2006) from Washington State; and for intersections, five-year HSIS data (2002-2006) from California State, were used for this adjustment.

Predictive models are typically expressed in this form: $N_{predicted} = N_{spf} \times C \times (CMF_r \times CMF_2 \times \ldots \times CMF_i)$ where the N_{spf} is the predicted average crash frequency determined by the Safety Performance Function (SPF) developed for a specific facility type, CMF_i represents the Crash Modification Factors to be applied when geometric and operational conditions differ from those used for the development of a given SPF, and C is the calibration factor used to adjust the model to jurisdiction-specific highway data.

In the HSM (2010), SPFs are accompanied by crash severity and collision type distribution tables and adjustment factors; similarly, some CMFs are accompanied by tables of collision type proportions of total crashes. These HSM default tables and factors were created using given state data sources, as noted in the HSM Part C Chapters.

In conclusion, the use of the predictive models in any jurisdiction calls for calibration of the HSM (2010) SPFs, and replacement of crash severity and collision type distribution tables and adjustment factors to local and current conditions. Different climate, driver populations, animal populations, crash reporting thresholds, crash reporting system procedures, time periods (i.e., different years) are some of the reasons for developing calibration factors for the SPFs and jurisdiction-specific distribution tables and factors toward more accurate local estimates of expected frequency and severity of crashes. Recent data are important in order to adjust for the reduction in crash occurrence and related injury levels that occurred in the past decade, nationwide. This Guide's aim is to support the development of calibration factors, and the adaptation of crash distribution tables and adjustment factors to local conditions.

1.2 Purpose of this Guide

This Guide supports the procedure for the development of calibration factors for HSM (2010) SPFs for rural two-lane, two-way roads (HSM Chapter 10); rural multilane highways (HSM Chapter 11); and urban and suburban arterials (HSM Chapter 12). The user of this Guide will need a copy of the HSM (2010) when consulting this Guide as references are made to chapters of the HSM. Basic description of the calibration procedures is found in Appendix A of Part C of the HSM (2010). The goal of this Guide is to expand Appendix A of Part C into a comprehensive and clear resource by providing guidance on four key aspects:

1. Why calibration is needed
2. How to implement the calibration process
3. How to assess the results of calibration
4. How to prepare for future calibration updates

2. Overview

2.1 Intended Audience

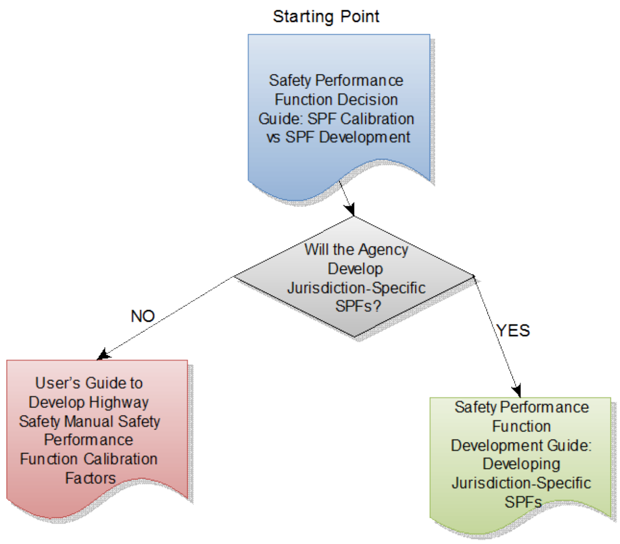
Agencies making decisions on how best to invest their available funds should be able to quantify the safety benefits anticipated for future alternative conditions versus the "do nothing" option and in combination with other costs and criteria such as capacity, delay, environmental, etc. This Guide provides relevant information for transportation and road / highway network managers and decision makers. The development of calibration factors and their use with SPFs require reliable and integrated safety, traffic, and roadway data, and this Guide provides information for data personnel responsible for data collection, capture, and management within a transportation and road / highway agency. The data preparation and the development of SPF calibration factors (as well as replacement of the crash distribution tables and adjustment factors) may be carried out by staff of the transportation agencies or other professionals at universities, research centers, or consulting firms, thus, safety engineers, statistical analysts, and safety modelers can also find useful information in this Guide.

2.2 Context of this Document

This Guide complements two other Guides, namely:

- Safety Performance Function Decision Guide: SPF Calibration vs SPF Development
- Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs

These guidebooks have been completed and can be accessed for downloading at *http://safety.fhwa.dot.gov/rsdp/* or *www.highwaysafetymanual.org*



<u>Interactive Highway Safety Design Model (IHSDM) and *SafetyAnalyst* software</u>

The HSM (2010) is supported by two tools, namely IHSDM and *SafetyAnalyst*. The IHSDM (http://www.ihsdm.org) is a tool developed, using HSM Part C predictive models, to assist in the process of planning and design decisions during a typical road project. While this Guide and the IHSDM tool focus on Part C of the HSM (2010), the *SafetyAnalyst* software (http://www.aashtoware.org/Safety/) incorporates methodologies set forth in Part B of the HSM (2010). Both tools recognize the need to calibrate SPFs and are equipped with a calibration function that uses jurisdiction-specific data. Information about both tools is presented in Appendix A.

2.3 Intended Use of Calibration Factors and other Local Adjustments

SPFs (HSM, 2010)

In the HSM (2010), there are 18 predictive models and respective SPFs corresponding to given site or facility types. The SPFs by facility type are listed below with their HSM respective Equation and Table numbers:

Rural two-lane, two-way roads

Roadway Segments (Equation 10-2)

1. Undivided rural two-lane, two-way roadway (2U) (Equation 10-6)

Intersections (Equation 10-3)

2. Three-leg STOP controlled on minor-road approach (3ST) (Equation 10-8)
3. Four-leg STOP controlled on minor-road approaches (4ST) (Equation 10-9)
4. Four-leg signalized (4SG) (Equation 10-10)

Rural multilane highways

Roadway Segments (Equation 11-2, and Equation 11-3)

5. Rural four-lane undivided (4U) (Equation 11-7 and Table 11-3)
6. Rural four-lane divided (4D) (Equation 11-9 and Table 11-5)

Intersections (Equation 11.4)

7. Three-leg STOP controlled on minor road approaches (3ST) (Equation 11-11 and Table 11-7)
8. Four-leg STOP controlled on minor road approaches (4ST) (Equation 11-11 and Table 11-7)
9. Four-leg signalized (4SG) (Equation 11-11 and Equation 11-12 and Table 11-8)

Urban and suburban arterials

Roadway Segments (Equation 12-2, Equation 12-3, Equation 12-4; Equation 12-10 and Table 12-3; Equation 12-13 and Table 12-5; Equation 12-16 and Table 12-7; Equation 12-19 and Table 12-8; Equation 12-20 and Table 12-9)

10. Two-lane undivided (2U)

11. Three-lane including a two-way left-turn lane(TWLTL)(3T)
12. Four-lane undivided (4U)
13. Four-lane divided including e.g., raised or depressed median (4D)
14. Five-lane including a TWLTL (5T)

Intersections (Equation 12-5, Equation 12-6, and Equation 12-7; Equation 12-21 and Table 12-10; Equation 12-24, Equation 12-27 and Table 12-12; Equation 12-28, Equation 12-29, and Table 12-14, Table 12-15; Equation 12-30 and Table 12-16; Equation 12-31 and Table 12-17)

15. Three-leg STOP controlled on the minor-road approach (3ST)
16. Three-leg signalized intersections (3SG)
17. Four-leg STOP controlled on the minor-road approaches (4ST)
18. Four-leg signalized (4SG)

Each predictive model is formed by a multiplication of the predicted average crash frequency (N_{spf}) determined for the base conditions of the SPF for a given site type, crash modification factors (CMFs) specific to the SPF for the given site type, and the calibration factor (C) to adjust the SPF to local and current conditions. The predictive model format can be shown as: $N_{predicted} = N_{spf} \times C \times (CMF_r \times CMF_2 \times ... \times CMF_i)$. In the HSM (2010), the N_{spf} was developed using as a given set of roadway, traffic and crash data and it is referred to as "base conditions." For example, the SPF for rural two-lane, two-way road segments includes base conditions such as tangent, straight (no horizontal curves) and flat (0% grade) roadway segments with 12-feet lane, 6-feet paved shoulder, no illumination, no passing lanes, no rumble strips, no two-way left-turn lane (TWLTL), up to 5 driveways/mile, no automated speed enforcement, and a typical roadside hazard rating (RHR) of 3 (i.e., clear zone about 10 feet; sideslope about 1V:3H, marginally recoverable). When considering rural two-lane, two-way road segments that have attributes different than the base conditions, CMFs are selected and multiplied to adjust the N_{spf} accordingly. The adjusted model will be used to determine the predicted or expected average crash frequency for the conditions being analyzed. The versatility of this approach enables professionals (designers, planners, etc) to consider the safety impact of modifying roadway elements such as increasing curve radius, decreasing vertical grade, improving roadside traversability, etc.

Default distributions of crash severity and collision types, and adjustment factors (HSM, 2010)

There are 24 tables or factors in the HSM Part C Chapters that were developed to be used in conjunction with predicted average crash frequency N_{spf} or CMFs., as indicated in the respective HSM chapters. These tables or factors are recommended to be replaced by jurisdiction-specific conditions. The distribution tables and adjustment factors are listed below by facility type with their HSM respective Equation and Table numbers:

Rural Two-lane, Two-way roads

Roadway segments

1. Crash distribution by crash severity level (Table 10-3)
2. Crash distribution by collision type for specific crash severity level (Table 10-4, Equation 10-11, and Equation 10-12)
3. Driveway-related crashes as a proportion of total crashes (Equation 10-18)
4. Nighttime crashes as a proportion of total crashes, and by severity level for unlit roadway segments (Table 10-12)

Intersections

5. Crash distribution by crash severity level (Table 10-5)
6. Crash distribution by collision type for specific crash severity level (Table 10-6)
7. Nighttime crashes as a proportion of total crashes by severity level and by intersection type (unlit intersections) (Table 10-15)

Rural Multilane Highways

Roadway segments

8. Crash distribution by crash severity level and collision type for undivided roadway segments (Table 11-4, Equation 11-13, and Equation 11-14)
9. Crash distribution by crash severity level and collision type for divided roadway segments (Table 11-6 and Equation 11-16)
10. Nighttime crashes as a proportion of total crashes, and by severity level and for unlit, undivided roadway segments (Table 11-15)
11. Nighttime crashes as a proportion of total crashes, and by severity level for unlit, divided roadway segments (Table 11-19)

Intersections

12. Crash distribution by crash severity level and collision type by intersection type (Table 11-9)
13. Nighttime crashes as a proportion of total crashes by intersection type (unlit intersections) (Table 11-24)

Urban and Suburban Arterials

Roadway segments

14. Crash distribution by crash severity level and collision type for multiple-vehicle non-driveway collisions by roadway segment type (Table 12-4)
15. Crash distribution by crash severity level and collision type for single-vehicle by roadway segment type (Table 12-6)
16. Crash distribution by crash severity level for driveway-related collisions by driveway type, and by roadway segment type (Table 12-7)
17. Vehicle-pedestrian crash adjustment factor by posted speed ranges (30mph or less, and greater than 30 mph) and roadway segment type (Table 12-8 and Equation A-2)
18. Vehicle-bicycle crash adjustment factor by posted speed ranges (30mph or less, and greater than 30 mph) by roadway segment type (Table 12-9 and Equation A-3)
19. Nighttime crashes as a proportion of total crashes, and by severity level and by roadway segment type (unlit only) (Table 12-23)

Intersections

20. Crash distribution by crash severity level and collision type for multiple-vehicle collisions by intersection type (Table 12-11)
21. Crash distribution by crash severity level and collision type for single-vehicle by intersection type (Table 12-13) and adjustment factor for 3ST and 4ST intersections (Equation 12-27) (Note: adjustments to Equation 12-27 are not listed in Part C Appendix A although their replacement with jurisdiction data is recommended in Part C Chapter 12)

22. Vehicle-pedestrian crash adjustment factor by intersection type for stop-controlled intersections (Table 12-16 and Equation A-2) and pedestrian crossing volumes based on general level of pedestrian activity (Table 12-15) (Note: adjustment to Table 12-15 values is not listed in Part C Appendix A although their replacement with jurisdiction data is recommended in Part C Chapter 12)
23. Vehicle-bicycle crash adjustment factor by intersection type (Table 12-17 and Equation A-3)
24. Nighttime crashes as a proportion of total crashes by intersection type (unlit only) (Table 12-27)

3. Organization of this Guide

A glossary of terms is provided at the front of the Guide to be easily accessible by all with particular focus on those new to the HSM and the science of safety. The Executive Summary is followed by two sections of this Guide that provide the introduction and the context of this document. The next section, Section 4, is for *managers and decision makers*; it provides a concise description of the purpose of calibration factors in the context of using the HSM Part C for planning, operational and design safety considerations, and the data requirements to undertake the calibration effort including developing jurisdiction-specific crash severity and collision type distributions. Section 5 is for *agency's data personnel* as well as *safety professionals* leading the calibration efforts; it provides an overview of the data needs for the development of the SPF calibration factors, as well as recommendations on good practices for long-term data storage, collection and management for cyclical re-calibration or jurisdiction-specific SPF development in future. Section 6 provides guidance to *statistical analysts as well as all others involved in the data preparation and prediction analysis*; it covers all stages of the development of calibration factors for each facility type including the development of jurisdiction-specific crash severity and collision type distributions, and adjustment factors. Section 7 gives a few examples and lessons learned by past calibration efforts, while Section 8 presents frequently-asked-questions aiming to be a quick source of responses for those considering developing calibration factors. References are provided and these are followed by Appendices.

4. SPF Calibration Factors and Jurisdiction-Specific Collision Type and Crash Severity Distributions – Rationale for this Effort

During the past decades, traffic and road professionals have studied the historical records of crashes with the intent of learning about the collision type and severity of crashes, and potential crash contributing factors along a corridor or site considered for engineering modifications. However, when doing so, the volatility of the annual crash records or observed crash frequency (and their short term averages and attributes) did not represent the "long-term average" magnitude and type of the problem on the corridor or site (Figure 4.1). When long-term averages were estimated for the "exceptional" cases when many years of data were available for sites where no modifications took place during these years, the need to consider the changes in annual traffic volumes became evident. It was also evident that there was a need to find a way to combine the short-term crash historical data and traffic volumes along any selected corridor and still be able to estimate the long-term average (namely, the expected average crash frequency and severity) and in such a way enhance the reliability of the results of the safety analysis.

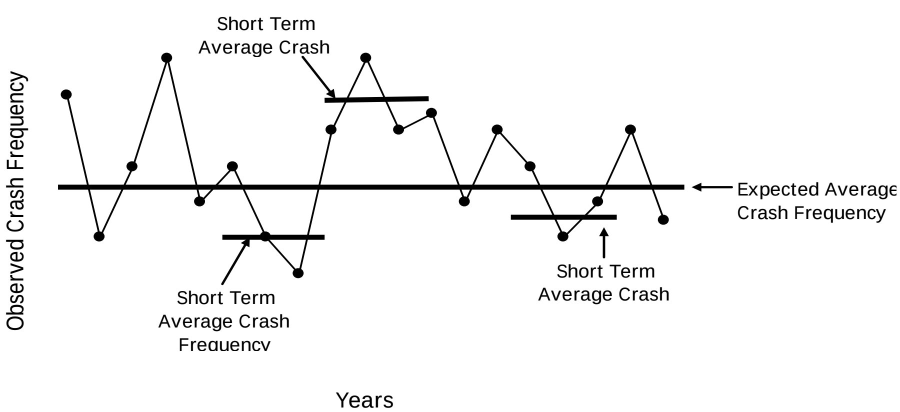


Figure 4.1 – Short-term and long-term (expected) average crash frequency (Source: HSM (2010) Volume 1, Figure 3-4, pg.3-11)

A statistical method, the Empirical Bayes (EB), was employed to meet the need for a reliable safety analysis. The EB method is presented in the HSM (2010). The EB method uses the history of annual crash records and related annual traffic volumes for a group of sites that have similar attributes. The homogeneity of these sites and their combined historical data records answers to the need to overcome the limitations of short-term records for any one site. Similar site groups can be urban four-leg signalized intersections, rural two-lane two-way roads, or rural multilane divided highways. By grouping sites with similar attributes and using statistical analysis, the best fit model or equation can be determined (Figure 4.2). This model, namely safety performance function (SPF), can be used to estimate the expected average crash frequency (by severity and type) for a given traffic volume, i.e., the "long-term average." This estimate value can be calculated with high level of accuracy even if there are just 1-3 years of recorded crashes for the site or corridor being studied. Good estimates of expected crash frequency facilitate the evidence-based management of road networks. In summary, recent traffic and safety data for any project corridor or site are sufficient for a sound analysis when using relevant SPF and the EB method. This method also allows for crash estimates in future years using forecasted traffic volumes with no other changes to the site or corridor.

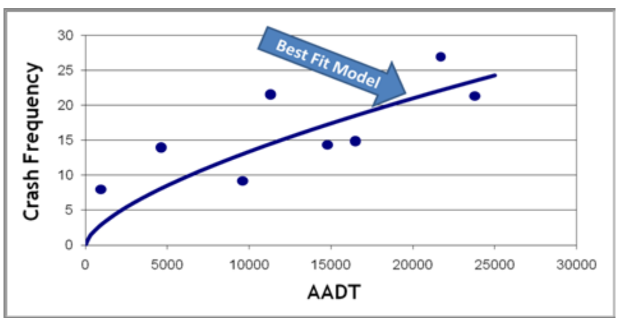


Figure 4.2 – Best fit model between observed crash frequency and traffic volume (Annual Average Daily Traffic) (Source: NCHRP Project # 17-38 Training Materials for the HSM)

4.1 The Use of HSM Predictive Models

Predictive models (consisting of SPFs, crash modification factors (CMFs), and calibration factors) are found in Part C of the HSM (2010). The predictive models allow for estimating predicted average crash frequency by severity and collision type (and expected average crash frequency when using EB method and historical observed crashes) of a road network, facility, or individual sites. "The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecast" (Part C, page C-3, HSM (2010)). The crash frequency estimate can be for:

- Existing facility or site conditions
- Alternatives to existing facility or site condition (i.e., future improvements)
- Proposed new facilities

Since 2000, a national effort has been undertaken to develop predictive models to support safety analyses. The HSM published in 2010 contains, in its Part C, predictive models for a number of facility types (Figure 4.3). For the development of the SPFs for these predictive models, data were extracted from comprehensive datasets belonging to a few highway agencies. For example, the SPFs for rural two-lane, two-way roads, presented in Chapter 10 of the HSM, were developed using datasets from Minnesota DOT, Washington DOT, Michigan DOT, and California DOT; while the urban and suburban arterial's signalized intersection predictive models originated from data found in datasets from Minnesota DOT, City of Charlotte in North Carolina, Florida DOT, and City of Toronto in Ontario. Prior to the HSM publication, the SPFs were adjusted using HSIS data from Washington and California (2002-2006).

HSM Chapter/ Facility Type	Undivided Roadway Segments	Divided Roadway Segments	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			3-Leg	4-Leg	3-Leg	4-Leg
10 - Rural Two-Lane Two-Way Roads	✓	-	✓	✓	-	✓
11 - Rural Multilane Highways	✓	✓	✓	✓	-	✓
12 - Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

Figure 4.3 – HSM (2010) facility types for which predictive models are found in the HSM (2010) (Source: HSM, Part C, Pg.C-5)

Traffic and road engineering professionals, when equipped with predictive models, are able to calculate the expected average crash frequency and severity of existing and future road corridors or sites, and compare the safety impacts of alternative design elements and/or traffic control devices for present and future traffic volumes. Predictive models can be used in all stages of project development and roadway safety management process (Figure 4.4). Predictive models form a powerful tool to support and defend decisions that were, in the past, mostly subjective or limited to a number of individual professional experiences.

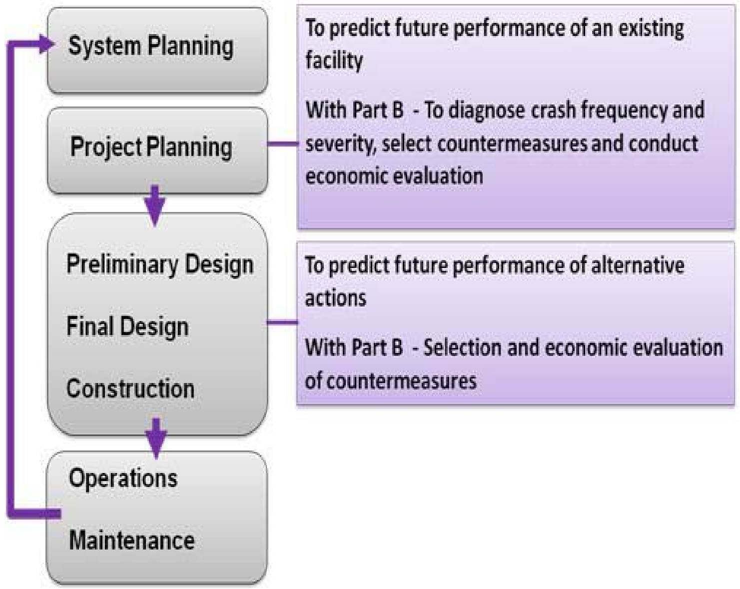


Figure 4.4 – Predictive models in the project development stages and road network safety management (Source: NCHRP Project # 17-38 Training Materials for the HSM)

Traffic and road engineering professionals are able to make defensible, more reliable decisions

When equipped with predictive models, decision-making is supported by the estimates of expected average crash frequency and severity of existing and future road corridors or sites, and the respective safety impacts of alternative design elements and/or traffic control devices for present and future traffic volumes.

Illustration

The safety impacts of adding a left-turn lane

The expected average crash frequency was estimated for a three-leg intersection with a minor road STOP control, using the relevant predictive model and the observed crashes for the past three years.

As part of an improvement program, a left-turn lane on the major road is under consideration. The HSM (2010) informs that one can expect a reduction of 44% of total crashes (CMF = 0.56 – Table 11-22, pg.11-34).

Assuming the improvement will take place in two years with a life cycle of 20 years, and using the respective traffic volumes forecast for the period, the estimates of future crashes with or without the installation of a left-turn lane, are calculated. The potential crash reduction estimates can be converted to monetary values and integrated with other cost factors, such as construction, right-of-way, environment, etc toward an informed decision-making.

4.2 The Need to Calibrate SPFs and Replace HSM Default Crash Distribution Tables and Adjustment Factors to Jurisdiction-Specific Conditions

The use of the predictive models in any jurisdiction calls for calibration of the HSM Part C's SPFs, and for replacement of "default" crash distribution tables and adjustment factors to local conditions, because the HSM SPFs were developed using data associated with a few highway networks around the country, and acquired several years ago (Section 1.1). If applied to another state or county network or corridor, or to another time period, the predictions are likely to be biased. The purpose of calibration is to ensure that the bias is tolerably small.

For the same reason, it is recommended to replace the many crash distribution tables and adjustment factors, found in the HSM (2010), using jurisdiction-specific data for the same years as the jurisdiction-specific SPF calibration factors. Differences in climate, driver populations, animal populations, crash reporting thresholds, crash reporting system procedures, time periods (i.e., different years) are some of the reasons why such calibration and adjustments are necessary.

Since the publication of HSM (2010), several state departments of transportation have engaged in assignments to develop calibration factors for HSM (2010) SPFs using their own data, such as Oregon, Illinois, Virginia, Washington, Louisiana, and Missouri. For example, the results of the Oregon Department of Transportation (ODOT) study have highlighted the critical need to calibrate the SPFs. The use of HSM (2010) "unadjusted" predictive models would have over-estimated the total crashes for most facilities in the state of Oregon. The errors in estimates would vary from 25% in the case of rural two-lane, two-way roadway segments and more than 80% for four-leg signalized intersections at rural multilane highways. This loss of precision would not have improved decision-making when selecting safety strategies, countermeasures, and design alternatives, and ultimately would have led to misallocation of resources and mistrust in safety analysis.

Illustration

Calibration Factors for Predictive Models using Oregon State Data

In 2010/11, the Oregon Department of Transportation (ODOT) commissioned a study to determine calibration factors based on Oregon safety and road data, to be used with the HSM (2010) predictive models for the state highways predictive models.

The most recent data dated 2004-06 and these were used to calibrate the HSM models developed with data from different periods between 1985 and 2003 (depending on the facility type). Additional details are given in Section7: Case Studies.

Some of the calibration factors (for total crashes) are listed below:
Rural two-lane, two-way road segment $C_{total} = 0.74$; *3-leg STOP controlled intersection* $C_{total} = 0.32$; *4-leg STOP controlled intersection* $C_{total} = 0.31$; *4-leg signalized intersection* $C_{total} = 0.47$

Rural multilane undivided segment $C_{total} = 0.36$; *divided segment* $C_{total} = 0.78$; *3-leg STOP controlled intersection* $C_{total} = 0.16$; *4-leg STOP controlled intersection* $C_{total} = 0.40$; *4-leg signalized intersection* $C_{total} = 0.15$

4.3 Data Needs for Current and On-Going Use of the Predictive Models

As said, the use of the predictive models in any jurisdiction calls for calibration of the HSM Part C's SPFs to local conditions. The development of calibration factors requires the integration of existing data on crashes, exposure (traffic volumes), and roadway elements, as well as the collection of missing required data. Three issues arise:

i. How to prioritize the facility types and predictive models for SPF calibration, assuming that the calibration effort will be phased based on monetary and human resource availability
ii. Identification of data available within jurisdiction-specific sources and their integration based on a common identifier (i.e., location coordinates), and feasibility of collecting missing data elements (by means of office tools such as GoogleMap Streetview, video-tapes, etc or field tools such as grade measurements, traffic counts, etc)
iii. Data preparation for the calibration procedure and for data preservation toward re-calibration (annually or multi-annual) or SPF development

Data collection, gathering, and preparation comprise the greater part of the effort when developing calibration factors for the first time. Potential methods to gather specific data elements are discussed in Section 5. It is paramount that jurisdictions realize that this process does not entail a single-time effort as calibration will be repeated periodically with updated and current data. There is a vital need to create an on-going data capturing program to support the application of safety prediction methods. The data ought to be housed in a format and software application that allow for easy annual data entry and expansion, as needed. These data could also be used for jurisdiction-specific SPF development in future, as discussed in Srinivasan et al (2013) (2).

4.4 Estimate of Costs and Project Duration when Developing Calibration Factors

The availability of data varies considerably among jurisdictions in general and for given facility types (e.g., AADTs for rural multilane highway signalized intersections may be counted annually as part of the annual traffic counting program while rural two-lane, two-way signalized intersections may be counted every five years). Thus, it is difficult to estimate the cost and project duration as they are very dependent on the amount of data to be collected and human resources available to carry out the data collection and preparation. A few examples of effort and project costs are listed in Table 4.1.

Table 4.1 – Examples of project costs and durations (Sources: Mr. W. Scott Jones for Utah, and Dr. Karen Dixon for Oregon)

State	*SPF Calibration Factors*	*Project Duration and Budget / General Comments*
Utah	Rural two-lane, two-way roads	About 12-month for $50,000 effort (Note: four negative binomial calibration models, followed by a Bayesian model using the results of the selected negative binomial model were also carried out in this project)
	General	The development of an SPF for intersections is typically about twice as time-consuming as for a roadway segment because many DOT databases do not include data for "intersections." Hence, the researcher has to identify the two roadway segments that intersect to have the road, traffic, and crash data needed for development. There are some economies of scale when more than one SPF is developed at the same time, but not much.
	General	For development of cost, a good point of reference could be the costs for NCHRP Projects 17-29 and 17-26 (these were the projects that developed SPFs for the HSM). SPF development for a DOT would not include the task of writing a draft HSM chapter, assembling an expert panel to identify CMFs, or assembly of data from multiple states. However, in most other respects, development of SPFs is similar to the work done in the original NCHRP projects. The total cost for NCHRP 17-29 was just over $700,000 for developing SPFs for multilane highways (Chapter 11 of the HSM). The total cost for NCHRP 17-26 was about $1.1 million and was for developing SPFs for urban and suburban arterials (Chapter 12 of the HSM). Estimate about 50% of those NCHRP Project costs to develop the same set of SPFs (as in HSM Part C) for a specific DOT.

State	*SPF Calibration Factors*	*Project Duration and Budget / General Comments (cont')*
Oregon	Rural two-way, two-lane highways, rural multilane highways, and the urban and suburban arterials	The Oregon project was performed by a team from Oregon State University (led by Karen K. Dixon, Ph.D., P.E. ; currently: Research Engineer, Texas A&M Transportation Institute) and Portland State University (led by Christopher M. Monsere, Ph.D., P.E., Assistant Professor, Portland State University). The project included calibration of the SPFs for the rural 2-lane highways, rural multilane highways, and the urban and suburban arterials. The total cost of this effort was $130,000. This included approximately 300 hours of professional time (primarily for Drs. Monsere and Dixon) plus around 1700 hours of graduate student time (basically a little more than 9 months for two graduate students). It is estimated that around 85 percent of the student effort was data collection, organization, spreadsheet input, and QC. No field data collection; and in-office procedures were used for all data collection. Oregon has a video library and it was supplemented, primarily in urban areas, with the GoogleMap Streetview. The Oregon road characteristic database, in combination with the crash database, served as their other primary data source. The administrative time included data collection spot checking (probably around 10%).

Some information about resources and costs of developing own SPFs can also be found in Srinivasan et al (2013) (2).

A recent publication by Lawrence et al (2012) provides useful information regarding the cost estimates that States may incur in order to gather the crash, exposure (traffic volumes), and roadway data that are not collected through the Highway Performance Monitoring System (HPMS), and other efforts. The cost categories considered in this report comprise investment costs, operations and maintenance costs, cost for locating and coding crashes, data storage, and other costs. The costs include data collection, reduction, and integration into a State's current systems.

5. SPF Calibration Factors for a Specific Jurisdiction – General Data Requirements

Earlier Sections of this Guide have noted that the development of SPF calibration factors requires the integration of existing data on crashes, exposure (traffic volumes), and roadway elements, as well as the collection and integration of missing required data. This Section advances the understanding of the general data requirements using jurisdiction-specific data sources, and describes various data collection methods such as office tools (e.g., GoogleMap Streetview, video-tapes) and field tools (e.g., site visits, traffic counts).

The information provided in this Section will be useful to data personnel in an agency, such as professionals managing the annual traffic counting program and estimating AADTs, professionals coding and maintaining / managing annual crash data, professionals collecting and managing roadway data and traffic control devices data, professionals managing the computer system interfaces of all the different data sources; and consultants to public agencies.

5.1 Overview of Data Assembling Process and Basic Data Elements

Every highway jurisdiction collects crash, traffic volume, and geometric data; data may be collected regularly and systematically, or sporadically as needed. Different data elements are typically collected and managed by various departments in an agency, and are not found under a common database or computer system. Thus, the steps in a data collection process for the development of SPF calibration factors may be as follows:

i. Based on the data required or desirable for the development of SPF calibration factors (Table 5.1A, Table 5.1B, and Table 5.1C), identify the sources of data elements within the jurisdiction-specific databases / data records / folders and the means to consolidate the existing data for further processing
ii. Identify the missing data elements and establish a methodology to acquire them
iii. Assess the resources needed and develop a work plan to acquire the missing data
iv. Record the newly acquired data elements with the consolidated existing data

v. Update the work plan for on-going data collection and preparation for updates of SPF calibration factors, as needed (and possible development of future jurisdiction-specific SPFs)

vi. Repeat the steps i-v for all facility types found in the HSM (2010), as per agency's priorities. *Note*: future editions of the HSM will include prediction models for additional facilities and these would follow the same data collection and process.

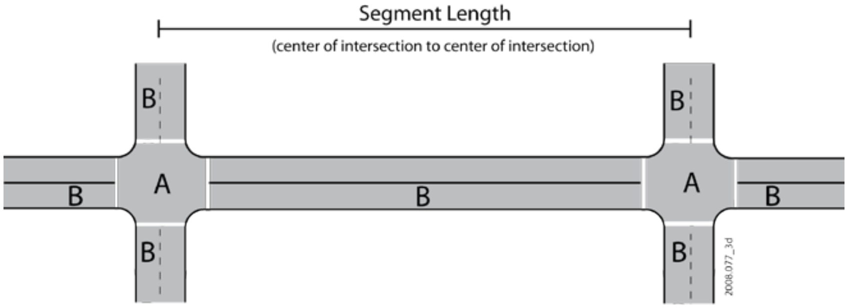
The first task in the process of assessing data availability and commencing their preparation entails identifying the sources of data (required and desirable elements) within the jurisdiction and how to bring them "under one umbrella" either by creating interface links between data sources or combining the data within one single platform. A successful connectivity among the data sources will be followed by obtaining data to classify a site as one of the facilities defined for each SPF in the HSM (2010). Thus, it is essential, at the outset, to identify and classify:

1. Any roadway segment as a rural two-lane, two-way road, or rural multilane divided or undivided highway, or an urban and suburban arterial street with two-lane, or three-lane (with TWLTL), or four-lane divided or undivided, or five-lane (with TWLTL) cross-section (i.e., the cross section and classification of each roadway segment are needed)
2. Any intersection as a rural two-lane, two-way road three- or four-leg STOP controlled, or a rural two-lane, two-way road four-leg signalized intersection; or as a rural multilane highway three- or four-leg STOP controlled, or a rural multilane highway four-leg signalized intersection; or as an urban and suburban arterial three- or four-leg STOP controlled, or an urban and suburban arterial three- or four-leg signalized intersection (i.e., the cross section, classification, and traffic control device at each intersection are needed)

The HSM defines rural areas as locations with less than 5,000 inhabitants; it does not distinguish between suburban and urban areas.

An important task in this process comprises defining a site unique location identifier (in milepost or geo-coordinates). All data elements (i.e., crash, traffic volumes, geometric elements, and traffic control devices) will be brought together onto one table (e.g., Excel spreadsheet) or database platform using this unique identifier. The unique location or site identifier will also play an ongoing key function as data elements are collated and entered into the databases for re-calibration of the SPFs during subsequent years.

Furthermore, by HSM (2010) definition, crashes are allocated to a roadway segment or an intersection, as shown in Figure 5.1. Intersection crashes include crashes that occur within Area A (i.e., within curb limits) and intersection-related crashes that occur on the intersection legs (Area B), such as rear-end collisions related to queues on an intersection approach. Thus, crashes that occur within Area B are assigned to either the roadway segment on which they occur or one of the intersections, depending on the crash characteristics and crash report/coded data. This definition of intersection-related crashes may be different than a jurisdiction's practice, and will require modifying it to comply with the HSM's SPFs and any future re-calibration assignments.



A All crashes that occur within this region are classified as intersection crashes.

B Crashes in this region may be segment or intersection related, depending on on the characteristics of the crash.

Figure 5.1 – Definition of roadway segments and intersections for crash assignment (Source: 2010 HSM, pg. 10-12)

As said earlier, traffic volume data are vital to safety estimation. The AADT volumes (vehicles/day) for each site are required for every year of crash data. Several jurisdictions undertake an annual traffic counting program and have reasonable estimates of the AADT volumes for major roadways and intersections. However, several jurisdictions would need to collect traffic volume data as they do not carry out comprehensive traffic count programs, or do not include minor roads or STOP-controlled intersections in their programs. In the next sub-sections, a few suggestions to overcome this limitation and other missing data elements are offered.

5.2 Required and Desirable Data Elements for Development of SPF Calibration Factors

The HSM (2010) Part C describes the elements needed for the development of calibration factors for each HSM prediction model for a given facility type. The HSM(2010) classifies some site characteristics as required (i.e., those elements considered to have high impact in crash occurrence) and others as desirable (i.e., those elements deemed to be less sensitive to crash occurrence). Jurisdiction-specific data are needed for each of the required elements, while for the data elements identified as desirable, the HSM (2010) provides guidance and some assumptions for data default values when jurisdiction-specific data are not available. It is, however, recommended that actual data be used for all elements whenever possible. The jurisdiction-specific data include observed crash frequency, collision type and severity level, roadway geometry, traffic control devices, annual traffic volumes, etc. Table 5.1A, Table 5.1B, and Table 5.1C show the data elements, and these are noted as required or desirable.

Typically, a time period of 1 to 3 years may be necessary to reach a sufficient sample size of crash frequencies that were observed / recorded at sites that are similar to those used for the development of each HSM SPF. If more years of data are available, they may be helpful to determine whether there is a time trend of annual estimates of calibration factors. The approach (i.e., annual data preparation and processing) adopted in this Guide will enable jurisdictions to assess the need or desire to combine two or more years of data to estimate an average calibration factor for the selected analysis period, or assess the annual calibration factors for trends by developing a calibration function (i.e., a function of time) when four or more years of data are assembled. This calibration function would be useful in past and future analysis for a given year. Section 6 provides guidance on the selection of sites and sample size required for a desired level of accuracy.

Table 5.1A – Data elements required / desirable for development of calibration factors for rural undivided two-lane, two-way roads

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years)			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF$_i$ in 2010 HSM; * **desirable**)*
Rural undivided two-lane, two-way - roadway segments (2U)	Observed crash frequency by severity for each year	Annual average daily traffic (AADT) for both traffic directions combined	Roadway segment length (mile) 1.Lane width (ft) 2.1Shoulder width (ft) 2.2.Shoulder type (paved, gravel, composite, turf) 3.1Horizontal curve length (miles) 3.2.Horizontal curve radius (ft) 3.3.Horizontal curve absence (0) / presence (1) or (1/2 on one approach only) of spiral transitions * 4.Horizontal curve superelevation (variance in ft/ft from maximum by AASHTO policy) * 5.Vertical grade (%) * 6.Driveway density (both roadway sides/mile) * 7.Centerline rumble strips (presence or absence) * 8.Passing lane/short 4-lane (presence or absence) * 9.Two-way left-turn lanes (presence or absence; if present, driveway-related crashes as a proportion of total crashes) 10.Roadside design (roadside hazard rating: 1-7) * 11.Lighting (presence or absence; if present, proportion of total nighttime crashes by severity level for unlit roadway segments, and proportion of crashes that occur at night at unlit roadway segments) * 12.Automated speed enforcement (presence or absence) *

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years) (Cont')			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF_i in 2010 HSM; * **desirable**)*
Rural two-lane, two-way three-leg (3ST) or four-leg STOP (4ST) controlled on minor-road approach or four-leg signalized (4SG) intersections	Observed crash frequency by severity for each year	Annual average daily traffic ($AADT_{maj}$ and $AADT_{min}$) (i.e., the larger of the two AADTs for major road approaches and the larger of the two AADTs for minor road approaches; for 3ST, $AADT_{min}$ of the single minor road leg)	1.Intersection skew angle (absolute value of deviation from 90 degrees) for STOP controlled intersections only * 2.Intersection left-turn lanes (presence or absence for each approach without STOP control) 3.Intersection right-turn lanes (presence or absence for each approach without STOP control; not applicable for long tapers, flares or paved shoulders) 4.Lighting (presence or absence; if present, the proportion of crashes that occur at night for unlit sites for each intersection type)

Table 5.1B – Data elements required / desirable for development of calibration factors for rural multilane highways

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years)			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF_i in 2010 HSM; * **desirable**)*
Rural four-lane undivided - Roadway segment (4U)	Observed crash frequency by severity for each year	Annual average daily traffic (AADT) for both traffic directions combined	Roadway segment length (mile) 1.Lane width (ft) 2.1Shoulder width (ft and proportion of total crashes constituting related crashes) 2.2.Shoulder type (paved, gravel, composite) 3.Sideslope (V:H) 4.Lighting (presence or absence; if present, proportion of total nighttime crashes by severity level for unlit roadway segments, and proportion of crashes that occur at night for roadway unlit segments) * 5.Automated speed enforcement (presence or absence) *
Rural four-lane divided – Roadway segment (4D)	Observed crash frequency by severity for each year	Annual average daily traffic (AADT) for both traffic directions combined	Roadway segment length (mile) 1.Lane width (ft) 2.Right shoulder width (ft) 3.Median width (ft) 4.Lighting (presence or absence; if present, proportion of total nighttime crashes by severity level for unlit roadway segments, and proportion of crashes that occur at night for unlit roadway segments) * 5.Automated speed enforcement (presence or absence) *

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years)(Cont')			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF i in 2010 HSM; * **desirable**)*
Rural multilane highways three-leg (3ST) or four-leg STOP (4ST) controlled on minor-road approach or four-leg signalized (4SG) intersections	Observed crash frequency by severity for each year	Annual average daily traffic ($AADT_{maj}$ and $AADT_{min}$) (i.e., the larger of the two AADTs for major road approaches and the larger of the two AADTs for minor road approaches; ; for 3ST, $AADT_{min}$ of the single minor road leg; for 4ST and 4SG, total AADT can also be used instead of entering volumes)	Presence of median on approaches (to determine divided or undivided multilane roadway segments for separate calibration, if feasible) 1.Intersection skew angle (absolute value of deviation from 90 degrees) for STOP-controlled intersections only * 2.Intersection left-turn lanes (presence or absence on major road approaches) for STOP-controlled intersections only 3.Intersection right-turn lanes (presence or absence for major road approaches) for STOP-controlled intersections only 4.Lighting (presence or absence; if present, the proportion of crashes that occur at night for unlit sites for each intersection type) for STOP-controlled intersections only Note: no CMFs for 4SG.

Table 5.1C – Data elements required / desirable for development of calibration factors for urban and suburban arterials

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years)			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF$_i$ in 2010 HSM; * **desirable**)*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments	Observed crash frequency by severity for each year	Annual average daily traffic (AADT) for both traffic directions combined	Roadway segment length (mile) 1.1 On-street parking (presence or absence; if present, which proportion of curb length with street parking for both sides of roadway) 1.2 On-street parking type (angle or parallel, one or both sides or roadway by area type: residential/ industrial/commercial/institutional, other) 2.Roadside fixed object (presence or absence for 4 inches in diameter and not breakaway; if present, fixed object density on the right side of the roadway: fixed objects/mile; average offset from edge of traveled way (ft), and proportion of fixed object collisions of total crashes) * 3.Median width (ft – for divided roadway segments with traversable medians – not applicable to TWLTL) 4.Lighting (presence or absence; if present, proportion of total nighttime crashes by severity level for unlit roadway segments, and proportion of crashes that occur at night at unlit roadway segments) * 5.Automated speed enforcement (presence or absence) * Note: Data are also required for the use of SPFs: a)Driveway by type (major or minor commercial, major or minor industrial/institutional, major or minor residential, other) b)Posted speed limit

For each site (i.e., intersection or roadway segment) historic data for a given time period (1-3 years)(Cont')			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric and Traffic Management Data (numbering coincides with CMF $_i$ in 2010 HSM; * **desirable**)*
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches or three-leg (3SG) or four-leg (4SG) signalized intersections	Observed crash frequency by severity for each year	Annual average daily traffic ($AADT_{maj}$ and $AADT_{min}$) (i.e., the larger of the two AADTs for major road approaches and the larger of the two AADTs for minor road approaches; for 3ST and 3SG, $AADT_{min}$ of the single minor road leg	1. Intersection left-turn lanes (presence or absence on each approach for signalized intersections but only on major uncontrolled road approaches for STOP-controlled intersections) 2.Intersection left-turn phasing (permissive, protected, protected/permissive, or permissive/protected) 3.Intersection right-turn lanes (presence or absence on each approach for signalized intersections but only on major uncontrolled road approaches for STOP-controlled intersections) 4.Right-turn-on-red (number of signalized intersection approaches for which right-turn-on-red is prohibited) 5.Lighting (presence or absence; if present, the proportion of crashes that occur at night for unlit sites by intersection type based on intersection calibration samples or all jurisdiction's intersections, if available) 6.Red-light cameras (presence or absence; if present, proportion of multiple-vehicle right-angle collisions by severity level; proportion of multiple-vehicle rear-end collisions by severity level based on selected intersections for the RLC program or all jurisdiction's signalized intersections)

For each site (i.e., intersection or roadway segment) historic data for a given time period (3-5 years)(Cont')			
Facilities and HSM Prediction Models	*Crash Data*	*Traffic volume (veh/day)*	*Geometric, Traffic Management, and Adjacent Land Use Data (numbering coincides with CMF i in 2010 HSM; * **desirable**)*
Cont'			These attributes are required only for vehicle-pedestrian collisions at signalized intersections 1p)Bus stops (presence or absence within 1000 ft of center of intersection; if present, number of bus stops) * 2p)Schools(presence or absence within 1000 ft of center of intersection) * 3p)Alcohol sales establishment s ((presence or absence within 1000 ft of center of intersection; if present, number of establishments) * Note: Data are also required for the use of SPFs: a)maximum number of lanes to be crossed by a pedestrian in any crossing maneuver at signalized intersection * b)pedestrian daily total volume at signalized intersection *

5. 3 Supplemental Data Collection Methods

Most highway agencies will need to collect data to supplement the typical annual data collection programs. A number of data collection methods recently deployed by agencies when developing calibration factors or jurisdiction-specific SPFs are described below. They include aerial and ground photography, roadway segment plans, and intersection diagrams for the collection of roadway elements and traffic control devices; estimation techniques for a) missing traffic volumes for segments or intersection approaches, or b) missing pedestrian volumes at urban and suburban arterial intersections. While these methods comprise office-based data assembling methods, others entail site visits to collate supplementary data, or deployment of traffic counting machines or personnel to complement traffic and pedestrian volume data.

<u>Aerial Photography</u>

Aerial photographs are used to collate or confirm the cross-section and alignment data elements. These photographs are available via Google Earth at a scale of 1:1200 for a number of years that can be used to identify geometric or traffic control device changes over time. Illustrations are given below. Bonneson et al (2012) describes the use of a Roadway Data Extraction (RDE) Tool developed to extract relevant data from Google Earth (Figure 5.2), and Dixon et al (2012) describes the used of aerial photos to obtain intersection lighting, intersection skew angle, and turn-lanes.

Illustration Google View

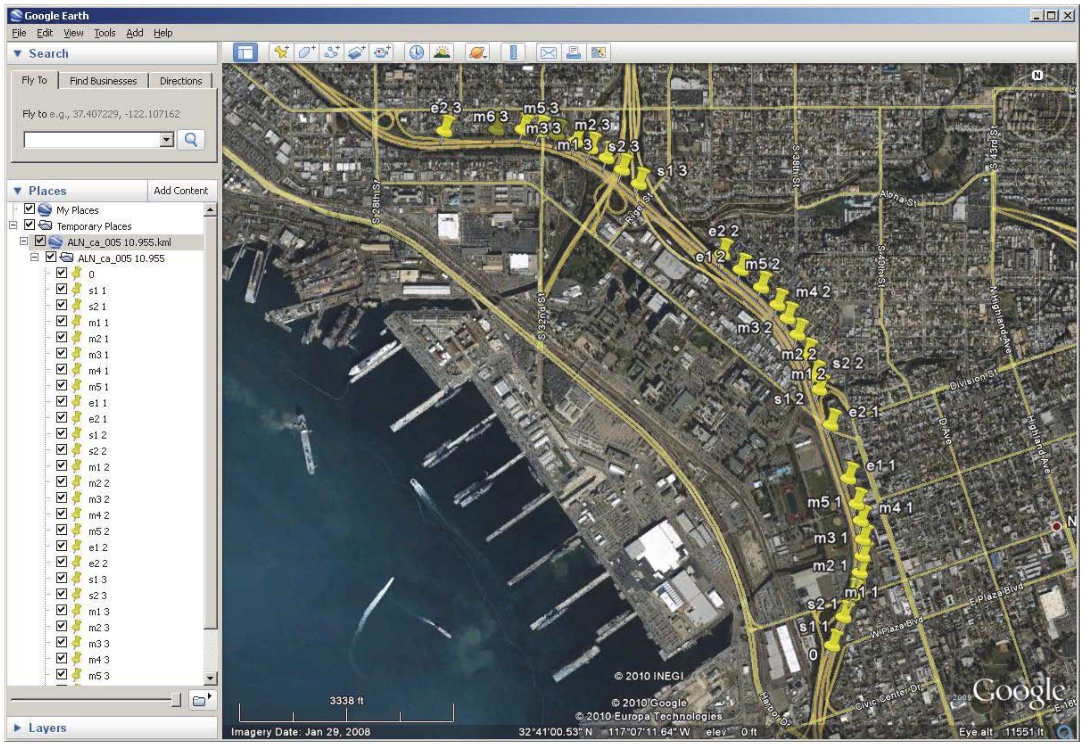


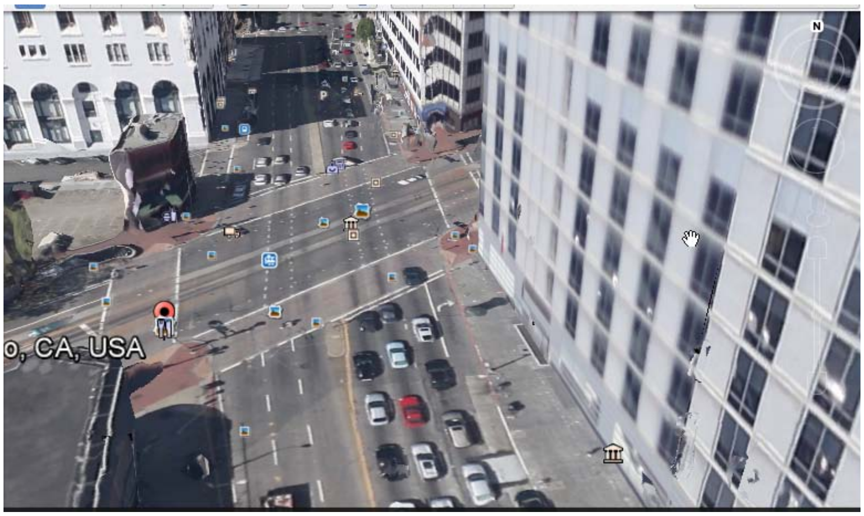
Figure 5.2 – Example of digitized alignment extracted from Bonneson et al (2012) (Figure B-1, Appendix B, page B-3)

Ground Photography: Google Street View and Video Logs

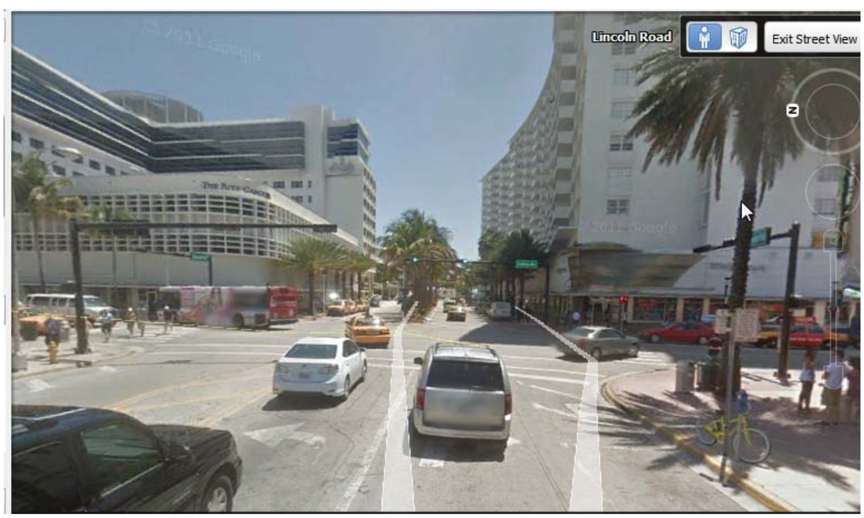
Ground photography complements aerial photos. Several agencies collect video-logs on annual or biennial cycles. The video logs are very useful to collate alignment and cross-section elements and confirm other data, such as posted speed limit, pavement markings, pedestrian crosswalks, barriers and other fixed roadside objects, etc. Google Street View is a supporting tool to video logs. Dixon et al (2012) used both tools to identify driveway types, and alcohol establishments and schools within 1,000 ft from signalized intersections, and to measure roadside objects' longitudinal and lateral positions.

Illustration

Google View



Google Earth – Street View



Roadway corridor construction and pavement marking plans, and intersection diagrams

These plans (in hardcopy or electronic format) may provide complementary information about lane markings, turn lanes, signs, traffic signals, etc that may not be clear from the Google Earth tool.

Traffic volume (AADT) for each roadway segment and intersection

The average daily two-way, 24-hour traffic volume is the most significant element in the prediction of crashes; it is imperative that annual average daily traffic (AADT) volumes for each roadway segment, and $AADT_{maj}$ (i.e., the larger of the two AADTs for major road approaches) and $AADT_{min}$ (the larger of the two AADTs for minor road approaches) or the AADT of the single minor road leg for 3ST and 3SG, for each intersection, for each year of data collection, be collected or estimated. As indicated, it is preferable that jurisdictions carry out an annual traffic counting program making it possible to update the traffic volumes on their roadways more accurately. Alternatively, the HSM (2010) provides some guidance:

- If data are available for only a single year, that same value is assumed to apply to the other years used for calibration
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation

Another option for when data are available for only a single year would consist of using an AADT annual growth rate as a multiplier to estimate AADTs for past or future years. The growth rate would be an acceptable value based on sites at nearby roadways in the jurisdiction, with similar adjacent land use, geometric and traffic characteristics.

In HSM Chapter 11 (2010), the $AADT_{total}$ for all approaches combined can be used if the jurisdiction does not have entering volumes for $AADT_{maj}$ and $AADT_{min}$.

Dixon et al (2012) developed alternative procedures to estimate missing $AADT_{min}$:

- for urban intersections, the ratio of ($AADT_{maj}$ / $AADT_{min}$) for the year when both AADTs were known, was used to multiply the $AADT_{maj}$ to estimate the missing $AADT_{min}$ for a given year
- for rural intersections, an AADT estimation model, using multiple linear regression technique, was developed for Oregon similarly to Indiana estimation model (Mohamad et al (1998)). The model considers independent variables such as distance to major highways,

the presence of a right-turn lane on major or minor road, the presence of a centerline marking, etc.

Pedestrian volumes for urban and suburban signalized intersections

In the HSM (2010), Chapter 11, the total pedestrian crossing volume for an intersection is determined as the sum of the pedestrian volumes crossing each intersection leg for each year of the calibration period. In the absence of jurisdiction-specific pedestrian volumes, the HSM (2010) provides some guidance:

- If two or more years of pedestrian volume data are available, the pedestrian volumes for intervening years are computed by interpolation
- HSM Table 12-15 provides estimates of pedestrian volumes based on general levels of pedestrian activity (i.e., high, medium-high, medium, medium-low, or low) at 3SG and 4SG intersections.

In addition, using aerial or ground photography, jurisdictions may be able to deduce the level of pedestrian activity based on the adjacent land use and density of residential, industrial or commercial buildings, and their knowledge of the transportation modes and accessibility choices.

5.4 Data Preservation and Expansion

The preservation of the data collected for the development of calibration factors is highly recommended. The process of data collection and preparation for the development of SPF calibration factors is not a "one time" event. Calibration factors need to be current to provide appropriate safety estimates based on most recent annual crash and traffic volumes. As indicated before, the approach (i.e., annual data preparation and processing) adopted in this Guide will enable jurisdictions to assess the annual calibration factors for trends by developing a calibration function (i.e., a function of time) when four or more years of data are assembled. This calibration function would be useful in past and future analysis for a given year. Thus, with additional years of data, time trends can be assessed and functions modified accordingly for better prediction estimates.

Furthermore, these data would be used for a future development of jurisdiction-specific SPFs (Refer to Srinivasan et al. (2013)(2)). Thus, it is important to plan for long-term data storage in a format allowing annual traffic and safety data entries (e.g., annual traffic volumes, observed annual crash frequencies and severity levels, etc), and updates about geometric and traffic control elements based on implemented modifications (e.g., stop-control intersection modified to signalized, addition of a left-turn lane at an intersection, shoulder is paved, etc), or completion of new roads.

Relevant policies and practices are typically a catalyst in supporting the collection and management of data, as discussed in this Guide. A recent publication (Sawyer et al (2012)) describes a roadway safety data capability assessment methodology focused in four areas:

- Roadway Inventory Data Collection / Technical Standards
- Data Analysis Tools and Uses
- Data Management
- Data Interoperability and Expandability

It is recommended that agencies continue advancing their data capability maturity levels in these focus areas considered essential to make robust, data-driven safety programs and decision-making. A comprehensive annual traffic counting program that includes all public roads is fundamental to achieve a sound safety management program. The Federal Highway Administration has developed two supporting models for data required for data-driven safety analysis: a) the Model Inventory of Roadway Elements (MIRE) (www.mireinfo.org) which provides a structure for roadway inventory data; and b) the Model Minimum Uniform Crash Criteria (MMUCC) (www.mmucc.us/) which provides a set of uniform crash data elements, definitions, and attributes. Highway agencies are encouraged to adopt MIRE and MMUCC for common consistent definitions and attributes as their data capability is enhanced.

It is also noted that the prediction models will be expanded in future editions of the HSM. For that reason, it is recommended that agencies include, in their roadway, traffic, and crash data management, additional facilities such as freeways and ramps, one-way streets, 6+ lane urban and suburban arterials, roundabouts, etc.

6. SPF Calibration Considerations – Calibration Procedural Steps and Assessing Results

As stated in previous sections of this Guide, the use of the predictive models in any jurisdiction calls for calibration of the HSM Part C's SPFs, and for replacement of default crash distribution tables and adjustment factors to local and current conditions. The purpose of calibration is to provide better estimates for jurisdiction-specific conditions; the calibrated models are used to estimate the existing and future safety of project corridors / sites while considering potential engineering improvements. Consequently, it is recommended that calibration factors be estimated using jurisdiction-specific conditions, whenever possible, for each HSM SPF by crash injury severity level (such as: calibration factors for rural multilane highway segments' SPF_{total} and $SPF_{fatal + injury}$; calibration factor for urban and suburban arterial segments' SPF_{total} and $SPF_{fatal + injury}$; calibration factor for urban and suburban arterial vehicle-pedestrian collision $SPF_{fatal + injury}$ at signalized intersection; etc). This recommendation is an expansion of the Appendix A of HSM Part C direction that a single calibration factor for each SPF_{total} is satisfactory. Furthermore, recommendations are also made, in the Guide, for further consideration of calibration factors that will account for differences in regional sub-sets of an agency's highway network, and account for different segment lengths, AADT volumes, etc.

Appendix A of HSM Part C presents the calibration procedure consisting of five steps:

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

The approach (i.e., annual data preparation and processing) adopted in this Guide will enable jurisdictions to assess the need or desire to combine two or more years of data to estimate an average calibration factor for the selected analysis period, or assess the annual calibration factors for trends by developing a calibration function (i.e., a function of time) when four or more years of data are assembled. This calibration functions would be useful for past and future analysis for a given year. Thus, Step 4 and Step 5, as described in the Appendix A of HSM Part C, are expanded in this Guide by providing an approach to assess the desirability to combine years of data for a single and multi-year calibration factor, or develop a calibration function by fitting a curve to the annual calibration factors.

The 5-step calibration procedure commences with the decision by the agency to which facility type/s and HSM SPFs it wishes to have calibrated to jurisdiction-specific conditions (Step 1). This is followed by selecting a random sample of sites representing the given facility type and HSM SPFs (by crash severity level) till reaching a sample size that may provide a calibration factor within the desired accuracy level (Step 2). Data elements are collated for each specific site selected to facilitate the estimation of unadjusted predicted crash frequency (Step 3). The unadjusted predicted crash frequency (i.e., assuming calibration factor = 1) for each group of sites relevant to a given SPF is calculated applying the necessary and jurisdiction-specific CMFs to the HSM SPF base model, as needed (Step 4). The unadjusted predicted crash frequency for each group of sites (or sub-group of sites, such as for sites within a region of a jurisdiction, or for sites with AADT volumes higher than a given value, etc) is compared with the respective crash frequency observed at these sites for the same time period pertinent to the geometric and traffic data (Step 5). The ratio between the observed and unadjusted predicted crash frequencies is the estimated calibration factor. Each step is described in detail in the next sub-sections.

6.1 Step 1 – Identify Facility Types for which the Predictive Model/s will be Calibrated

As discussed in Section 4.3, it is assumed that the calibration effort will be phased based on monetary and human resource availability in an agency. Thus, the issue of which facility type/s and predictive model/s should be given priority, needs to be considered at the onset of this effort.

Section 5 describes the general data elements needed for the development of SPF calibration factors, and the initial steps of jurisdiction-specific data assessment. The subsequent step is presented in this sub-section. It involves gathering broad information to respond to the criteria forming the prioritization process. The information comprises upcoming planning and design projects, and the completeness and accuracy of crash, traffic volume, and roadway geometric and traffic management inventory data for sites within each facility type and for the envisioned calibration time period.

The prioritization process, proposed here, provides an easy and concise way to assist the agency in the decision making. Table 6.1 provides a template for agencies to enter the information related to three criteria to be considered during the prioritization process; they are:

- Criterion 1 (C1): Which facility types correspond to safety-motivated, planning, and design projects in the upcoming years? (Rank from current or near future (1) to longer term (4))
- Criterion 2 (C2): Which facility types have one to three years of traffic volume data coinciding with same period of crash data? (√=yes; blank= no)
- Criterion 3 (C3): Which facility types have a corresponding inventory of geometric elements that can be integrated into a dataset with crash and traffic volume respective data?(√=yes for most; ~ = yes for required and limited to none for desirable elements; blank = none or very few elements) *Refer to Table 5.1A, Table 5.1B, and Table 5.1C for required and desirable data elements, as per HSM (2010)

An illustration of the prioritization process is provided in the next pages. A review of the information entered into Table 6.1 would indicate leading decision factors:

- The anticipated predictive models that would be needed to support the imminent safety treatment, planning, and design decisions
- Typical availability of data in the agency, related to exposure (traffic volumes in terms of AADTs) for the same crash time periods to be used for the development of SPF calibration factors
- Typical availability of data, in the agency, related to geometric and traffic management inventory (Table 5.1) for the same crash time periods to be used for the development of SPF calibration factors
- Specific exposure (traffic volume) ranges and site locations in terms of jurisdictional regions where most upcoming projects may take place, leading to a potential focus on one or more sub-sets of sites within a facility type

Table 6.1 - Prioritization of predictive models for SPF calibration, assisted by jurisdiction-specific needs/data availability

Facilities and HSM Predictive Models							
Rural two-lane, two-way roads				**Urban and suburban arterials**			
	C1	C2	C3		C1	C2	C3
Undivided rural two-lane, two-way roadway (2U)				Two-lane undivided (2U)			
Three-leg STOP controlled on minor-road approach (3ST)				Three-lane including a two-way left-turn lane(TWLTL)(3T)			
Four-leg STOP controlled on minor-road approaches (4ST)				Four-lane undivided (4U)			
Four-leg signalized (4SG)				Four-lane divided including e.g., raised or depressed median (4D)			
Rural multilane highways				Five-lane including TWLTL (5T)			
Rural four-lane undivided (4U)				Three-leg STOP controlled on the minor-road approaches (3ST)			
Rural four-lane divided (4D)				Three-leg signalized intersections (3SG)			
Three-leg STOP controlled on minor road approaches (3ST)				Four-leg STOP controlled on the minor-road approaches (4ST)			
Four-leg STOP controlled on minor road approaches (4ST)				Four-leg signalized (4SG)			
Four-leg signalized (4SG)				**Legend**: **C1**: Which facility types correspond to safety-motivated, planning, and design projects in the upcoming years? (Rank from current or near future (1) to longer term (4)) **C2**: Which facility types have one to three years of traffic volume data coinciding with same period of crash data? (√=yes; blank= no) **C3**: Which facility types have a corresponding inventory of geometric elements that can be integrated into a dataset with crash and traffic volume respective data?(√=yes for most; ~ = yes for required and limited to none for desirable elements; blank = none or very few elements) *refer to Table 5.1			

Illustration: Prioritization of predictive models for the development of SPF calibration factors assisted by jurisdiction-specific needs and data availability

Rural two-lane, two-way roads				**Urban and suburban arterials**			
	C1	C2	C3		C1	C2	C3
Undivided rural two-lane, two-way roadway (2U)	4			Two-lane undivided (2U)	3	√	~
Three-leg STOP controlled on minor-road approach (3ST)	4			Three-lane including a two-way left-turn lane(TWLTL)(3T)	3	√	~
Four-leg STOP controlled on minor-road approaches (4ST)	3			Four-lane undivided (4U)	2	√	~
Four-leg signalized (4SG)	3	√		Four-lane divided including e.g., raised or depressed median (4D)	2	√	~
Rural multilane highways				Five-lane including TWLTL (5T)	4	√	~
Rural four-lane undivided (4U)	1	√		Three-leg STOP controlled on the minor-road approaches (3ST)	1		
Rural four-lane divided (4D)	2	√		Three-leg signalized intersections (3SG)	1		
Three-leg STOP controlled on minor road approaches (3ST)	1			Four-leg STOP controlled on the minor-road approaches (4ST)	2		
Four-leg STOP controlled on minor road approaches (4ST)	1			Four-leg signalized (4SG)	1	√	~
Four-leg signalized (4SG)	1	√	~				

Illustration

Prioritization of predictive models for the development of SPF calibration factors assisted by jurisdiction-specific needs and data availability (cont')

As per table above, the agency assessed, in a broad sense, their anticipated predictive models that would be needed to support safety treatment, planning, and design decisions in the near future; the availability of data related to exposure (traffic volumes in terms of AADTs) and geometric elements. It also assessed these data linkages with crashes / location for a selected time period (i.e., most recent three years).

The information indicates that rural multilane highways (undivided segments and intersections) and urban and suburban signalized intersections are the most needed calibration factors, based on the upcoming safety-motivated, planning, and design projects. Furthermore, there is a general lack of traffic volume and geometric elements data relevant to STOP–controlled intersections, as well as lack of geometric elements data for rural four-lane undivided segments. It is also concluded that four-leg signalized intersections (for rural multilane highways and for urban and suburban arterials) are supported by required data, with missing elements in the desirable list of elements. Important to recognize that desirable elements are still needed for the development of calibration factors; in the absence of local values, the HSM or jurisdiction's default values will be used (refer to Table 5.), though it is preferable to use measured site values, whenever possible. The agency may have also identified some priority regions within the road network where most upcoming projects will take place, as well as some exposure levels (i.e., low or high volume sites). Thus, for example, in the event that most upcoming projects relate to high traffic volume sites or to a given region of the network, the agency may decide to focus their efforts on a sub-set of data to develop specific SPF calibration factors for their most pressing needs.

In conclusion, it seems the following is the best strategy for this agency's development of calibration factors:

1. *Proceed with calibration factors development for four-leg signalized intersections (for rural multilane highways and for urban and suburban arterials)*
2. *Gather data for rural multilane undivided highway segments and STOP–controlled intersections, and proceed with calibration factors development*
3. *Gather data for rural multilane divided highway segments and urban and suburban four-leg STOP-controlled intersections and 4-lane divided and undivided segments, as they are scored 2 in their need for upcoming safety-motivated, planning, and design projects*
4. *Subsequently, continue gathering data for the remaining facility types that scored 3 and 4*
5. *It is noted that a change in the upcoming projects (e.g., change in priority emphasis areas in the strategic highway safety plan (SHSP)) may trigger a need for an adjustment in the*

6.2 Step 2 – Select Sites for Calibration of the Predictive Model for Each Facility Type

Following the decision in Step 1, sites representing the facility type/s and prediction model/s for which calibration factor/s are required need to be assembled. HSM (2010) Appendix A, Part C provides the following direction when selecting sites for SPF calibration for each facility type:

- Desirable minimum sample size of 30 to 50 sites, with each segment site long enough to adequately represent physical and safety conditions for the facility
- Sites should be selected without regard to the number of crashes on individual sites, so that calibration would not be intentionally done for high or low crash frequencies
- Desirable to select sites randomly from a larger set of candidate sites
- At the conclusion of the site selection, the entire group of calibration sites should represent at least 100 crashes/year
- If there is a larger number of sites with the data required (to be determined during the next Step 3 of the calibration procedure) ; use the larger number of sites for the development of SPF calibration factors
- If a jurisdiction has fewer than 30 sites for a particular facility type, all sites should be used for the development of SPF calibration factors

The aspect of selecting sites randomly is an important one because it is anticipated that calibration factors will differ for various subsets of the facility type such as for regional subsets, low and high AADT ranges, etc (Dixon et al (2012), Persaud et al (2002), Srinivasan 2011). Since the dependence of the calibration factor C to these elements is unknown, the only way to ensure that a sample is representative is to select units by some random process. One such process would be to assign a computer generated random number to each individual site of the facility type selected, to sort the units in the decreasing order of the random number, and then select a sufficient number of sites from the top of the list. <u>Guidance about choosing a sample size is given later in this Step 2</u>.

Recent publications have demonstrated that the HSM (2010) direction regarding sample size, for development of calibration factors for any given facility type, may not be appropriate to estimate a calibration factor of sufficient accuracy (Banihashemi (2011), Banihashemi (2012), Dixon et al (2012), Persaud et al (2012), Read (2012)). In fact, some researchers have stated that the accuracy of the resultant calibration factors as unknown or uncertain (Sacci et al, 2012; Kweon et al (2013), Read (2012)). Furthermore, there is evidence that better estimates of predicted crash frequencies, when using jurisdiction-specific conditions, are attained when calibration factors are developed for separate crash injury severity SPFs and / or for sub-sets of sites such as per different AADT strata or jurisdiction regions (Dixon et al (2012), Persaud et al (2002), Srinivasan 2011). A limited exploratory study was done during the development of this Guide and it will be described later in Step 5 of the calibration process. It is concluded that it is important to consider variables such as AADT, segment length, crash severity, terrain, etc, when developing calibration factors, as well as how the calibration factors vary with time.

Table 6.2 lists the HSM (2010) SPFs and potential calibration factors. As discussed above, it is further recommended that agencies, during this Step 2, consider other variables when creating sub-sets of data for the selection of the sample of sites for calibration purpose.

When selecting sites for SPF calibration for each facility type

Consider preparing sub-sets of data for the selection of a random sample of sites:

i. *Regional networks or separate terrain types or climate regions*
ii. *AADT ranges (e.g., may prioritize the calibration effort for high volume sites if upcoming projects are situated on such traffic volume ranges)*

When deciding on sample size to estimate a calibration factor to a desired accuracy

Consider separating observed crash frequency by crash injury severity level for separate calibration factors for available HSM SPFs, consisting of:

i. *Total (i.e., all crashes)*
ii. *Fatal and injury (i.e., KABC crashes)*
iii. *PDO (i.e., O crashes)*

Table 6.2–Possible calibration factors for SPFs in HSM (2010)

Facility Type and HSM Prediction Models	HSM Safety Performance Function (SPFs)	Calibration Factors	Comments
Rural undivided two-lane, two-way roadway segments (Equation 10-2)	**For 2U**: Equation 10-6 for total (KABCO) crash frequency	$C_{2U\ total}$	No HSM SPFs for crash severity levels; jurisdiction-specific distributions replaced in HSM Table 10-3 are used for predicted average crash frequencies for KABC and for O
Rural undivided two-lane, two-way roadway intersections (Equation 10-3)	**For 3ST**: Equation 10-8 for total (KABCO) crash frequency	$C_{2U\ 3ST\ total}$	No HSM SPFs for crash severity levels; jurisdiction-specific distributions replaced in HSM Table 10-5 are used for predicted average crash frequencies for KABC and for O
	For 4ST: Equation 10-9 for total (KABCO) crash frequency	$C_{2U\ 4ST\ total}$	
	For 4SG: Equation 10-10 for total (KABCO) crash frequency	$C_{2U\ 4SG\ total}$	
Rural multilane roadway segments (Equation 11-2, and Equation 11-3)	**For 4U**: Equation 11-7 and Table 11-3 for total (KABCO), fatal and injury (KABC), or fatal and injury (KAB)crash frequency	$C_{4U\ total}$	No HSM SPFs for property-damage-only (O)crash prediction; predicted average O crash frequencies are calculated as the difference between the jurisdiction-specific a) calibrated predicted average total (KABCO)crash frequencies and b) calibrated predicted average fatal and injury (KABC) crash frequencies
		$C_{4U\ KABC}$	
		C_{4UKAB}	
	For 4D: Equation 11-9 and Table 11-5 for total (KABCO), fatal and injury (KABC), or fatal and injury (KAB)crash frequency	$C_{4D\ total}$	
		$C_{4D\ KABC}$	
		C_{4DKAB}	
Rural multilane roadway intersections (Equation 11-4)	**For 3ST**: Equation 11.11 and Table 11-7 for total (KABCO), fatal and injury (KABC), or fatal and injury (KAB)crash frequency	$C_{4R\ 3STtotal}$ $C_{4RU\ 3STtotal}$ $C_{4RD\ 3STtotal}$	No HSM SPFs for property-damage-only (O) crash prediction; predicted average O crash frequencies are calculated in a similar manner as per multilane segments (above). HSM recommends separate calibration of the intersections on divided and undivided (C_{4RU} and C_{4RD}) roadway segments (HSM page 11-21); otherwise, C_{4R} will be used.
		$C_{4R\ 3ST\ KABC}$ $C_{4RU\ 3ST\ KABC}$ $C_{4RD\ 3ST\ KABC}$	
		$C_{4R\ 3ST\ KAB}$ $C_{4RU\ 3ST\ KAB}$ $C_{4RD\ 3ST\ KAB}$	
	For 4ST: Equation 11.11 and Table 11-7 for total (KABCO), fatal and injury (KABC), or fatal and injury (KAB)crash frequency	$C_{4R\ 4STtotal}$ $C_{4RU\ 4STtotal}$ $C_{4RD\ 4STtotal}$	No HSM SPFs for property-damage-only (O) crash prediction; predicted average O crash frequencies are calculated in a similar manner as per multilane segments (above). HSM recommends separate calibration of the intersections on divided and undivided (C_{4RU} and C_{4RD}) roadway segments (HSM page 11-21); otherwise, C_{4R} will be used.
		$C_{4R\ 4ST\ KABC}$ $C_{4RU\ 4ST\ KABC}$ $C_{4RD\ 4ST\ KABC}$	
		$C_{4R\ 4ST\ KAB}$ $C_{4RU\ 4ST\ KAB}$ $C_{4RD\ 4ST\ KAB}$	
	For 4SG: Equation 11-11 (or 11-12) and Table 11-8 for total (KABCO), fatal and injury (KABC), or fatal and injury (KAB)crash frequency	$C_{4R\ 4SG\ total}$ $C_{4RU\ 4SG\ total}$ $C_{4RD\ 4SG\ total}$	No HSM SPFs for property-damage-only (O) crash prediction; predicted average O crash frequencies are calculated in a similar manner as per multilane segments (above). HSM recommends separate calibration of the intersections on divided and undivided (C_{4RU} and C_{4RD}) roadway segments (HSM
		$C_{4R\ 4SG\ KABC}$ $C_{4RU\ 4SG\ KABC}$ $C_{4RD\ 4SG\ KABC}$	
		$C_{4R\ 4SG\ KAB}$	

		$C_{4RU\ 4SG\ KAB}$ $C_{4RD\ 4SG\ KAB}$	page 11-21); otherwise, C_{4R} will be used.
Urban and suburban arterial roadway segments (Equation 12-2, Equation 12-3, Equation 12-4)	**For 2U:**		
	Multiple-vehicle non-driveway collisions: Equation 12-10 and Table 12-3 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRMV\ 2U\ total}$ $C_{BRMV\ 2U\ KABC}$ $C_{BRMV\ 2U\ O}$	The predicted average multiple-vehicle non-driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
	Single-vehicle crashes: Equation 12-13 and Table 12-5 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRSV\ 2U\ total}$ $C_{BRSV\ 2U\ KABC}$ $C_{BRSV\ 2U\ O}$	
	Multiple-vehicle driveway-related collisions: Equation 12-16 and Table 12-7 for total (KABCO)	$C_{BRDRY\ 2U\ total}$	The predicted average multiple-vehicle driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions. Jurisdiction-specific proportions replaced in HSM Table 12-7 are used for predicted average multiple-vehicle driveway fatal and injury (KABC), or property-damage-only (O) collision frequencies
	For 3T:		
	Multiple-vehicle non-driveway collisions: Equation 12-10 and Table 12-3 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRMV\ 3T\ total}$ $C_{BRMV\ 3T\ KABC}$ $C_{BRMV\ 3T\ O}$	The predicted average multiple-vehicle non-driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
	Single-vehicle crashes: Equation 12-13 and Table 12-5 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRSV\ 3T\ total}$ $C_{BRSV\ 3T\ KABC}$ $C_{BRSV\ 3T\ O}$	
	Multiple-vehicle driveway-related collisions: Equation 12-16 and Table 12-7 for total (KABCO)	$C_{BRDRY\ 3T\ total}$	The predicted average multiple-vehicle driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions. Jurisdiction-specific proportions replaced in HSM Table 12-7 are used for predicted average multiple-vehicle driveway fatal and injury (KABC), or property-damage-only (O) collision frequencies
	For 4U:		
	Multiple-vehicle non-driveway collisions: Equation 12-10 and Table 12-3 for total (KABCO), fatal and injury (KABC), or property-damage-	$C_{BRMV\ 4U\ total}$ $C_{BRMV\ 4U\ KABC}$ $C_{BRMV\ 4U\ O}$	The predicted average multiple-vehicle non-driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions

	only (O) crash frequency		
	Single-vehicle crashes: Equation 12-13 and Table 12-5 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRSV\ 4U\ total}$ $C_{BRSV\ 4U\ KABC}$ $C_{BRSV\ 4U\ O}$	
	Multiple-vehicle driveway-related collisions: Equation 12-16 and Table 12-7 for total (KABCO)	$C_{BRDRY\ 4U\ total}$	The predicted average multiple-vehicle driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions. Jurisdiction-specific proportions replaced in HSM Table 12-7 are used for predicted average multiple-vehicle driveway fatal and injury (KABC), or property-damage-only (O) collision frequencies
	For 4D:		
	Multiple-vehicle non-driveway collisions: Equation 12.10 and Table 12-3 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRMV\ 4D\ total}$ $C_{BRMV\ 4D\ KABC}$ $C_{BRMV\ 4D\ O}$	The predicted average multiple-vehicle non-driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
	Single-vehicle crashes: Equation 12-13 and Table 12-5 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRSV\ 4D\ total}$ $C_{BRSV\ 4D\ KABC}$ $C_{BRSV\ 4D\ O}$	
	Multiple-vehicle driveway-related collisions: Equation 12-16 and Table 12-7 for total (KABCO)	$C_{BRDRY\ 4D\ total}$	The predicted average multiple-vehicle driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions. Jurisdiction-specific proportions replaced in HSM Table 12-7 are used for predicted average multiple-vehicle driveway fatal and injury (KABC), or property-damage-only (O) collision frequencies
	For 5T:		
	Multiple-vehicle non-driveway collisions: Equation 12-10 and Table 12-3 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRMV\ 5T\ total}$ $C_{BRMV\ 5T\ KABC}$ $C_{BRMV\ 5T\ O}$	The predicted average multiple-vehicle non-driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
	Single-vehicle crashes: Equation 12-13 and Table 12-5 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BRSV\ 5T\ total}$ $C_{BRSV\ 5T\ KABC}$ $C_{BRSV\ 5T\ O}$	

	Multiple-vehicle driveway-related collisions: Equation 12-16 and Table 12-7 for total (KABCO)	$C_{BRDRY\ 5T\ total}$	The predicted average multiple-vehicle driveway collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions. Jurisdiction-specific proportions replaced in HSM Table 12-7 are used for predicted average multiple-vehicle driveway fatal and injury (KABC), or property-damage-only (O) collision frequencies
Urban and suburban arterial Intersections (Equation 12-5,equation 12-6, and Equation 12-7)	**For 3ST:**		
	Multiple-vehicle collisions: Equation 12-21 and Table 12-10 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BIMV\ 3ST\ total}$	The predicted average multiple-vehicle collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
		$C_{BIMV\ 3ST\ KABC}$	
		$C_{BIMV\ 3ST\ O}$	
	Single-vehicle crashes: Equation 12-24 and Table 12-12 for total (KABCO) crash frequency, or property-damage-only (O) crash frequency	$C_{BISV\ 3ST\ total}$	Jurisdiction-specific proportion of fatal and injury crashes (KABC)for 3ST are used for predicted average single-vehicle fatal and injury (KABC), as per Equation 12-27
		$C_{BISV\ 3ST\ O}$	
	For 4ST:		
	Multiple-vehicle collisions: Equation 12-21 and Table 12-10 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BIMV\ 4ST\ total}$	The predicted average multiple-vehicle collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
		$C_{BIMV\ 4ST\ KABC}$	
		$C_{BIMV\ 4ST\ O}$	
	Single-vehicle crashes: Equation 12-24 and Table 12-12 for total (KABCO) crash frequency, or property-damage-only (O) crash frequency	$C_{BISV\ 4ST\ total}$	Jurisdiction-specific proportion of fatal and injury crashes (KABC)for 3ST are used for predicted average single-vehicle fatal and injury (KABC), as per Equation 12-27
		$C_{BISV\ 4ST\ O}$	
	For 3SG:		
	Multiple-vehicle collisions: Equation 12-21 and Table 12-10 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{BIMV\ 3SG\ total}$	The predicted average multiple-vehicle collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
		$C_{BIMV\ 3SG\ KABC}$	
		$C_{BIMV\ 3SG\ O}$	
	Single-vehicle crashes: Equation 12-24 and Table 12-12 for total (KABCO) crash frequency, fatal and injury (KABC)crash frequency, or property-damage-only (O) crash frequency	$C_{BISV\ 3SG\ total}$	
		$C_{BISV\ 3SG\ KABC}$	
		$C_{BISV\ 3SG\ O}$	

	Vehicle-pedestrian collisions: Equation 12-29 and Table 12-14 for fatal and injury (KABC) collision frequency	$C_{\text{ped 3SG KABC}}$	All vehicle-pedestrian collisions are considered fatal-and-injury collisions.
	For 4SG:		
	Multiple-vehicle collisions: Equation 12-21 and Table 12-10 for total (KABCO), fatal and injury (KABC), or property-damage-only (O) crash frequency	$C_{\text{BIMV 4SG total}}$ $C_{\text{BIMV 4SG KABC}}$ $C_{\text{BIMV 4SG O}}$	The predicted average multiple-vehicle collision frequency excludes vehicle-pedestrian and vehicle-bicycle collisions
	Single-vehicle crashes: Equation 12-24 and Table 12-12 for total (KABCO) crash frequency, fatal and injury (KABC)crash frequency, or property-damage-only (O) crash frequency	$C_{\text{BISV 4SG total}}$ $C_{\text{BISV 4SG KABC}}$ $C_{\text{BISV 4SG O}}$	
	Vehicle-pedestrian collisions: Equation 12-29 and Table 12-14 for fatal and injury (KABC) collision frequency	$C_{\text{ped 4SG KABC}}$	All vehicle-pedestrian collisions are considered fatal-and-injury collisions.

Guidance is provided here regarding choosing a sample size to estimate a calibration factor to a given accuracy; it also includes a simple technique for a random selection of sites.

Choosing a sample size to estimate the calibration factor to a given accuracy

The HSM (2010) Equation A-1 (pg. A-7) shows how a calibration factor is estimated. This can be shown as:

$$C = \frac{\sum_{\text{all j}} \text{observed crashes at site j}}{\sum_{\text{all j}} N_u \text{at site j}} \quad \textbf{Eq.6.1}$$

Where: C is the estimate of the calibration factor for the SPF of a given facility type j; and N_u is the "unadjusted $N_{predicted}$" based on the HSM base conditions for which calibration factor is C= 1. The issue of choosing a sample size requires an answer to how many observed crashes in total (Eq. 6.1 numerator) or how many sites must be in a sample, for the estimate of calibration factor to be sufficiently accurate. Appendix B presents the working paper developed by Dr. Ezra Hauer to answer this question. It is concluded that the sample size can be determined based on the jurisdiction-specific data and an analyst-selected desired variance or standard deviation for the estimate of calibration factor C.

The working paper presents five alternative ways to calculate the variance or standard deviation for the estimate of calibration factor, depending on the data available. The alternative ways are:

1. Based on a lower limit, assuming no overdispersion. This alternative does not require AADT, segment length, or observed crash data but provides merely an initial estimate of the absolute minimum number of observed crashes for a desired standard deviation and a guess estimate of what the calibration factor C may be.
2. Based on segment length, AADT, and observed crashes for segments (or $AADT_{max}$, $AADT_{min}$, and observed crashes for intersections), and the calculation of unadjusted $N_{predicted}$ for each site. This alternative is recommended when segment length, AADT, and observed crash data are available.
3. Based on observed crash frequencies for segments (or intersections), and a guess estimate of what the calibration factor C may be. This alternative is valuable when AADT data are missing or incomplete.

4. Based on segment length and AADT for segments (or AADT $_{max}$, AADT $_{min}$, for intersections), the calculation of unadjusted $N_{predicted}$ for each site, and a guess estimate of what the calibration factor C may be. This alternative leads to a smoother estimate of variance of the estimate of C. This alternative is also valuable when observed crash data are missing.
5. Based on average length and average AADT for segments (or AADT $_{max}$, AADT $_{min}$, for intersections), a guess estimate of what the calibration factor C may be, and a desired standard deviation of the estimate of C. This alternative is an approximation option when observed crash data are missing, and only the average segment length and the average AADT values are available.

The procedure for the data preparation and use of one of the alternatives above is as follows:

a) Prepare a table, similarly to the one shown in Figure 6.1, with data about sites belonging to the facility type selected in Step 1.
    - This table comprises the site ID, length, AADT $_{year\ 1}$, and observed crash frequency for each site in year 1.
    - Based on the analyst-selected alternative, among the five listed above, to calculate the variance or standard deviation for the estimate of calibration factor, the AADT or observed crash frequency may not be needed at this stage.
    - As discussed earlier, it is recommended that the calculation of distinct C_i for each SPF available in the HSM (2010) be considered. Accordingly, if calibration factors by crash severity levels are to be estimated, observed crash frequency should be listed by crash severity level (i.e., KABCO or total, KABC, KAB, or O).
    - As shown in Table 6.1, if sufficient data are available to attain calibration factors to the degree of accuracy desired, it is also recommended that consideration be given to the possible development of calibration factors for urban and suburban arterial segment multiple-vehicle non-driveway SPFs, for urban and suburban arterial segment single-vehicle SPFs, and urban and suburban arterial signalized intersection vehicle-pedestrian SPFs.

b) As discussed in the HSM, the calibration sites need to be representative of jurisdiction-specific conditions for the facility type selected. Towards this aim, as shown in Figure 6.1, an Excel RND function was used to generate the random number (column B) and sites were sorted in the decreasing order of this random number.

	A	B	C	D	E	F
1	Two-lane,two-way rural roads					
2			Data			
3						Observed
4	Site j	RND	Site J ID	L	AADT	Crashes
5	1	0.966173801	R2 023	0.08	3715	0
6	2	0.956428133	R2 054	1.14	220	1
7	3	0.95286274	R2 043	0.94	2133	3
8	4	0.949927362	R2 065	0.66	2569	0
9	5	0.90983927	R2 032	1.13	1451	0
10	6	0.898339991	R2 076	0.99	2867	1
11	7	0.8876841	R2 134	1.33	2167	5
12	8	0.842358112	R2 765	0.78	2639	2
13	9	0.837499109	R2 333	0.74	3482	0
14	10	0.808755122	R2 099	1.40	1816	2
15	11	0.781915198	R2 022	0.40	872	0
16	12	0.773333647	R2 098	0.87	834	0
17	13	0.759841641	R2 234	0.48	3646	1
18	14	0.72593503	R2 123	0.93	1239	1
19	15	0.724419231	R2 555	1.78	1441	0
20	16	0.717699695	R2 443	0.86	522	0
21	17	0.684200153	R2 767	1.20	943	0
22	18	0.646649279	R2 236	1.13	3647	1
23	19	0.636461442	R2 763	0.31	2843	0
24	20	0.569654225	R2 584	1.44	3283	0
25	21	0.564676442	R2 042	0.39	3817	0

Figure 6.1 – Example of data preparation for selection of sample size

c) Complete the Excel table with the calculations based on the selected alternative to calculate the variance or standard deviation for the estimate of calibration factor, shown in Appendix B. The calculation of the unadjusted $N_{predicted}$ for each site is done on the basis of the relevant HSM SPF only, by assuming base conditions for all sites (i.e., CMF=1 for all conditions). This simplification is adopted to facilitate the calculations during this Step 2 only, as detailed roadway data for each site will be needed in the subsequent Steps.

d) Select the desired standard deviation of the estimate of C and note the relevant number of sites required to meet this accuracy. The effort necessary to undertake this calibration process depends essentially on the analyst's choice of the desired standard deviation of C. Based on the considerations in Appendix B, on our guess about how accurate are the predictions of expected crashes in the HSM (2010), and on our assessment of what fairness and efficiency require, it is suggested that the standard deviation of the estimate of the calibration factor C be of ±0.1C. Thus, for a C=1.3, a sample size of sites that results in a standard deviation of ±0.13 is deemed reasonable or for a C=0.8, a sample size that results in a standard deviation ±0.08 is deemed reasonable.

e) If the standard deviation desired requires a larger sample than originally envisioned, it is recommended to increase the sample size of representative sites (preferred option).
   - If the required number of sites is deemed too large for the resources available for the geometric and traffic management data collection, consider adding one more year of observed crash frequencies and an average AADT (for the two years) to each site in the Excel table.
   - It is recommended to limit the addition of years to three years for the estimate of a single (multi-year) calibration factor, if needed, recognizing that a calibration factor based on a two- or three-year combined data is an average calibration factor for the whole period and does not represent any given year.

As noted earlier, jurisdictional differences, differences in AADT ranges, and differences in other factors may require estimates of calibration factors for sub-sets of data. In Step 5 (Section 6.5), a method is described for assessing the need to develop separate calibration factors or create a multi-variable calibration *function* of two or more variables, such as segment length, AADT, terrain, etc, to attain greater accuracy in the estimate of expected crash frequencies. When sub-dividing the sample of sites initially selected for calibration of given sets of data, e.g., for two or more regions of the state network, or for low and high AADT volumes, it is necessary to reassess the accuracy of the calibration factor in terms of its standard deviation. If this is done in Step 5 of the calibration process after the calibration factor is actually estimated on the basis of jurisdiction-specific data, one can then evaluate it against the calibration factor guess estimate of Step 2. The result of this reassessment could indicate that additional sites may be required to maintain the original desired standard deviation of the calibration factor, and the process would return to Step 2 and continue through Steps 3 to 5 for the re-estimation of more accurate calibration factors. Alternatively, if it is anticipated that sub-sets of data will be desirable for the estimates of calibration factors, the process of determining the sample size for a selected accuracy could be done proactively for separate sets of data.

6.3 Step 3 – Obtain Data for each Facility Type Applicable to a Specific Calibration Period

Subsequent to the selection of sites in Step 2, data elements are needed to estimate the N_u (the unadjusted $N_{predicted}$) for each site. An overview of the data required and desirable for a given facility type is shown in Table 5.1A, Table 5.1B, and Table 5.1C. As described in Section 6.1 (Step 1), each site with its unique location identifier (expressed in milepost or geo-coordinates) is classified as a roadway segment or an intersection by one of the facility types.

An important aspect to be considered during this step of data assembling is the range of traffic volumes (AADTs) used in the development of the HSM (2010) SPFs. The HSM (2010) notes "*Application to sites with AADTs significantly outside this range may not provide reliable results*" (e.g., HSM page 10-15 (2010)). Appendix C contains tables of AADT ranges for all HSM(2010) SPFs. In the event that jurisdiction-specific data are significantly outside any of the given AADTs, the agency may consider develop their own SPFs.

As discussed in Step 2, a calibration factor based on a two- or three-year combined data is an average calibration factor for the whole period and does not represent any given year. In the event that the agency has crash and traffic volume data for the sites selected in Step 2 for more than three years, it is recommended that all available years of data be included in the calibration data preparation and processing in this Step 3 and subsequent ones. Annual calibration factors for several years will enable assessment of whether there is a time trend leading to a calibration function (i.e., a function of time) for use in past and future analysis for a given year.

<u>Assigning crashes to intersections or segments</u>

As presented in Section 5, the HSM (2010) assigns crashes to a roadway segment or an intersection, as shown in Figure 5.1. Intersection crashes include crashes that occur within Area A (i.e., within curb limits) and intersection-related crashes that occur on the intersection legs (Area B), such as rear-end collisions related to queues on an intersection approach. Thus, crashes that occur within Area B are assigned to either the roadway segment on which they occur or one of the intersections, depending on the crash characteristics and crash report/coded data. It is noted that some agencies may classify crashes within Area B differently (e.g., based on a given distance from an intersection) and they will need to check and possibly reassign crashes to match the HSM definition.

Segmentation into homogeneous sub-segments

As we proceed with tabling additional data for each site and for each year, it is important to integrate the segmentation process, as defined in the HSM (2010). A basic requirement of the HSM (2010) prediction method is the segmentation of roadway segments into homogeneous sub-segments. By definition, a roadway segment (or sub-segment) is homogeneous when the AADT volume is constant along the roadway length, for a given year i, as well as each of the geometric and traffic management elements (as listed in relevant facility portion of Table 5.1A, Table 5.1B, or Table 5.1C) has a consistent value along the roadway length. For example, a rural two-lane, two way roadway segment will be segmented into two sub-segments (each listed on a separate table row) when any change is noted, such as different lane width, or shoulder width, or transition to or from a horizontal curve, or a change in vertical grade, or a presence (vs. absence) of automated speed enforcement, or a change in traffic volume, etc.

Thus, roadway segments between two landmarks in a jurisdiction highway database may need to be subdivided into smaller homogeneous sub-segments, during this process. If these sub-segments are shorter than 0.1 mile, it is recommended to regroup them to a length of 0.1 mile, as a minimum, and calculate a combined average CMF value for estimation of the N_u , the unadjusted $N_{predicted}$. It is noted that when a homogeneous roadway segment begins or ends at an intersection, the length of the segment is measured from the center of the intersection.

During segmentation, there will be data elements that are classified in the HSM as required or desirable jurisdiction's data values (as marked in Tables 5.1A, table 5.1B, and Table 5.1C). It is important to recognize that desirable elements are still needed for the development of calibration factors; in the absence of local values, the HSM or jurisdiction's default values can be used, though it is preferable to use measured site values, whenever possible.

In the next diagrams, roadway segmentation is described for each one of the facility types of the HSM Part C (2010).

Rural Two-lane, Two-way Roads - Segmentation

A roadway segment is found between two intersections, and a new roadway segment begins at the center of each intersection. The roadway segment between two intersections may be subdivided or segmented to produce homogeneous segments. A new homogeneous roadway segment begins at any of the following:

- *Different AADT*
- *Beginning or end of a horizontal curve (spiral transitions are part of the curve)*
- *Point of vertical intersection (PVI) for crest vertical curve, a sag curve, or an angle point at which two different roadway grades meet (vertical curve are part of the grades they join)*
- *Beginning or end of a passing lane or short 4-lane section*
- *Beginning or end of center TWLTL*
- *Different lane width (measured to a 0.1ft level of precision and rounded to nearest .0.5 or 1.0 ft)**
- *Different shoulder width (measured to a 0.1ft level of precision and rounded to nearest 1.0 ft, e.g., 0.5ft or less rounded to 0ft or 0.6 to 1.5 rounded to 1.0 ft)**
- *Different shoulder type**
- *Driveway density (it is recommended to adopt a facility driveway density for segments shorter than 0.5ft) based on all types of land use excluding driveways used less frequent than daily*
- *Roadside hazard rating – RHR (it is recommended that a homogeneous segment may have RHR that varies as much as 2 rating levels – an average RHR is attached to the homogenous roadway segment)**
- *Presence or absence of centerline rumble strip*
- *Presence or absence of lighting*
- *Presence or absence of automated speed enforcement*

**When conditions differ between the two directions of travel, CMFs will be calculated as an average of the two CMFs*

It is recommended that homogeneous segment length be to a minimum of 0.1 ft; to this effect, smaller homogeneous adjacent segments are grouped applying average or weighted CMF values for the distinct conditions, in order to form a 0.1 or longer not-so homogenous segment.

Rural Multilane Highways - Segmentation

A roadway segment is found between two intersections, and a new roadway segment begins at the center of each intersection. The roadway segment between two intersections may be subdivided or segmented to produce homogeneous segments. A new homogeneous roadway segment begins at any of the following:

- *Different AADT*
- *Different lane width (measured to a 0.1ft level of precision and rounded to nearest .0.5 or 1.0 ft)**
- *Different shoulder width (measured to a 0.1ft level of precision and rounded to nearest 1.0 ft, e.g., 0.5ft or less rounded to 0ft or 0.6 to 1.5 rounded to 1.0 ft)**
- *Different shoulder type**
- *Presence or absence of median (determining divided or undivided roadway segment)*
- *Median width (measured to a 1ft level of precision and rounded to nearest 10.0 ft, e.g., 1ft to 14ft is rounded to 10ft or 25ft to 34ft rounded to 30.0 ft)*
- *Different sideslope (for undivided roadway segments)**
- *Presence or absence of lighting*
- *Presence or absence of automated speed enforcement*

**When conditions differ between the two directions of travel, CMFs will be calculated as an average of the two CMFs*

It is recommended that homogeneous segment length be to a minimum of 0.1 ft; to this effect, smaller homogeneous adjacent segments are grouped applying average or weighted CMF values for the distinct conditions, in order to form a 0.1 or longer not-so homogenous segment.

Urban and Suburban Arterials - Segmentation

A roadway segment is found between two intersections, and a new roadway segment begins at the center of each intersection. The roadway segment between two intersections may be subdivided or segmented to produce homogeneous segments. A new homogeneous roadway segment begins at any of the following:

- *Different AADT*
- *Different number of through lanes*
- *Beginning or end of center TWLTL*
- *Presence or absence of median (determining divided or undivided roadway segment – measured to a 1ft level of precision and rounded to the nearest 10ft; e.g., 1ft to 14 ft rounded to 10ft, 45 ft to 54 ft rounded to 40ft)*
- *Presence or type of on-street parking*
- *Roadside fixed-object density*
- *Presence or absence of lighting*
- *Speed category (based on posted speed limit or actual traffic speed)*
- *Presence or absence of automated speed enforcement*

**When conditions differ between the two directions of travel, CMFs will be calculated as an average of the two CMFs*

It is recommended that homogeneous segment length be to a minimum of 0.1 ft; to this effect, smaller homogeneous adjacent segments are grouped applying average or weighted CMF values for the distinct conditions, in order to form a 0.1 or longer not-so homogenous segment.

Replacement of the HSM default crash severity and collision type distribution tables and adjustments factors

Another data preparation aspect for the development of SPF calibration factors consists of gathering the data for the replacement of the HSM default crash severity and collision type distribution tables (such as HSM Table 10-3 reproduced below) and adjustments factors with jurisdiction-specific values, as described in Section 2.3. These distributions are preferably compiled using all jurisdiction-specific data available for each facility type with predictive models, for the same years of crash data used for the sample of individual sites. Most crash severity and collision type distribution tables and the crash adjustment factors are used with relevant SPFs. Exceptions are the crash severity and collision type tables related to driveway crashes, and the tables with proportions of nighttime crashes along/at unlit locations which are used with given CMFs in the predictive method (such as HSM Table 10-12) .

***Reproduced HSM Table 10-3**. Default Distribution for Crash Severity Level on Rural Two-Lane, Two-Way Roadway Segments*

Crash Severity Level	***Percent of Total Roadway Segment Crashes [a]***
Fatal	*1.3*
Incapacitating Injury	*5.4*
Nonincapacitating Injury	*10.9*
Possible Injury	*14.5*
Total Fatal plus Injury	*32.1*
Property Damage Only	*67.9*
Total	*100.0*

[a] Based on HSIS data for Washington (2002 - 2006)

Table 6.3A, Table 6.3B, and Table 6.3C tabulate the data required for these distribution tables and adjustment factors.

Table 6.3A – Data elements required for the replacement of the crash severity and collision type distribution tables and adjustment factors for rural undivided two-lane, two-way roads

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1A)		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Rural undivided two-lane, two-way - roadway segments (2U)	Table 10-3	1.Fatal (K) 2U crashes 2.Incapacitating injury (A) 2U crashes 3.Non-incapacitating injury (B) 2U crashes 4.Possible injury (C) 2U crashes 5.Total fatal plus injury (KABC) 2U crashes 6.Property damage only (0) 2U crashes 7.Total (KABCO) 2U crashes
	Table 10-4	1.**Single-vehicle 2U crashes by total (KABCO), by KABC, and by O, for**: 1.1Collisions with animal 1.2Collisions with bicycle 1.3Collisions with pedestrian 1.4Overturned collisions 1.5Ran-off-road collisions 1.6Other single-vehicle collisions 1.7.Total single-vehicle crashes 2.**Multiple-vehicle 2U crashes by total (KABCO),by KABC, and by O for**: 2.1Angle collisions 2.2Head-on Collisions 2.3Rear-end collisions 2.4Sideswipe collisions 2.5Other multiple-vehicle collisions 2.6.Total multiple-vehicle crashes

* Data required to replace HSM Equation 10-18 (P_{dwy} – driveway related crashes as a proportion of total crashes) and HSM Table 10-12 (Nighttime crash proportions for unlighted roadway segments) are found in Table 5.1A

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1.A) (Cont')		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Rural two-lane, two-way three-leg (3ST) <u>or</u> four-leg STOP (4ST) controlled on minor-road approach <u>or</u> four-leg signalized (4SG) intersections	Table 10-5	1.**Three-leg STOP controlled intersections by**: 1.1.Fatal (K) 3ST crashes 1.2.Incapacitating injury (A) 3ST crashes 1.3.Non-incapacitating injury (B) 3ST crashes 1.4.Possible injury (C) 3ST crashes 1.5.Total fatal plus injury (KABC) 3ST crashes 1.6.Property damage only (0) 3ST crashes 1.7. Total (KABCO) 3ST crashes 2.**Four-leg STOP controlled intersections by:** severity level listed above (as per 1.1. to 1.7.) for 4ST 3.**Four-leg signalized intersections by:** severity level listed above (as per 1.1. to 1.7.) for 4SG

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1A) (Cont')		
Facilities and HSM Prediction Models	*HSM Table**	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Rural two-lane, two-way three-leg (3ST) <u>or</u> four-leg STOP (4ST) controlled on minor-road approach <u>or</u> four-leg signalized (4SG) intersections (Con't)	Table 10-6	1.**Three-leg STOP controlled intersections by**: 1.1**Single-vehicle 3ST crashes by total (KABCO), by KABC, and by O for**: 1.1.1Collisions with animal 1.1.2Collisions with bicycle 1.1.3Collisions with pedestrian 1.1.4Overturned collisions 1.1.5Ran-off-road collisions 1.1.6Other single-vehicle collisions 1.1.7.Total single-vehicle crashes 1.2.**Multiple-vehicle 3ST crashes by total (KABCO), by KABC, and by O for**: 1.2.1Angle collisions 1.2.2Head-on collisions 1.2.3Rear-end collisions 1.2.4Sideswipe collisions 1.2.5Other multiple-vehicle collisions 1.2.6.Total multiple-vehicle crashes **2. Four-leg STOP controlled intersections by**: 2.1**Single-vehicle 4ST crashes by total (KABCO), by KABC, and by O for** collision types listed above (as per 1.1.1. to 1.1.7) for 4ST 2.2**Multiple-vehicle 4ST crashes by total (KABCO), by KABC, and by O for**: collision types listed above (as per 1.2.1. to 1.2.6)for 4ST **3.Four-leg signalized intersections by** : 3.1**Single-vehicle 4SG crashes by total (KABCO), by KABC, and by O for**: collision types listed above (as per 1.1.1. to 1.1.7) for 4SG 3.2**Multiple-vehicle 4SG crashes by total (KABCO), by KABC, and by O for**: collision types listed above (as per 1.2.1. to 1.2.6) for 4SG

* Data required to replace HSM Table 10-15 (Nighttime crash proportions for unlighted intersections) are found in Table 5.1A

Table 6.3B – Data elements required replacement of the crash severity and collision type distribution tables and adjustment factors for rural multilane highways

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1B)		
Facilities and HSM Prediction Models	*HSM Table**	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Rural four-lane undivided – Roadway segment (4U)	Table 11-4	1. **4U crashes by total (KABCO), by KABC, by KAB, by O for:** 1.1. All (Total) 4D crashes 1.2.4Dhead-on collisions 1.3.4D sideswipe collisions 1.4.4D rear-end collisions 1.5.4D angle collisions 1.6.4D single-vehicle collisions 1.7. 4D other collisions
Rural four-lane divided – Roadway segment (4D)	Table 11-6	1. **4D crashes by total (KABCO), by KABC, by KAB, by O for:** 1.1. All (Total) 4D crashes 1.2.4Dhead-on collisions 1.3.4D sideswipe collisions 1.4.4D rear-end collisions 1.5.4D angle collisions 1.6.4D single-vehicle collisions 1.7.4D other collisions

* Data required to replace HSM Table 11-15 (Nighttime crash proportions for unlighted roadway segments (4U)) and HSM Table 11-19 (Nighttime crash proportions for unlighted roadway segments (4D)) are found in Table 5.1B

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1B)(Cont')		
Facilities and HSM Prediction Models	*HSM Table**	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Rural multilane highway three-leg (3ST) <u>or</u> four-leg STOP (4ST) controlled on minor-road approach <u>or</u> four-leg signalized (4SG) intersections	Table 11-9	1.**Three-leg STOP controlled intersections by total (KABCO), by KABC, by KAB, by O for**: 1.13ST head-on collisions 1.23ST sideswipe collisions 1.33ST rear-end collisions 1.4.3ST angle collisions 1.53ST single-vehicle collisions 1.63ST other collisions 1.7.All 3ST (total) crashes 2.**Four-leg STOP controlled intersections by total (KABCO), by KABC, by KAB, by O** for collision types listed above (as per 1.1 to 1.7) for 4ST **3. Four-leg signalized intersections by total (KABCO), by KABC, by KAB, by O** for collision types listed above (as per 1.1 to 1.7) for 4SG

* Data required to replace HSM Table 11-24 (Nighttime crash proportions for unlighted intersections) are found in Table 5.1B

Table 6.3C – Data elements required replacement of the crash severity and collision type distribution tables and adjustment factors for urban and suburban arterials

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C)		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments	Table 12-4	**Multiple-vehicle non-driveway collisions by KABC, and by O for**: 1.**Two-lane undivided arterials (2U) for**: 1.12U rear-end collisions 1.22U head-on collisions 1.32U angle collisions 1.4.2U sideswipe, same direction collisions 1.52U sideswipe, opposite direction 1.62U other multiple-vehicle collisions 1.7.All 2U (total) crashes 2.**Three-lane arterials including a TWLTL (3T) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 3T 2.**Four-lane undivided arterials (4U) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 4U 2.**Four-lane divided arterials (4D) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 4D 2.**Five-lane arterials including a TWLTL (5T) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 5T

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments (cont')	Table 12-6	**Single-vehicle crashes by KABC, and by O for**: 1.**Two-lane undivided arterials (2U) for**: 1.12U collisions with animal 1.22U collisions with fixed object 1.32U collisions with other object 1.42U other single-vehicle collisions 1.5.Total 2U single-vehicle collisions 2.**Three-lane arterials including a TWLTL (3T) by KABC, and by O** for collision types listed above (as per 1.1 to 1.5) for 3T 3.**Four-lane undivided arterials (4U) by KABC, and by O** for 4U collision types listed above (as per 1.1 to 1.5) for 4U 4.**Four-lane divided arterials (4D) by KABC, and by O** for 4D collision types listed above (as per 1.1 to 1.5) for 4D 5.**Five-lane arterials including a TWLTL (5T) by KABC, and by O** for 5T collision types listed above (as per 1.1 to 1.5) for 5T

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments (cont')	Table 12-7 (last two rows only) Table 12-8	**Multiple-vehicle driveway related collisions by KABCO, by KABC and by O,** for all driveways (irrespective of the driveway type) for each of the facilities as follows: 1.Two-lane undivided arterials (2U) 2.Three-lane arterials including a TWLTL (3T) 3.Four-lane undivided arterials (4U) 4.Four-lane divided arterials (4D) 5.Five-lane arterials including a TWLTL (5T) **1. Observed vehicle-pedestrian crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes for arterials with posted speed limit 30 mph or lower** for: 1.1.Two-lane undivided arterials (2U) 1.2.Three-lane arterials including a TWLTL (3T) 1.3.Four-lane undivided arterials (4U) 1.4.Four-lane divided arterials (4D) 1.5.Five-lane arterials including a TWLTL (5T) **2. Observed vehicle-pedestrian crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes for arterials with posted speed limit greater than 30 mph** for each of the five facilities listed above (as per 1.1 to 1.5) for 2U, 3T, 4U, 4D, and 5T

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table**	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments (cont')	Table 12-9	**1.Observed vehicle-bicycle crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes for arterials with posted speed limit 30 mph or lower** for: 1.1.Two-lane undivided arterials (2U) 1.2.Three-lane arterials including a TWLTL (3T) 1.3.Four-lane undivided arterials (4U) 1.4.Four-lane divided arterials (4D) 1.5.Five-lane arterials including a TWLTL (5T) **2. Observed vehicle-bicycle crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes for arterials with posted speed limit greater than 30 mph** for each of the five facilities listed above (as per 1.1 to 1.5) for 2U, 3T, 4U, 4D, and 5T

* Data required to replace HSM Table 12-23 (Nighttime crash proportions for unlighted roadway segments) are found in Table 5.1C

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches or three-leg (3SG) or four-leg (4SG) signalized intersections	Table 12-11	1.**Multiple-vehicle collisions at three-leg STOP (3ST) controlled intersections by KABC, and by O for**: 1.13ST rear-end collisions 1.23ST head-on collisions 1.33ST angle collisions 1.4.3ST sideswipe collisions 1.53ST other multiple-vehicle collisions 1.6.All 3ST (total) crashes 2. **Multiple-vehicle collisions at three-leg signalized intersections (3SG) by KABC, and by O** for collision types listed above (as per 1.1 to 1.6) for 3SG 3.**Multiple-vehicle collisions at four-leg STOP(4ST) controlled intersections by KABC, and by O** for collision types listed above (as per 1.1 to 1.6) for 4ST **3. Multiple-vehicle collisions at four-leg signalized intersections(4SG) by KABC, and by O** for collision types listed above (as per 1.1 to 1.6) for 4SG

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table*	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches or three-leg (3SG) or four-leg (4SG) signalized intersections	Table 12-13	1. **Single-vehicle collisions at three-leg STOP (3ST) controlled intersections by KABC, and by O for**: 1.13ST collisions with parked vehicle 1.23ST collisions with animals 1.33ST collisions with fixed object 1.4.3ST collisions with other object 1.53ST other single-vehicle collisions 1.63ST noncollisions 1.7.All 3ST (total) crashes 2. **Single-vehicle collisions at three-leg signalized intersections (3SG) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 3SG 3.**Single-vehicle collisions at four-leg STOP(4ST) controlled intersections by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 4ST **3. Single-vehicle collisions at four-leg signalized intersections(4SG) by KABC, and by O** for collision types listed above (as per 1.1 to 1.7) for 4SG

For each table or factor, historic jurisdiction-specific crash data required for the same time period used for SPF calibration factors (as per Table 5.1C) (Cont')		
Facilities and HSM Prediction Models	*HSM Table**	*Jurisdiction-specific facility type's observed crash frequency for each year:*
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches	Table 12-16	**1. Observed vehicle-pedestrian crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes** for: 1.1.Three-leg STOP controlled intersections (3ST) 1.2.Four-leg STOP controlled intersections (4ST)
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches or three-leg (3SG) or four-leg (4SG) signalized intersections	Table 12-17	1.**Observed vehicle-bicycle crash frequency (assumption: all are KABC) and observed frequency for all crashes not including vehicle-pedestrian and vehicle-bicycle crashes** for: 1.1.Three-leg STOP controlled intersections (3ST) 1.2Three-leg signalized intersections (4SG) 1.3.Four-leg STOP controlled intersections (4ST) 1.4Four-leg signalized intersections (4SG)

* Data required to replace HSM Table 12-27 (Nighttime crash proportions for unlighted intersections) are found in Table 5.1C

Tabular format for consolidation of the data elements for the development of calibration factors

The data elements required to develop SPF calibration factors are listed in previous pages of this Guide. In the next pages, Tables 6.4A to 6.9A, Tables 6.4B to 6.9B , and Tables 6.4C to 6.9C show a possible tabular format for consolidation of the data elements for the development of calibration factors. Each set of tables supports a given facility type (e.g., Table 6.4A. Table 6.4B, and Table 6.4C describe data elements for rural undivided two-lane, two-way roadway segments (2U)). The data elements are consistent with Table 5.1A, Table 5.1B, or Table 5.1C, and Table 6.3A, Table 6.3B, or Table 6.3C respectively:

- Tables 6.4A to 6.9A (shown in landscape format) take account of all data elements to be entered for each homogeneous roadway segment or intersection, for each year. The tabular form can be copied to an Excel spreadsheet for use during the current calibration process, and future calibration updates or jurisdiction-specific SPF development. The guidance for default assumptions is also noted under each table, as provided by HSM (2010), in the event of missing jurisdiction data for the desirable data elements.
- Tables 6.4B to 6.9B (shown in landscape format) contain the crash data required for each homogeneous segment or intersection for the replacement of crash severity and collision type tables used to calculate specific CMFs such as CMF_{9r} – TWLTLs and CMF_{11r} – Lighting (for rural undivided two-lane two-way roadway segments) or CMF_{4i} – Lighting (for rural undivided two-lane two-way roadway intersections).
- Tables 6.4C to 6.9C (shown in landscape format) consist of the observed crash data required to replace the crash severity and collision type distribution tables for different facility types, found in the HSM (refer to this Guide's Section 2.3 for the list of HSM tables and equations). The observed crash data do not need to be assigned to specific segments or intersections as the other two tables (i.e., Tables 6.4A to 6.9A and Tables 6.4B to 6.9B). For each facility type, the entire jurisdiction-specific annual crash data should be used to identify the observed crash frequencies / severity and collision type for each year used during the development of the SPF calibration factors for a given facility type. The data should be derived from the same year/s of geometric and traffic management, exposure (traffic volumes), and crash data used for the development of SPF calibration factors (i.e., the time period used to complete Table 6.4C would be the same time period used to complete Table 6.4A and Table 6.4B). However, the time period for Tables 6.4C to 6.9C can be extended to include a sufficient number of crashes. HSM (2010) recommends that each replacement value for a given facility type be derived from data from a set of site that, as a group, includes at least a minimum of 100

crashes and preferably more for the time period considered. Thus, the joint distribution of two variables requires a minimum of 200 crashes for the time period considered. For example, a minimum of 200 single-vehicle crashes on two-lane undivided urban and suburban arterial segments are required for the distribution of single-vehicle crashes by collision type and severity level as shown in the HSM Table 12-6.

Table 6.4A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for rural undivided two-lane two-way roadway segments (2U) (for year i)

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate	End MP or coordinate	AADT (year i)	Tangent (T) or curve (H or V)	Length (mi)	Lane width(ft)	Shoulder width(ft)	Shoulder Type (p, g, c, or t)	Horizontal curve radius (ft)	Curve spiral transition 1or ½ (if one approach only) or 0 (none) [a]	Curve superelevation (ft/ft) [b]	Vertical grade (%)[c]	Driveway density (both sides) per mile [e, g]	Centerline rumble strips (y or n) [a]	Passing lane or short 4-lane (PL, SH or n)	TWLTL (y or n)	Roadside design(1 to 7) [f]	Lighting (y or n) [d]	Automated speed enforcement (y or n) [a]

if local data not available ([a] to [f]) base on agency design policy/practice; [b] no variance; [c] base on terrain; [d] assume no lighting; [e] assume 5 driveways/mile; [f] assume RHR = 3 ; [g] signalized driveways are considered intersections for analysis

Table 6.4B– Crash data preparation for developing SPF Calibration Factors rural undivided two-lane two-way roadway segments (2U) (for year i)*

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate (homogenous as per Table 6.3A)	End MP or coordinate (homogeneous as per Table 6.3A)	Observed total (KABCO) crash frequency for year i	Observed fatal and injury (KABC) crash frequency for year i	Observed PDO (O)crash frequency for year i	Observed driveway-related crash frequency (if TWLTL are present – refer to Table 6.3A) [a]	Observed total (KABCO) nighttime crash frequency at unlit segment (if lighting is present, refer to Table 6.3A) [b]	Observed fatal and injury (KABC) nighttime crash frequency at unlit segments (as above) [b]	Observed PDO (O) nighttime crash frequency at unlit segments (as above) [b]

* HSM (2010) stipulates a minimum of 100 driveway-related crashes for a set of sites; and of 100 nighttime crashes. [a] refer to HSM Equation 10-18; [b] refer to HSM Table 10-12

Table 6.4C– Crash data preparation for replacement of the crash severity and collision type distribution tables for rural undivided two-lane two-way roadway segments (2U) (for year i)

Observed Fatal (K) crash frequency [a]	**Observed Incapacitating Injury (A) crash frequency [a,b]**	**Observed Non-Incapacitating Injury (B) crash frequency [a,b]**	**Observed Possible Injury (C) crash frequency [a,b]**	**Observed PDO (O) crash frequency [a]**	**Observed Fatal and Injury (KABC) crash frequency [a]**	**Observed Total (KABCO) crash frequency [a]**	**Observed KABCO/KABC/O Single-vehicle crash frequency [c, d]**							**Observed KABCO/KABC/O Multiple-vehicle crash frequency [c, d]**					
							Collisions with animal	Collisions with bicycle	Collisions with pedestrian	Overturned collisions	Ran-off-road collisions	Other single-vehicle collisions	Total single-vehicle crashes	Angle collisions	Head-on collisions	Rear-end collisions	Sideswipe collisions [e]	Other multiple-vehicle collisions	Total multiple-vehicle collisions

[a] refer to HSM Table 10-3; [b] if jurisdiction does not keep injury crashes by A, B , C severity levels, HSM (2010) specifies using the default severity level relative proportions found in HSM Table 10-3 to distribute the jurisdiction's all observed injury crash frequency; [c] refer to HSM Table 10-4 ; [d] HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type; [e] if available, record same direction and opposite-direction sideswipe collisions separately

Table 6.5A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for rural undivided two-lane, two-way roadway intersections (3ST or 4ST or 4SG for 2U) (for year i)

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	AADT $_{maj}$ (year i)	AADT$_{min}$ (year i) [a]	Number of intersection legs (3 or 4)	Traffic control type (minor road STOP or Signal)	Intersection skew angle (degrees departure from 90 degrees) [b], [c]		Number of approaches with left-turn lanes (excludes minor road STOP-controlled leg/s)	Number of approaches with right-turn lanes (excludes minor road STOP-controlled leg/s) [d]	Lighting (y or n)

[a] need actual data or best estimate; [b] assume no skew (preferably to include only intersections with known skew) [c] for 4ST and 4SG, skew angle for two minor road legs are recorded as they may differ; for 4SG, different skew angle values are not used in CMFs as per HSM (2010); [d] applies to marked or signed right-turn lanes only; not applicable to long tapers, flares, or shoulders

Table 6.5B– Crash data preparation for developing SPF Calibration Factors for rural undivided two-lane two-way roadway intersections (3ST or 3SG or 4 SG for 2U) (for year i)*

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	Observed total (KABCO) crash frequency for year i [a]	Observed fatal and injury (KABC) crash frequency for year i	Observed PDO (O)crash frequency for year i	Observed total (KABCO) nighttime crash frequency at unlit intersections (if lighting is present, refer to Table 6.4A) [a]

* HSM (2010) stipulates a minimum of 100 nighttime crashes for a set of sites. [a] refer to HSM Table 10-15

Table 6.5C– Crash data preparation for replacement of the crash severity and collision type distribution tables for rural undivided two-lane two-way roadway intersections (3ST or 3SG or 4 SG for 2U) (for year i)

Observed Fatal (K) crash frequency [a]	**Observed Incapacitating Injury (A) crash frequency** [a, b]	**Observed Non-Incapacitating Injury (B) crash frequency** [a , b]	**Observed Possible Injury (C) crash frequency** [a, b]	**Observed PDO (O) crash frequency** [a]	**Observed Fatal and Injury (KABC) crash frequency** [a]	**Observed Total (KABCO) crash frequency** [a]	**Observed KABCO/KABC/O Single-vehicle crash frequency** [c, d]							**Observed KABCO/KABC/O Multiple-vehicle crash frequency** [c, d]					
							Collisions with animal	Collisions with bicycle	Collisions with pedestrian	Overturned collisions	Ran-off-road collisions	Other single-vehicle collisions	Total single-vehicle crashes	Angle collisions	Head-on collisions	Rear-end collisions	Sideswipe collisions	Other multiple-vehicle collisions	Total multiple-vehicle collisions

[a] refer to HSM Table 10-5; [b] if jurisdiction does not keep injury crashes by A, B , C severity levels, HSM (2010) specifies using the default severity level relative proportions found in HSM Table 10-5 to distribute the jurisdiction's all observed injury crash frequency; [c] refer to HSM Table 10-6 ; [d] HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type

Table 6.6A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for rural multilane undivided and divided highway segments (4U or 4D) (for year i)*

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate	End MP or coordinate	AADT (year i)	Length (mi)	Lane width(ft)	Shoulder width(ft) (for 4D – right shoulders only)	Shoulder Type (p, g, or c) [a]	Presence of median (y or n) [d]	Median width (ft) [e]	Sideslope (for 4U only)	Lighting (y or n) [c]	Automated speed enforcement (y or n) [b]

*for divided highways built at different times to very different alignments, HSM (2010) recommends application of methodology twice using combined traffic volume, and averaging the predicted crash frequencies; [a] for 4D, paved shoulder only; if local data not available: [b] base on agency design policy/practice; [c] assume no lighting; [d] flush separator or painted median are between two direction of travel are considered undivided roadways, [e] median width is measured between the inside edges of the through lanes in the opposing direction of travel, thus, inside shoulder and turning lanes are included

Table 6.6B– Crash data preparation for developing SPF Calibration Factors for rural multilane undivided and divided highway segments (4U or 4D) (for year i)*

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate (homogenous as per Table 6.5A)	End MP or coordinate (homogeneous as per Table 6.5A)	Observed total (KABCO)crash frequency for year i	Observed fatal and injury (KABC) crash frequency for year i	Observed fatal and injury (KAB) crash frequency for year i	Observed PDO (O)crash frequency for year i	Observed total (KABCO) nighttime crash frequency at unlit segment (if lighting is present, refer to Table 6.5A) [a]	Observed fatal and injury (KABC) nighttime crash frequency at unlit segments (as above) [a]	Observed PDO (O) nighttime crash frequency at unlit segments (as above) [a]

* HSM (2010) stipulates a minimum of 100 nighttime crashes. [a] refer HSM Table 11-15 (4U) and HSM Table 11-19 (4D)

Table 6.6C– Crash data preparation for replacement of the crash severity and collision type distribution tables for multilane undivided and divided highway segments (4U or 4D) (for year i)

Observed Fatal and Injury (KABC) crash frequency [a]	**Observed Fatal and Injury (KAB) crash frequency [a]**	**Observed PDO (O) crash frequency [a]**	**Observed Total (KABCO) crash frequency [a]**	**Observed KABCO/KABC/KAB/O crash frequency [a, b]**						
				Head-on collisions [c]	Sideswipe collisions [c]	Rear-end collisions	Angle collisions	Single-vehicle collisions	Other vehicle collisions	Run-off-road (KABCO only) [c]

[a] refer to HSM Table 11-4 and Table 11-6; [b] HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type; [c] refer to Eq. 11-13 and Eq. 11-16

Table 6.7A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for rural multilane highway intersections (3ST or 4ST or 4SG for 4U) (for year i)**

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	AADT $_{maj}$ (year i)	AADT$_{min}$ (year i) [a]	AADT $_{total}$ (year i)	Number of intersection legs (3 or 4)	Traffic control type (minor road STOP or Signal)	Presence of median on approaches (to establish divided or undivided approach intersections) [f]	Intersection skew angle (degrees departure from 90 deg.) [b, c, e]		Number of approaches with left-turn lanes (excludes minor road STOP-controlled leg/s) [e]	Number of approaches with right-turn lanes (excludes minor road STOP-controlled leg/s) [d, e]	Lighting (y or n) [e]

** if feasible, HSM (2010) recommends separate calibration of the intersection models for applications to intersections on divided and undivided multilane segments (HSM page 11-21)
[a] need actual data or best estimate; [b] Skew angle is needed for 3ST and 4ST only; assume no skew (preferably to include only intersections with known skew) [c] for 4ST skew angle for two minor road legs are recorded as they may differ; [d] applies to marked or signed right-turn lanes only; not applicable to long tapers, flares, or shoulders; [e] HSM (2010) does not include CMFs for 4SG thus these data elements are not used presently; these data, if available, should be entered for future applications such as jurisdiction-specific SPF and future HSM versions; [f] HSM page 11-21 recommends separate calibration of SPFs for intersections in divided and undivided roadway segments.

Table 6.7B– Crash data preparation for developing SPF Calibration Factors for rural multilane highway intersections (3ST or 3SG or 4 SG [a] for 4U) (for year i)*, **

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	Observed total (KABCO) crash frequency for year i [b]	Observed fatal and injury (KABC) crash frequency for year i	Observed fatal and injury (KAB) crash frequency for year i	Observed PDO (O)crash frequency for year i	Observed total (KABCO) nighttime crash frequency at unlit intersections (if lighting is present, refer to Table 6.6A) [b]

* HSM (2010) stipulates a minimum of 100 nighttime crashes for a set of sites. ** if feasible, HSM (2010) recommends separate calibration of the intersection models for applications to intersections on divided and undivided multilane segments (HSM page 11-21)

[a] (see table title) HSM (2010) does not include CMFs for 4SG thus these data elements are not used presently; these data, if available, should be entered for future applications such as jurisdiction-specific SPF and future HSM versions; [b] refer to HSM Table 11-24

Table 6.7C– Crash data preparation for replacement of the crash severity and collision type distribution tables for rural multilane highway intersections (3ST or 3SG or 4 SG for 4U) (for year i)**

Observed Fatal and Injury (KABC) crash frequency [a]	**Observed Fatal and Injury (KAB) crash frequency** [a]	**Observed PDO (O) crash frequency** [a]	**Observed Total (KABCO) crash frequency** [a]	**Observed KABCO/KABC/KAB/O crash frequency** [a, b]																							
				Head-on collisions				Sideswipe collisions [c]				Rear-end collisions				Angle collisions				Single-vehicle collisions				Other vehicle collisions			

** if feasible, HSM (2010) recommends separate calibration of the intersection models for applications to intersections on divided and undivided multilane segments (HSM page 11-21)

[a] refer to HSM Table 11-9; [b] HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type

Table 6.8A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for urban and suburban arterial segments (2U or 3T or 4U or 4D or 5T) (for year i)

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate	End MP or coordinate	Number of through lanes	AADT (year i)	Length (mi)	Presence of median (y or n)	Median width (ft)	TWLTL (y or n)	**Number of driveways by land use type on both sides combined** (major commercial, minor commercial, major industrial / institutional, minor industrial / institutional, major residential, minor residential, other driveways [a])							Posted speed limit (mph)	Curb length with on-street parking by type and land use (parallel or angle, and residential/other, or commercial/industrial/institutional)				Roadside fixed object density (for both sides of the road combined (fixed objects / mi) and fixed object distance(ft) [b, c]		Lighting (y or n) [d]	Automated speed enforcement (y or n) [d]

[a] actual number of driveways may be used with simplified land use categories, e.g., residential and commercial only; major refers to 50 parking spaces or more; [b] may simplify to three categories of fixed-object density: 0, 50, or 100 objects/mile; [c] may simplify to two categories of fixed-object offset (i.e., estimate of the average distance from the edge of the traveled way to the object over an extended segment): either 5 ft or 20ft; by definition, fixed objects are 4 inches or more in diameter and do not have breakaway design; [d] if local data not available, base default on agency design practice

Table 6.8B– Crash data preparation for developing SPF Calibration Factors for urban and suburban arterial segments (2U or 3T or 4U or 4D or 5T)(for year i)*

Site ID	Site #	Segment #	HWY #	Beg MP or coordinate (homogenous as per Table 6.7A)	End MP or coordinate (homogeneous as per Table 6.7A)	Observed total (KABCO)crash frequency for year i	Observed fatal and injury (KABC) crash frequency for year i	Observed PDO (O)crash frequency for year i	Observed total multiple-vehicle non-driveway (KABCO)crash frequency for year i	Observed fatal and injury (KABC) multiple-vehicle non-driveway crash frequency for year i	Observed PDO (O) multiple-vehicle non-driveway crash frequency for year i	Observed total single-vehicle (KABCO)crash frequency for year i	Observed fatal and injury (KABC) single-vehicle crash frequency for year i	Observed PDO (O) single-vehicle crash frequency for year i	Observed total multiple-vehicle driveway (KABCO)crash frequency for year i [a, c]	Observed fatal and injury (KABC) multiple-vehicle driveway crash frequency for year i [a, c]	Observed PDO (O) multiple-vehicle driveway crash frequency for year i [a, c]	Total (KABCO) observed nighttime crash frequency at unlit segment (if lighting is present, refer to Table 6.7A) [b]	Fatal and Injury (KABC) observed nighttime crash frequency at unlit segments (as above) [b]	PDO (O) observed nighttime crash frequency at unlit segments (as above) [b]

* HSM (2010) stipulates a minimum of 100 driveway-related crashes for a set of sites; and of 100 nighttime crashes. [a] refer to HSM Table 12-7; [b] refer to HSM Table 12-23; [c] unsignalized driveways only

Table 6.8C– Crash data preparation for replacement of the crash severity and collision type distribution tables for urban and suburban arterial segments (2U or 3T or 4U or 4D or 5T) (for year i)

Observed Total (KABCO) crash frequency [g]	Observed Fatal and Injury (KABC) crash frequency [g]	Observed PDO(O) crash frequency [g]	Observed KABCO/KABC/O Single-vehicle crash frequency [b, c, g]															Observed KABCO/KABC/O Multiple-vehicle crash frequency [a, c, g]																					Observed vehicle-pedestrian collisions [d, f, g]	Observed vehicle-bicycle collisions [e, f, g]
			Collisions with animal			Collisions with fixed object			Collisions with other object			Other single-vehicle collisions			Total single-vehicle crashes			Rear-end collisions			Head-on collisions			Angle collisions			Sideswipe , same direction collisions			Sideswipe , opposite direction collisions			Other multiple-vehicle collisions			Total multiple-vehicle collisions				

[a] refer to HSM Table 12-4; [b] refer to HSM Table 12-6; [c] HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type; [d] refer to HSM Table 12-8 and Eq.A-2; all vehicle-pedestrian crashes are considered fatal and injury (KABC) crashes; [e] refer to HSM Table 12-9 and Eq. A-3; all vehicle-bicycle crashes are considered fatal and injury (KABC) crashes; [f] a set of sites that as a group have experience a minimum of 20 vehicle-pedestrian crashes, or 20 vehicle-bicycle crashes for replacement of adjustment factors; [g] crash frequencies exclude all vehicle-pedestrian collisions and all vehicle-bicycle collisions

Table 6.9A– Geometric, traffic management, and exposure data preparation for developing SPF Calibration Factors for urban and suburban arterial intersections (3ST, 4ST, 3SG or 4SG) (for year i)

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	AADT $_{maj}$ (year i)	AADT$_{min}$ (year i) [a]	Number of intersection legs (3 or 4)	Traffic control type (minor road STOP or Signal)	Pedestrian volume for all crossings combined (ped/day) [h]	Intersection skew angle (degrees departure from 90 degrees) [b, c]		Number of approaches with left-turn lanes (excludes minor road STOP-controlled leg/s)	Number of approaches with right-turn lanes (excludes minor road STOP-controlled leg/s) [d]	Lighting (y or n)	If signalized, type of left-turn phasing (n=none, per= permissive; proper = protected/permissive or permissive/protected; pro = protected only) [e]				If signalized, number of approached for which right-turn-on -red is prohibited	If signalized, red light camera (y or n)	Number of lanes crossed by pedestrian on each approach [f]				Number of bus stops within 1,000 ft [g,i]	Presence of schools within 1,000ft (y or n) [g]	Number of alcohol establishments within 1,000 ft [g,j]

[a] need actual data or best estimate; [b] assume no skew (preferably to include only intersections with known skew) [c] for 4ST and 4SG, skew angle for two minor road legs are recorded as they may differ; for 4SG, different skew angle values are not used in CMFs as per HSM (2010); [d] applies to marked or signed right-turn lanes only; not applicable to long tapers, flares, or shoulders. [e] prefer actual data, but agency practice may be used as a default; [f] maximum number of lanes crossed at any approach is needed; if not available, it can be estimated from number of lanes and presence of median on major road; [g] if local data not available, assume not present; [h] if not available, estimate with HSM Table 12-15; [i] multiple bus stops at all quadrants are counted; [j] any liquor store, bar, restaurant, convenient store, or grocery store that sells alcohol drinks is counted

Table 6.9B– Crash data preparation for developing SPF Calibration Factors for urban and suburban arterial intersections (3ST, 4ST, 3SG or 4SG) (for year i)*

Site ID	**Site #**	**HWY 1 - # or name**	**HWY2 - # or name**	**Intersection MP or coordinate**	**Observed total (KABCO) crash frequency for year i [a, b]**	**Observed fatal and injury (KABC) crash frequency for year i [b]**	**Observed PDO (O)crash frequency for year i [b]**	**Observed total multiple-vehicle (KABCO)crash frequency for year i [b]**	**Observed fatal and injury (KABC) multiple-vehicle crash frequency for year i [b]**	**Observed PDO (O) multiple-vehicle crash frequency for year i [b]**	**Observed total single-vehicle (KABCO)crash frequency for year i [b]**	**Observed fatal and injury (KABC) single-vehicle crash frequency for year i [b]**	**Observed PDO (O) single-vehicle crash frequency for year i [b]**	**Observed total (KABCO) nighttime crash frequency at unlit intersections (if lighting is present, refer to Table 6.8A) [a, b]**	**Observed total vehicle-pedestrian collision frequency , if a signalized intersection (3SG or 4SG) (all assumed to be KABC)**

[*] HSM (2010) stipulates a minimum of 100 nighttime crashes for a set of sites. [a] refer to HSM Table 12-27 [b] crash frequencies exclude all vehicle-pedestrian collisions and all vehicle-bicycle collisions

Table 6.9C– Crash data preparation for replacement of the crash severity and collision type distribution tables for urban and suburban arterial intersections (3ST, 4ST, 3SG or 4SG) (for year i)

Observed total (KABCO) crash frequency [e]	Observed Fatal and Injury (KABC) crash frequency [e]	Observed PDO(O) crash frequency [e]	Observed total vehicle-pedestrian collision frequency [f]	Observed total vehicle-bicycle collision frequency [f]	Observed KABCO/KABC/O Single-vehicle crash frequency [b, c, d, e]							Observed KABCO/KABC/O Multiple-vehicle crash frequency [a, d, e]					
					Collisions with parked vehicle	Collisions with animal	Collisions with fixed object	Collisions with other object	Other single-vehicle collisions	Non-collision	Total single-vehicle crashes	Rear-end collisions	Head-on collisions	Angle collisions	Sideswipe collisions	Other multiple-vehicle collisions	Total multiple-vehicle collisions

[a] refer to HSM Table 12-11; [b] refer to HSM Table 12-13 ; [c] refer to f_{bisv} in HSM Eq. 12-27 ; [d] - HSM (2010) stipulates a minimum of 200 crashes for a set of sites for a given crash type; [e] crash frequencies exclude all vehicle-pedestrian collisions and all vehicle-bicycle collisions, [f] all vehicle-pedestrian collisions and vehicle-bicycle collisions are assumed to be KABC; refer to HSM Table 12-16 and HSM Table 12-17

6.4 Step 4 – Apply the Applicable Predictive Model to Predict Crash Frequency for Each Site during the Calibration Period

The estimation of unadjusted $N_{predicted}$ will be done during this Step 4, after assembling the data in tables similar to the ones shown in Section 6.2 and Section 6.3. As described in Section 1.1, the predictive models, in the HSM (2010) are typically expressed in the form:

$$N_{predicted} = N_{spf} \times C \times (CMF_r \times CMF_2 \times \ldots \times CMF_i)$$

The procedure to estimate unadjusted $N_{predicted}$ is as follows:

1. Calculate N_{spf} , the predicted average crash frequency determined by the SPF developed for a specific facility type for each intersection or homogeneous segment (or grouping of homogenous segment if shorter than 0.1 mile).
2. Calculate each CMF_i based on each intersection or homogeneous segment's geometric and traffic operational conditions that differ from those base conditions used for the development of the selected SPF.
3. Calculate the unadjusted $N_{predicted}$ by multiplying the N_{spf} by the relevant CMF_i that are different than CMF = 1.0 (i.e., same as base conditions), and assuming the calibration factor is C=1

This procedure (bullets 1-3 above) is repeated for each predictive model available in HSM (2010), or selected by the agency for the development of calibration factor/s .

Following this procedure for all predictive models available in the HSM (2010) would potentially result in:

- Unadjusted $N_{predicted}$ for *total* (KABCO) predicted average crash frequency for a given year and for each selected site on rural two-lane, two-way roadway segments or intersections
- Unadjusted $N_{predicted}$ for *total* (KABCO) and *fatal plus injury* (KABC) predicted average crash frequencies for a given year and for each selected site on rural multilane highway segments or intersections,
- Unadjusted $N_{predicted}$ for *total* (KABCO), *fatal plus injury* (KABC), and *property-damage-only* (O) predicted average multiple-vehicle non-driveway crash frequencies, and

single-vehicle crash frequencies, for a given year for each selected site for urban and suburban arterial segments

- Unadjusted $N_{predicted}$ for *total* (KABCO), *fatal plus injury* (KABC), and *property-damage-only* (O) predicted average multiple-vehicle crash frequencies, and single-vehicle crash frequencies for a given year for each selected site for urban and suburban arterial intersections
- Unadjusted $N_{predicted}$ *values* for *fatal plus injury* (KABC)vehicle-pedestrian collision frequencies for a given year for each signalized urban and suburban arterial intersection selected for calibration process.

Table 6.10 depicts an example table with such calculations, as per procedure above. Table 6.10 expands on Table 6.5A.

Table 6.10–Example table for the calculation of unadjusted $N_{predicted}$ for rural undivided two-lane, two-way roadway intersections (3ST or 4ST or 4SG for 2U) (for year i) for total crashes (KABCO)*

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	AADT $_{maj}$ (year i)	AADT$_{min}$ (year i)	Number of intersection legs (3 or 4)	Traffic control type (minor road STOP or Signal)	Intersection skew angle (degrees departure from 90 degrees)	Number of approaches with left-turn lanes (excludes minor road STOP-controlled leg/s)	Number of approaches with right-turn lanes (excludes minor road STOP-controlled leg/s) [d]	Lighting (y or n)	Calculation of N_{spf} (total predicted number of crashes /year i for base conditions – HSM Eq 10-8 or Eq. 10-9 or Eq. 10-10)	CMF $_{1i}$ for 3ST or 4ST skew angle (HSM Eq. 10-22or Eq. 10-23)	CMF $_{2i}$ for 3ST or 4ST or 4SG left-turn lanes (HSM Table 10-13)	CMF $_{3i}$ for 3ST or 4ST or 4SG right-turn lanes (HSM Table 10-14)	CMF $_{4i}$ for 3ST or 4ST or 4SG lightning (HSM Eq. 10-24)	Calculation of unadjusted $N_{predicted}$ (total predicted number of crashes / year i for site j – HSM Eq. 10-3 for C =1)

* Table 6.10 expands on Table 6.5A

Tables similar to Table 6.10 would be developed for each facility type and each relevant prediction model for which SPF calibration factors are needed. To this effect, Tables 6.4 A to 6.9 A would be expanded to include:

- a column for the calculation of N_{spf} for each site (intersection or homogeneous segment)
- additional columns to accommodate the respective CMF_i to each SPF
- a column for the calculation of the unadjusted $N_{predicted}$

As per this Guide's recommendations, additional columns should be added to allow for the calculation of the N_{spf} and unadjusted $N_{predicted}$ values for each of the different crash severity levels (KABCO or total, and KABC) when relevant prediction models are available (e.g., rural multilane segments). These unadjusted $N_{predicted}$ values by crash severity level will be used in the calculation of calibration factors using respective site's observed crash frequencies by crash severity (Refer to Table 6.2 for relevant HSM Equation and Table numbers).

The following diagrams provide applicable CMF_i conditions for each facility type. They are relevant when calculating the CMF_i for each intersection or homogeneous segment site. It is noted that in future editions of the HSM, there may be a different method to calibrate CMFs as a result of a on-going NCHRP Project 17-63: "Guidance for the Development and Application of Crash Modification Factors." This project aims to develop 1) guidelines for calibration of current CMFs to assess treatment effectiveness at sites for which the site characteristics (e.g., geographical location, terrain, traffic demand, geometric design, traffic control features) may be different; 2) guidelines for how existing and future CMFs can be combined in a single location with multiple treatments; and 3) recommended procedures for formulating and calibrating future CMFs that identify key influential site characteristics. The publication of the findings of this project is anticipated in 2016.

*Rural Undivided Two-lane, Two-way Road Segments – Applicable CMF_{ir} Conditions***

- *Each CMF_{ir} apply to total roadway segment crashes.*
- *P_{ra} for CMF_{1r} and CMF_{2r} are replaced by the jurisdiction value, i.e., the proportion of the sum of single-vehicle run-off-road, multiple-vehicle head-on, opposite direction sideswipe, and same-direction sideswipe to total crashes, as collated by a jurisdiction-specific table similar to Table 6.4C and HSM Table 10-4.*
- *CMF_{1r} for lane width is the average of the sum of the CMFs determined for each direction of travel when their width values differ.*
- *CMF_{2r} for shoulder width and type is the average of the sum of the CMFs determined for each direction of travel when their width and type values differ.*
- *CMF_{3r} for horizontal curves uses the entire length of the horizontal curve, even if portion of the curve is outside the homogeneous segment; if the entire length is less than 100ft, the length is set to 100ft; likewise, if the radius of curvature is less than 100ft, the radius is set to 100ft. If the resulting value of CMF_{3r} is less than 1.00, the CMF_{3r} is set to 1.00.*
- *CMF_{5r} could use default values when jurisdiction-specific data are not available as follows: CMF=1.00 for level terrain; CMF = 1.06 for rolling terrain; and CMF = 1.14 for mountainous terrain (HSM Table A-2).*
- *CMF_{8r} provides two values: a)the effect on both directions of travel when passing or climbing lane is provided for one direction, or b)the effect of side-by-side passing lanes in opposite directions on same section of roadway*
- *P_{dwy} for CMF_{9r} is replaced by the jurisdiction value, i.e., the proportion of driveways-related crashes to total crashes, as collated by a jurisdiction-specific table similar to Table 6.4B. CMF_{9r} = 1 for driveway density less than 5 driveways/mile.*
- *CMF_{10r} for roadside design is the average of the sum of the CMFs determined for each direction of travel when their RHR values differ.*
- *P_{inr} P_{pnr} P_{nr} for CMF_{11r} is replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury, the proportion of total nighttime crashes for unlighted roadway segments that involve property damage only, or the proportion of total nighttime crashes for unlighted roadway segments that occur at night, respectively, as collated by a jurisdiction-specific table similar to Table 6.4B.*

*** Consult HSM page 10-23 to page 10-31when determining CMF_i*

*Rural Undivided Two-lane, Two-way Road Intersections – Applicable CMF_{ii} Conditions***

- *Each CMF_{ii} apply to total intersection crashes*
- *CMF_{1i} for four-leg intersections with STOP-Control on minor approaches is the average of the sum of the CMFs determined for each minor road leg when their skew angle values differ.*
- *CMF_{2i} does not consider the presence of a left-turn lane on an approach controlled by a stop sign*
- *CMF_{3i} does not consider the presence of a right-turn lane on an approach controlled by a stop sign; and CMF_{3i} does not apply to long tapers, flares, or paved shoulders.*
- *P_{ni} for CMF_{4i} is replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that occur at night, as collated by a jurisdiction-specific table similar to Table 6.5B*

*** Consult HSM page 10-31 to page 10-33 when determining CMF_i*

*Rural Multilane Highway Segments (4U and 4D) – Applicable CMF_{ir} Conditions***

- *Each CMF_{ru} and CMF_{rd} applies to total roadway segment crashes.*
- *p_{ra} for CMF_{1ru}, CMF_{2ru} and for CMF_{1rd} are replaced by the jurisdiction values for undivided and divided roadway segments, respectively, i.e., the proportion of the sum of KABCO run-off-road, head-on, sideswipe crashes to total (KABCO)crashes, as collated by a jurisdiction-specific table similar to Table 6.6C.*
- *CMF_{1ru} (or CMF_{1rd}) for lane width is the average of the sum of the CMFs determined for each direction of travel when their width values differ for undivided (or divided) roadway segments.*
- *CMF_{2ru} for shoulder width and type is the average of the sum of the CMFs determined for each direction of travel when their width and type values differ.*
- *CMF_{2rd} for shoulder width is the average of the sum of the CMFs determined for each direction of travel when their width values differ; CMF_{2rd} applies to paved shoulders only.*
- *CMF_{3ru} for sideslope for undivided roadway segments is the average of the sum of the CMFs determined for each direction of travel when their sideslopes differ.*
- *CMF_{3rd} for median width applies only to traversable medians without traffic barriers. Thus, CMF assumed 1.0 for medians with any traffic barriers.*
- *P_{inr} P_{pnr} P_{nr} for CMF_{4ru} and CMF_{4rd} are replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury, the proportion of total nighttime crashes for unlighted roadway segments that involve property damage only, or the proportion of total nighttime crashes for unlighted roadway segments that occur at night, respectively, as collated by a jurisdiction-specific table similar to Table 6.6B.*
- *for divided highways built at different times to very different alignments, HSM (2010) recommends application of methodology twice using combined traffic volume, and averaging the predicted crash frequencies*

*** Consult HSM page 11-25 to page 11-32 when determining* CMF_{i}

*Rural Multilane Highway Intersections (4U and 4D) – Applicable CMF_{ii} Conditions***

- *Each CMF_{ii} applies to total intersection crashes.*
- *CMF_{1i} for four-leg intersections with STOP-Control on minor approaches is the average of the sum of the CMFs determined for each minor road leg when their skew angle values differ.*
- *CMF_{2i} does not consider the presence of a left-turn lane on an approach controlled by a stop sign*
- *CMF_{3i} does not consider the presence of a right-turn lane on an approach controlled by a stop sign; and CMF_{3i} does not apply to long tapers, flares, or paved shoulders.*
- *P_{ni} for CMF_{4i} is replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that occur at night, as collated by a jurisdiction-specific table similar to Table 6.7B*

*** Consult HSM page 11-32 to page 11-35 when determining CMF_i*

*Urban and Suburban Arterial Roadway Segments (2U, 3T, 4U, 4D, 5T) – Applicable CMF_{ir} Conditions***

- *Each CMF_{ir} applies to total roadway segment crashes.*
- *CMF_{1r} for on-street parking may have a different parking type and land use on either side of the roadway, thus an average value of f_{pk} (HSM Table 12-19) may be used for the combined CMF value for the segment.*
- *CMF_{2r} for roadside fixed objects may have a different offset to fixed objects on either side of the roadway, thus an average value of f_{offset} (HSM Table 12-20) may be used for the combined CMF value for the segment.*
- *CMF_{3r} for median width applies only to 4D roadway segments with traversable medians without traffic barriers. CMF_{3r} is 1.00 for all other roadway segment types and for medians with traffic barriers.*
- *P_{inr} P_{pnr} P_{nr} for CMF_{4r} are replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury, the proportion of total nighttime crashes for unlighted roadway segments that involve property damage only, or the proportion of total nighttime crashes for unlighted roadway segments that occur at night, respectively, as collated by a jurisdiction-specific table similar to Table 6.8B .*

*** Consult HSM page 12-39 to page 12-43 when determining* CMF_i

*Urban and Suburban Arterial Intersections (3ST, 4ST, 3SG, 4SG) – Applicable CMF_{ii} Conditions for Multiple-Vehicle Collision SPFs and Single-Vehicle Collision SPFs (excludes vehicle-pedestrian and vehicle-bicycle collisions) ***

- *Each CMF_{ii} applies to total intersection crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions).*
- *CMF_{2i} does not consider the presence of a left-turn lane on an approach controlled by a stop sign*
- *If several approaches to a signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.*
- *CMF_{3i} does not consider the presence of a right-turn lane on an approach controlled by a stop sign; and CMF_{3i} does not apply to long tapers, flares, or paved shoulders.*
- *P_{ni} for CMF_{5i} is replaced by the jurisdiction values, i.e., the proportion of total nighttime crashes for unlighted roadway segments that occur at night, as collated by a jurisdiction-specific table similar to Table 6.9B*
- *P_{ra}, and P_{re} for CMF_{6i} are replaced by the jurisdiction values, i.e., the proportion of crashes that are multiple-vehicle, right-angle collisions, and the proportion of crashes that are multiple-vehicle, rear-end collisions, as collated by a jurisdiction-specific table similar to Table 6.9C or alternatively, as recommended by HSM (2010), page 12-45, these proportions are estimated based on P_{ramv} and P_{remv} for FI and PDO, i.e., the proportion of multiple-vehicle crashes represented by right-angle collisions, and proportion of multiple-vehicle crashes represented by rear-end collisions respectively, using the estimated predicted crash frequency as indicated in HSM (2010) page 12-46.*

*** Consult HSM page 12-43 to page 12-46 when determining CMF_i*

*Urban and Suburban Arterial Intersections (3SG, 4SG) – Applicable CMF_{ip} Conditions for Vehicle-Pedestrian Collisions ***

- *Each CMF_{ip} applies to total vehicle-pedestrian intersection collisions.*

*** Consult HSM page 12-46 to page 12-47 when determining CMF_i*

6.5 Step 5 – Compute Calibration Factors for use in Part C Predictive Models for Each Facility Type

The tasks to compute calibration factors, following the completion of Step 4 (Section 6.4) are listed here:

i. Sum all unadjusted $N_{predicted}$ calculated values for the sample of sites representing the selected facility type and its prediction model for each year of the analysis period. Table 6.11 depicts an example table with such calculations. Table 6.11 expands on Table 6.10 and incorporates data gathered as depicted in Table 6.5B.

ii. Sum all observed crashes for each year of the analysis period for the same sample of sites (Table 6.11)

iii. Calculate calibration factor C using equation 6.1: $C = \frac{\sum_{\text{all j}} \text{observed crashes at site j}}{\sum_{\text{all j}} N_u \text{at site j}}$

- For a single and multi-year combined calibration factor, sum for all years of the analysis period the total annual unadjusted $N_{predicted}$ values (calculated in i. above) and sum for the same years of the analysis period the total annual observed crashes (calculated in ii. above)
- For annual calibration factors, for each given year substitute in equation 6.1 the sum of all unadjusted $N_{predicted}$ (calculated in i. above) and the respective sum of observed crashes(calculated in ii. above)

iv. Compare the calculated single and multi-year combined C with the guess estimate C (Step 2 of the SPF calibration process) to confirm the desired accuracy of the calibration factor; if the accuracy does not meet the desired level, consider increasing the sample size of sites or number of years of data and returning to Step 2 of the SPF calibration process.

v. Consider developing a calibration function (i.e., a time function)

- to assess time trend of the annual calibration factors. If no trend is found meaning that the annual calibration factors are similar year after year, one can conclude that a single and multi-year combined calibration factor is appropriate
- the curve fitted using the annual calibration factors will enable extrapolating calibration factors for safety analysis in a future year (or a past year, if needed)

vi. Consider regrouping the data for separate calibration factors for distinct strata of AADT volumes , segment length, regional networks. Appendix D should be consulted.

Appendix D (consisting of a working paper developed by Dr. Ezra Hauer) provides some guidance on:

- when to estimate separate calibration factors
- how to assess the potential effects of applying a single versus separate calibration factors when estimating the expected crash frequency of a site
- how to estimate separate calibration factors by simply using Excel Pivot Tables. The tables are created using sub-groupings of the data collected for elements such as AADT volumes, segment length, terrain, etc. The respective sums of unadjusted $N_{predicted}$ and the observed crashes for each sub-grouping are used to calculate separate calibration factors (as per equation 6.1).

The exploratory work documented in Appendix D concludes that agencies should consider developing separate calibration factors for different groupings of AADT and/or segment length, or even better, attempt to fit a regression model to:

$$N_{observed} = N_u C(\text{segment length}, \text{ADT})$$

The function C(segment length, ADT) could be replaced by a model equation such as $C = \beta_o e^{\beta_1(\text{segment length})} e^{\beta_2 \text{ADT}}$. With this, the model equation would be

$$N_{observed} = N_u C$$

and

$$C = \beta_o e^{\beta_1(\text{segment length})} e^{\beta_2 \text{ADT}}$$

The parameters β_0, β_1, and β_2 can then be estimated in the usual manner from the data collected for the calibration process.

Step 5's tasks i. to vi. described earlier are repeated for each facility type and SPF selected for the development of calibration factor/s. To this effect, tables created in Step 4 (similar to Table 6.10) will be expanded (similar to Table 6.11) to include:

- a column with observed crash frequency by severity for year i (collected as shown in Tables 6.4 B to 6.9.B)
- a row for the sum of unadjusted $N_{predicted}$ or sum of observed crash frequency, for year i

Table 6.11–Example table with the calculation of calibration factor for rural undivided two-lane, two-way roadway intersections (3ST or 4ST or 4SG for 2U) (for year i) for total crashes (KABCO) *

Site ID	Site #	HWY 1 - # or name	HWY2 - # or name	Intersection MP or coordinate	AADT $_{maj}$ (year i)	AADT$_{min}$ (year i)	Number of intersection legs (3 or 4)	Traffic control type (minor road STOP or Signal)	Intersection skew angle (degrees departure from 90 degrees) [b], [c]	Number of approaches with left-turn lanes (excludes minor road STOP-controlled leg/s)	Number of approaches with right-turn lanes (excludes minor road STOP-controlled leg/s) [d]	Lighting (y or n)	Calculation of N $_{spf}$ (total predicted number of crashes /year i for base conditions – HSM Eq 10-8 or Eq. 10-9 or Eq. 10-10)	CMF $_{1i}$ for 3ST or 4ST skew angle (HSM Eq. 10-22or Eq. 10-23)	CMF $_{2i}$ for 3ST or 4ST or 4SG left-turn lanes (HSM Table 10-13)	CMF $_{3i}$ for 3ST or 4ST or 4SG right-turn lanes (HSM Table 10-14)	CMF $_{4i}$ for 3ST or 4ST or 4SG lightning (HSM Eq. 10-24)	Calculation of unadjusted N$_{predicted}$ (total predicted number of crashes / year i for site j – HSM Eq. 10-3 for C$_i$ =1)	Observed total (KABCO) crash frequency for year I [a]
Sum of unadjusted N$_{predicted}$ or Sum of observed crash frequency, for year i																			

*Table 6.11 expands on Table 6.10 and incorporates data gathered as depicted in Table 6.5B; [a] observed crashes for different crash severity levels may entered here to be in accordance with the crash severity level of the unadjusted N$_{predicted}$

7. Case Studies – Recent Experiences and Lessons Learned

Several state DOTs have developed or are in the process of developing jurisdiction-specific calibration factors for the HSM Part C's SPFs. Some have published their studies and these are summarized in this Section. Each document is summarized in a consistent manner; the summaries are presented chronologically.

Reference
Lubliner, H., *Evaluation of the Highway Safety Manual Crash Prediction Model for Rural Two-lane Highway Segments in Kansas*. Submitted to the graduate degree program in Civil, Environmental and Architectural Engineering and Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy, defended on July 15th, 2011
Synopsis The study aims to validate the effectiveness of HSM crash predictive models for Kansas highways. It does not develop jurisdiction-specific SPFs or CMFs for Kansas. The researcher derives a calibration procedure and validates the outcome of these procedures (with and without EB method with historical crash records) vs. the HSM calibration procedures (with and without EB method with historical crash records, as well).
Calibration Attributes
Site Selection There are 8,600 miles of this facility type in Kansas and 41 % of fatalities occur on these roads in Kansas. Definitions clarify that segments represents any part of the highway that is not an intersection; site means a homogeneous highway segment, and section (unique to this document) is a group of adjacent sites that are aggregated and analyzed as one element. Concentrated effort to collect all data elements was carried out as the Kansas databases do not contain most of the variables required by the HSM Part C methods. The attempt was to collect local data and to not adopt default values of the HSM as the local values will be used at the project level application. Similar data collection effort was given to each variable; most time-consuming effort was aligning the data from different sources (a problem not relevant to a project level application). The definition of rural in the HSM was found to be inconsistent with the application of going through cities with population of less than 5,000; thus, this research only account for roads that do not go through a city of ANY size. This is an aspect that needs additional study.
Sample size A total of 19 ten-mile sections was used to develop the calibration factor for Kansas.
Data collection and management (incl. preservation with on-going collection for future uses) IHSDM files were created for the two-lane roads. Future entries of crash data and other data elements' updates for recalibration will need a much simpler effort than this initial effort, described in this document.
Data Analysis and Findings Site-specific EB method of calibrating consistently showed improvement in accuracy of the predictive models. It is recommended that historical crash records be used in future applications of the HSM (i.e., use of expected and not predicted for comparisons). Recalibration will be done with 2008-2010 data when available. Jurisdiction-specific crash distributions were considered and compared against the default HSM values. The comparisons showed that prediction for a 10-mile section could vary as much as 8.4% (both over- and under-predictions when compared with the HSM default). It also showed that for a state-wide comparison, the

differences may be quite small, but at section level, it could be significant. Animal crashes (58.9% - found to be significantly over-represented in Kansas in comparison to HSM default values) were analyzed to try to find tendencies in the calibration factor vs. animal crash rates.
Regional and State Calibration Factors Large geographic divisions in KDOT did not show promise in enhancing the accuracy of predictions. Three calibration procedures (section, county, and single-statewide) were carried forward for analysis in the validation portion of the research.
Procedure for Validation and Comparison The validation of the three calibration procedures suggested that the county-specific calibration outperformed the single statewide value for accuracy of prediction. It is also noted that both procedures resulted in reliable outcomes. The section-specific procedure tried during this research study did not result in accepted outcomes and was not brought forward.
Recommendations and Future Steps
Own SPFs The SPF calibration factors did not lead to the accuracy desired. It is recommended that jurisdiction-specific SPFs be developed for Kansas, with consideration of possible different functional forms as well as calibrated CMFs for Kansas DOT data.
Refinements for Future Calibration Factors **Site Selection** The definition of rural roads going through cities of population less than 5,000 or any size needs additional review, and evaluation. Additional work should expand to model safety performance of highways going through small towns and compare them with other SPFs in the HSM. The researcher recommends assessing the predictive differences for possible jurisdiction-specific SPFs for these conditions. These sites tend to be very short segments and may also affect the results. **Sample Size** NA **NOTE**: Related work was published by Cheryl Bornheimer: *Finding a New Safety Performance Function for Two-Way, Two-Lane Highways in Rural Areas,* submitted to the graduate degree program in Civil Engineering and Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Mater of Science, defended on December 21, 2011. This work explored new SPFs that excluded animal crashes, and has found promising results. Additional research is needed in this area.

Reference
Srinivasan, R, and D. Carter. *Development of Safety Performance Functions for North Carolina*. 2010-09 Final Report University of North Carolina Highway Safety Research Center, Chapel Hill, NC, for the North Carolina Department of Transportation, December 2011
Synopsis This report describes the calibration of HSM predictive models for North Carolina state highways (segments and intersections) following the guidance for calibration in Appendix A of Part C of HSM. SPFs using AADT as the only independent variable were also developed for 9 crash types on 16 roadway types in North Carolina; these SPFs are intended for network screening and other system procedures as per Part B of HSM, and are suitable for *SafetyAnalyst*.
Calibration Attributes
Site Selection The Highway Safety Information System (HSIS) is managed by the University of North Carolina Highway Safety Research Center (HSRC) under contract with FHWA. Data were extracted from HSIS for the study and augmented by other data stored in other data systems in the NSDOT such as the traffic engineering accident analysis system (TEAAS), as described in pg. 26 and pg. 27 of the report. The crash data used in this analysis dated 2007-2009. Sites were also identified based on the topographical area of the state: coast, piedmont, or mountain. Random selection per se was not used in the process; the researchers chose to select adjacent sites and to minimize route selection bias, they selected complete counties and if necessary adjacent counties till getting the sample sizes, as per HSM Part C's Appendix A. Roughly equal sizes for the three geographical areas were selected.
Sample size The researchers gathered sites till getting to the HSM recommended 30-50 sites and 100 crashes/ year for each facility type. Each roadway segment was carefully reviewed, and when one came to an intersection, the intersections crashes and related crashes were extracted from the segment and allocated to the relevant intersection.
Data collection and management (incl. preservation with on-going collection for future uses) The HSIS data were investigated and several site attributes were modified to reflect current conditions and to correct some erroneous entries years back. Aerial and street-view of Google were also used to update the sites and add attributes to intersections. The latitude and longitude of each intersection was logged for future review of attributes in future modeling or calibration assignments.
Data Analysis and Findings Several previous studies had developed SPFs for North Carolina and they did not need to be re-modeled (pgs. 14-18). Calibration factors had been developed for rural 2-lane, 2-way segments and rural 4-lane undivided; and for intersections between rural 4-lane and minor road 3ST, and between rural 4-lane and minor road

4ST. Thus, calibration factors for the HSM SPFs were developed for following roadway segments: Rural 4D, Urban 2U,3T,4D, 4U, and 5T; and for intersections: Rural 2-lane 3ST, 2lane 4ST, 2 lane 4ST, and 4 lane 4SG; and Urban arterial 3SG, Urban arterial and minor 3ST, urban arterial 4SG,Urban arterial and minor road 4ST.. Tables 3 and 4 show the annual calibration factor and the 3-year average. The geographical calibration factors are found in Appendix E.
Regional and State Calibration Factors All HSM segment types and intersection types were analyzed and calibration factors generated using NCDOT data. Separate calibration factors were developed for three geographical areas; these are in Appendix E.
Procedure for Validation and Comparison SPFs for *SafetyAnalyst* were developed using 2004-2008 crash data and relevant AADT volumes. Roadway segments with less than 500 veh/day were not included as NCDOT noted that they were not reliable.
Recommendations and Future Steps
Own SPFs The researchers note that "*the ultimate aim should be to develop North Carolina specific SPFs*" (pg.13). Data are not available to do so for all facilities as it is recognized that calibration requires smaller data samples and provides predictive models adapted to local North Carolina conditions. North Carolina specific SPFs developed to suit *SafetyAnalyst* (with AADT as the only independent variable and for use in the network screening procedure when specific data attributes are not considered in the modeling effort) should be further studied for potentially a different functional form better representing the local data. There is no goodness of fit statistics for negative binomial regression models universality accepted; the researchers used Freeman-Tukey R^2 and Pseudo R^2. The coefficients that are not statistically different from zero at 55% significance level are shown in *italics* (Appendix E)
Refinements for Future Calibration Factors **Site Selection :** The SAS code developed for this study was preserved and entered into the final report for future calibration efforts. Recommendations about data needs and potential advancement of calibration in future years are included in Section 6, pg.49. **Sample Size** NA

Reference
Brimley, B. K., S. Mitsuru, G. G. Schultz. *Calibration of the Highway Safety Manual Safety Performance Function and Development of New Models for Rural Two-Lane Two-Way Highways*. Texas Transportation Institute in College Station, Texas, and Brigham Young University in Provo, Utah, Proceedings to the 91st Annual Meeting of the Transportation Research Board, Washington, DC, January 2012
Synopsis This paper documents the calibration of the HSM SPF for rural two-lane, two-way road segments in Utah, as well as the development of jurisdiction-specific SPFs using negative binomial regression. The calibration was done to tangent sections only as the data about curves are not available to enable the development of their calibration to Utah. In addition, the researchers developed jurisdiction-specific SPFs with additional variables not used explicitly in the HSM Part C, thus recognizing that the HSM CMFs may not be applicable to the Utah's own SPFs.
Calibration Attributes
Site Selection There are 157 study segments in Utah with crash data for selected three years: 2005-07. Of these, only 14 segments are similar to the base conditions of the HSM SPFs developed for Part C.
Sample size Randomly selected segments were used and only tangent ones. The UDOT Roadview Explorer tool was used to select the segments, and Google Earth tools to gather geometric measurements.
Data collection and management (incl. preservation with on-going collection for future uses) Using the segments selected, variables were gathered such as the elements listed in the HSM, as well as additional ones such as percent of single-unit trucks, percent combo-unit trucks (in relation to AADT), and posted speed limit. Roadway segments with AADT > 10,000 veh/day were not included in the calibration or SPF development.
Data Analysis and Findings The calibration factor using three years of data and applicable CMFs is 1.16. Crash severity levels and crash type distribution were not developed for Utah; and the analysis was done on total crashes only. Four jurisdiction-specific SPFs were developed using Utah data; these SPFs have different functional forms (not linear as per HSM) and provided more accurate representation of the crash prediction by AADT and other variables. Using the Bayesian information criteria (BIC) as a model selection tool, the natural log models have shown to have the lowest BIC, thus deemed the preferred model form for predicting crashes on these roads in Utah..
Regional and State Calibration Factors NA

Procedure for Validation and Comparison Own SPFs using different functional forms were studied and comparisons made.
Recommendations and Future Steps
Own SPFs NA
Refinements for Future Calibration Factors **Site Selection :** Data on curves and other geometric and operational elements are needed to develop more accurate calibration factors. **Sample Size** NA **NOTE**: A report completed by the researchers for Utah DOT contains additional information about this study: "Report no. UT-10.12b, dated March 2011." In this report, the researchers noted the high proportion of animal collisions (about 30%) and the need to further investigate this factor in future SPF development and estimation of calibration factors.

Reference
Lou, Y., *Preliminary Analysis of the Safety Performance Function for Alabama (Task 7)* and *Calibration Efforts and SPF Development in Alabama,* Internal Report and Presentation at the Lead State Initiative for Implementing the HSM Peer Exchange Meeting in Baltimore, Maryland, August 2012.
Synopsis The researcher developed calibration factors for the HSM Part C's SPFs as well jurisdiction-specific SPFs for the three facility types. It was concluded that jurisdiction-specific SPFs produce better crash estimates than calibrated HSM models.
Calibration Attributes
Site Selection CARE system was used to extract data for the study.
Sample size All applicable data were used for the analysis; no details are found on the sample sizes.
Data collection and management (incl. preservation with on-going collection for future uses) Sites selected were divided to generate homogeneous segments as per HSM guidance. Missing data are noted for driveway type and density, curve, and grade.
Data Analysis and Findings It is concluded that the HSM procedure to develop calibration factors based on predicted with unadjusted SPF and observed crashes performed just as well, and it is simpler, than developing a NB regression model with the unadjusted SPF and an additional variable for calibration factor. It is also concluded that the best functional form for the data in Alabama, for all three facility types, is of the exponent form with natural log of AADT, speed limit, lane width, segment length, and a dummy variable for the year (a proxy variable to account for other unobserved factors that may vary from year to year).
Regional and State Calibration Factors NA
Procedure for Validation and Comparison Two subsets are sampled from the set of homogeneous segments for each facility type using stratified sampling. One subset is used to develop calibration factor and a jurisdiction-specific SPF, and the other is used as a validation set. The model validations used five performance measures, namely, mean absolute deviance (MAD), mean prediction bias (MPB), mean prediction squared error (MPSE), log-likelihood value (LL), and Akaike's information criteria (AIC). They all supported the conclusion for jurisdiction-specific SPF of the given form, as described above.
Recommendations and Future Steps
Own SPFs It is discussed that probabilistic performance measure need information about its variance, and this

information is currently omitted in the HSM.
Refinements for Future Calibration Factors **Site Selection :** NA **Sample Size** NA

Reference
Sacci, E., B. Persaud and M. Bassani. *Assessing International Transferability of the Highway Safety Manual Crash Prediction Algorithm and its Components*. Department of Hydraulics, Transportation and Civil Infrastructures, Torino, Italy and Ryeson University Department of Civil Engineering, Toronto Canada, Proceedings to the 91st Annual Meeting of the Transportation Research Board, Washington, DC, January 2012
Synopsis The purpose of the study is to investigate the calibration of the HSM crash predictive models using data for two-lane, two-way rural roads in Italy, and to demonstrate the validity and compatibility (the transferability) of the CMFs and base models of the HSM. In addition, a comparison is made between the calibration values using Ontario, Canada's data and the Turin, Italy's data. In this study, fatal and injury crashes were analyzed. The researchers note: "*The variability in the calibration factors and even within jurisdictions suggests that an evaluation not only of the C_x, but also of the validity of the SPFs as well as CMFs should be conducted when the HSM models are considered for application in another jurisdiction, particularly outside the US. This is because a C_x value that is substantially different from 1.0 may be capturing the crash prediction differences from variability in crash reporting thresholds and road environments as well as lack of suitability of the baseline SPFs and CMFs*" (pg.2). The goodness of prediction measures selected to be used in the study are: mean absolute deviation (MAD), the value of the recalibrated dispersion parameter, and the cumulative residual (CURE) plot.
Calibration Attributes
Site Selection Dataset was extracted from the Province of Turin with mountainous and hilly/plain areas. Motor vehicle crash records for 472 km of road were available including interprovincial freeways and two-lane rural highways (2005-2008). The definition of two-lane, two-way rural roads in the HSM is equivalent to type C minor collectors that attract traffic over medium distances and type F local roads that primarily provide access to adjacent land and to the collector network. Fatal and Injury crashes were included in this study.
Sample size AADTs and minimum length of 160 m (0.10 mile) guided the homogeneous segments' assignment as well as the other triggers for new segments such as lane and shoulder widths, the beginning and end of a horizontal curve, intersections, and the point of a crest or sag vertical curve. A total sample of 242 homogenous sections with a combined length of 115.35 km (71.67 miles) of road was selected. The researchers excluded more mountainous areas to better match the original radii of the base conditions used for the HSM models. They also omitted segments with an AADT of more than 20,000 veh/day to match the HSM baseline SPF.
Data collection and management (incl. preservation with on-going collection for future uses) Table 1 in the paper summarizes the database used and the assumptions made to the elements (CMFs) missing data. There is no mention of data preservation or routine data collection for future assignments.

Data Analysis and Findings It is concluded that the predictive results for higher AADTs are not satisfactory, and that the overall data analysis seem to indicate (as per other studies, such as Fitzpatrick et al (2006) and Martinelli et al (2009)) that the HSM models tend to overestimate crash frequency for segments with few collisions and underestimate it for segments with higher number of collisions.	
Regional and State Calibration Factors	NA
Procedure for Validation and Comparison Goodness of fit evaluation was carried out. MAD $= \sum_{i=1}^{n} \left\| \frac{\hat{Y}i-Y}{n} \right\|$ When MAD is close to 0, the recalibrated model predicts the observed data well; however MAD could be very close to zero and the model could still be systematically under and over predict. The CURE method addresses this issue by testing how well a model fits the observed data over the entire range of each independent variables. The cumulative residuals (difference between observed and predicted crash values) are plotted and the values on each plot are viewed in relation to their variation around the zero line and within the two standard deviation limits (95% confidence limit). The other goodness of fit measure is the dispersion parameter. The larger its value, the more the crash data vary as compared to a poison distribution with the same mean. Table 6, pg. 9, summarizes the values for these three measures of goodness of fit. It is concluded that the HSM models calibrated to Italian rural 2U segments have low reliability, and the CURE plot of cumulative residual for AADT volumes leads to a non-significant bias although for higher AADTs the residuals stray close to the lower 2 standard deviation boundary. The CURE plots for degrees of curvature, driveway density/km, and grade (%) show very poor fit.	
Recommendations and Future Steps	
Own SPFs The transferability study findings indicate the need to develop jurisdiction-specific SPFs and CMFs for the jurisdictions outside the US (and Canada, possibly). The functional form of the models needs to be revisited for better application to other datasets.	
Refinements for Future Calibration Factors **Site Selection :** Additional study is recommended. **Sample Size** It is noted that the HSM recommendation for calibration sample sizes is "*somewhat arbitrary and if nothing else, this study and others mentioned, do provide the basis for fine-tuning the HSM recommendations in future editions, in particular, for fatal plus injury collisions used in this study for which smaller samples may suffice, given that these data are more reliable than those based on all crashes*. (pg. 5)" **Other issues** Constant values of C_x are not recommended and additional studies required for model transferability.	

Reference
Dixon, K, C. Monsere, F. Xie, and K. Gladhill *Calibrating The Future Highway Safety Manual Predictive Methods for Oregon State Highways.* Final Report SPR 684, OTREC-RR-12-02, Oregon State University and Portland State University, Oregon, 2012
Synopsis This report summarizes the calibration of the HSM predictive models for the state of Oregon. All segment and intersection types found in the HSM were calibrated and deemed acceptable for use in the state of Oregon, except for the urban four-lane divided facilities. The researchers explained the problem as due to the small sample size and the difference between the higher design of the related data set used for the HSM SPFs and the segments in the Oregon calibration set. Oregon threshold crash reporting value of $1,500 is different to that used by the jurisdictional HSM predictive models' data. In addition, the self-reporting procedures also lead to differences in the data in Oregon. The study demonstrated the calibration factors resulted in greater accuracy of the crash estimates when using the local proportions of crash types and crash severity levels. Table 7.1 on pg. 55 presents the calibration factors based on the locally-derived crash proportions (shown in Appendix B of their report).
Calibration Attributes
Site Selection For each facility type, as per HSM, the historical crash data were grouped for 2004-2006. Random sampling techniques and procedures were applied for each road type, focused on state-maintained roads. For example, R2U segments were subdivided into 2-mile segments and given a number – random selection of numbers led to 75 segments to be used in the calibration analysis. These 75 segments presented on average 131 crashes / year thus the criterion recommended in the HSM was met, and no need for more R2U segments. MRU segments had much shorter segments due to the sections within rural towns and their intersections, thus only segments of 0.5 miles or longer were included in the procedure to avoid bias of too short segments.
Sample size For facilities with less than 30 sites on total, all sites were included in the sample for that road or intersection type. For facilities with few crashes/year, the sample size was increased to 100 and 200 sites / facility type (e.g., R3ST and R4ST). For urban segments, due to many intersections along a corridor, segments were quite short and very few crashes were recorded for each short segment – the sample sizes ranged between 86-491 (the latter for 2-lane undivided urban and suburban). At times, intersections with approaches maintained by local agencies were included to increase the sample size, after confirming that they were similar to the State's intersections.
Data collection and management (incl. preservation with on-going collection for future uses) Intersection crashes included those crashes positioned in the physical limits and within 250ft from the intersection, as well those noted as intersection-related in the approaches of the intersection. As much as possible, data were collected from the Oregon roadway system minimizing the use of default

values suggested by the HSM. Table 4.1 (pg. 16) summarizes the required data elements. Section 4 of the report describes the data collection methods used with examples. The data tables are described in the report (e.g., Table 3.2). Some excerpts of the data collections methods:

1. GIS based method was used to identify the Urban and Suburban arterial segment.
2. Intersections were identified by their milepost in the DOT database; video logs were used to determine the traffic control device at intersections prior to entering them into the random selection process.
3. Urban intersections with missing recent AADT from the minor road were not included; digital video log used to confirm two-way approaches (HSM does not include one-way streets).

The method developed by Mohamad et al (1998) for Indiana was used to estimate missing AADT volumes; they are based on urban and rural areas, proximity to freeways, county size etc.

Data Analysis and Findings

Data preparation post collection and coding:

Roadway segments were divided into homogeneous segments, as per HSM procedure. For rural segments, a minimum length of 0.1 miles was obtained by combining similar segments of smaller sizes as they are shown in the ODOT database. This approach led at times, to heterogeneous segments in some aspects and when dramatically different, weighted CMFs were used (example shown in Table 5.4 and Table 5.5, pg. 34 and pg. 35 respectively). For urban segments, the presence of intersections (and lane widths, number of lanes, median type, posted speed limit, or speed category) created very small segments – the average homogeneous segment is 0.07 miles.

Assigning crashes to intersections or specific segments is a critical step of the process and needs to be done carefully. In pg. 27, the authors explain the procedure followed in this study. Of particular note, driveway-related crashes were assigned to its segment; rear-end crashes at higher speed rural locations were considered intersection related and allocated as such.

A multiple linear regression technique was used for the estimation of minor roads' AADTs. Section 5.3 describes the method and procedures followed for roadway segments; while Section 5.4 describes the simple ratio approach for the calculation of the intersection minor road AADTs using the major road AADTs for the known years of data.

Calibration Factors

The calibration factors were calculated for each year of data for each facility type. The researchers concluded that the calibration factors were similar by using either one of two options: 1) summing the three annual calibration factors and dividing the sum result by three; or 2) summing three years of observed and three years of predicted crash values and calculating a single calibration factor value (pg. 36). The calibration factors for urban 4-lane divided facilities are not recommended for use as they are unreliable due to the small sample of these facilities in Oregon.

Locally-derived values for crash and severity types for select CMF and crash type estimates There are 24 tables or factors, found in the HSM Part C that can be calibrated to local conditions based on proportions (Table 5.6, pg. 38). Thus, if the default HSM CMFs are included in the calculation of the predicted (unadjusted) crashes, it may introduce a bias to the jurisdiction-specific crash prediction estimates. states. Thus, locally derived values were developed and their impact assessed in terms of differences in calibration factors. The locally derived proportions were developed using the complete state crash database with the exception of some values, such as "*proportion of total crashes for unlit roadway segments that occur at nigh*t." The presence of illumination is not found in the state crash database and the calibration database (a subset) was used based on the special data collection effort made for this attribute. Tables 5-7 to 5-13 show all the local proportions and the HSM default values. Significant differences between Oregon-derived values that showed a much larger proportion of fatal and injury level crashes than the HSM default values. The different threshold reporting values between Oregon and the other states used for the HSM may have contributed to this difference. Due to this disparity, the authors decided to develop jurisdiction-specific calibration factors for fatal and injury severity level as well as for total crashes.
Regional and State Calibration Factors The research team considered the 9 climate regions in the state; these regions were divided on the basis of the measurable snowfall and days with temperature below freezing; they also signify the primary geographic and weather differences in the state. However, with the exception of one zone, none of the other zones had sufficient sample sizes of annual crashes as per HSM requirements, even after grouping some zones with similar weather conditions and adding years of datat (up to 5 years of data). The conclusion was that the data needs did not justify the collection efforts and when using local EB estimations, the observed crashes / site would take into consideration the regional differences.
Procedure for Validation
NA
Recommendations and Future Steps
Own SPFs NA
Refinements for Future Calibration Factors **Site Selection :** It is recommended that representation of the network be secured by 1. Not separating high crash locations for sampling, though it would lead to meeting the requirement by HSM, but would not be representative of the network 2. Considering rural diversity in the State and ensure that there is a secondary selection step for proper representation of all such areas There is a need to enhance the HSM sample size and minimum crash thresholds for each facility (pg. 13). For example, 100 crashes / year for 50 rural multilane signalized intersections represent about two crashes per

year, on average. Some R3ST intersections do not typically experience this number while urban signalized intersections would experience a much higher number / year. It is clear that the thresholds in the HSM are arbitrary and merit additional study to determine facility type's site specific thresholds and appropriate sample size estimates.

Data Collection

It is recommended that ODOT introduce, to their database, the road elements required for calibration as these elements will be needed for a number of safety analyses in future, such as the recalibration of SPFs and safety performance of design elements' decisions at the project level. The preservation of the data collected is of value for future similar efforts. Of particular importance is the future and routine collection of AADT volumes for minor roads, pedestrian volumes at intersections, signal phasing information in urban areas, presence of lighting, and presence of centerline rumble strips. Furthermore, it is recommended, as a lower priority, that driveway density and type, presence and type of parking, roadside hazard rating, sideslope, roadside fixed object density, and average offset to fixed object be collected. Some studies should be carried out to estimate pedestrian volumes if their field collection is not included in the state routine data collection.

Calibration Factors and Local Proportions of Crashes (vs.24 HSM default values)

It was determined the need to develop calibration factors for fatal and injury severity level as well as for total crashes when it became evident that there is a significant different proportion of severe crashes in Oregon vs. the proportion shown in the HSM. The authors recommend that, in future, the calibration factors for total crashes can be done without the local proportions of crashes, if data are not available, but for specific distributions of crash types, such as single-vehicle crashes by severity level, there is a critical need to use locally-derived proportions, and to develop calibration factors for fatal and injury (even for 2-lane rural roads when HSM refers to total crashes only for this road facility type).

The authors recommend developing calibration factors for each severity level and not only for total crashes, as per recommendation in the HSM. If the HSM procedure is followed, meaning developing and applying the total calibration factor for all severity models, the result will be an underestimation of the fatal and injury crashes (in Oregon). The authors warn about the need to study the sample size needs when there is an interest to develop calibration factors for fatal and injury severity level crashes. It is anticipated that the HSM recommendation for sample size may not be adequate for all cases. There is also a need to modify the HSM procedures to "balance: the predicted total crashes = predicted fatal and injury crashes + predicted PDO crashes. This rebalancing is required prior to applying the CMFs and calibration factor. To apply severity calibration factors, the HSM procedures will need to be modified (pg. 49).

Functional Form of SPFs

It is recommended that, in future, jurisdiction-specific SPFs be studied to confirm whether they reflect a

similar form to the HSM SPFs' functional forms or not.
NOTE: another publication based on the same study can be found below. No additional information was extracted from this source. Xie, F, K. Gladhill, K. K Dixon, and C. M. Monsere Calibration of Highway Safety Manual Predictive Models for Oregon State Highways. *In Transportation Research Record: Journal of the Transportation Research Board,* No. 2241, Transportation Research Board of the National Academies, D.C., 2011, pp. 19-28.

8. Frequently-Asked Questions (FAQ)

This section consists of frequently-asked-questions (FAQ) and answers related to calibration factors. These FAQs were generated by HSM implementation lead state DOT participants in a peer exchange workshop under NCHRP Project #17-50. Answers were developed for this Guide.

- How large should a site sample size be for calibration?
  - In this Guide, Section 6.2 presents a procedure to determine the sample size in accordance with the standard deviation desired for the estimate of the calibration factor. In this procedure, the sample size is based on the annual observed crash frequency and the unadjusted predicted crash frequency for a sample of sites randomly selected to represent a given facility type.
- When should an agency develop jurisdiction-specific SPFs?
  - A recently publication, "Safety Performance Function Decision Guide: SPF Calibration vs SPF Development", provides a comprehensive document to assist in the decision process.
- Should separate calibration factors be developed for different crash severity levels?
  - Yes, whenever feasible, calibration factors should be developed for all SPFs available
- Should separate calibration factors be developed for different AADT ranges?
  - Studies have found that greater accuracy in predictive crash frequencies was achieved when calibration was done for groupings of AADT volumes. In this Guide, Section 6 and Appendix D provide a simple procedure using Excel Pivot Tables to assess the differences between different AADT groupings. It is recommended to consider developing a calibration AADT-based function during the calibration process.
- Should calibration factors be developed for portions of a highway network?
  - Studies have indicated that there are significant differences in calibration factors due to many variables such as climate, terrain, segment length, roadside design, etc. It is recommended that the agency consider key variables and if data are available, assess the need for separate calibration factors, or preferably a calibration function, as discussed in this Guide, Appendix D.
- Is it important to replace the HSM default crash severity and collision type distribution tables by jurisdiction-specific data?
  - Yes, HSM tables should be replaced by jurisdiction-specific data, whenever possible. Observed crashes on all sites for a given facility type within the jurisdiction network should be included in the distribution tables.

- Should a jurisdiction replace the HSM default crash severity and collision type distribution tables using regional or state data when developing regional calibration factors using jurisdiction-specific data?
  - Yes, if there are significant differences in the calibration factors between regions of a network and the whole network combined, it is likely that there are differences among the road characteristics, climate and subsequently resulting on different crash severity and collision types distributions in the different regions.
- How often should calibration factors be updated?
  - Calibration factors should be developed for the year / years as close to the application. In other words, if a project planning or design is carried out in 2014, it would be best to use calibration factor/s developed using data as recent as 2012 or 2013. If a calibration function is developed using AADT as the independent value, it would be useful when assessing the expected crash frequency based on a future AADT volume.
- Can data assembled for the development of calibration factors be used for a recalibration effort?
  - Definitely. It is very important to preserve the data collected for future calibration efforts. Traffic and geometric elements remain the same unless a project was carried out, such as addition of turn lanes, signalization of a 2-way STOP intersection, etc. The current crash and exposure (traffic volumes) data will be entered to the database linking to the unchanged roadway elements.
- Can data assembled for the development of calibration factors be used for development of jurisdiction-specific SFPs?
  - Yes, the same data elements are needed for SPF development.
- How should an agency prioritize data collection efforts?
  - This Guide presents prioritization criteria that would assist an agency identify their priorities in relation to the road improvement and expansion program, and availability and interoperability of traffic, geometric and crash data.

The User Liaison and Technology Facilitation Subcommittee of the TRB ANB25 Committee has compiled FAQs and these are posted on the website www.highwaysafetymanual.org. Excerpts from that compilation that are related to the development of calibration factors are below:

- How is IHSDM related to HSM Part C?
  - The IHSDM Crash Prediction Module (CPM) is a faithful software implementation of the predictive methods documented in Part C of the HSM, which includes capabilities to evaluate rural two-lane, two-way roads, rural multilane highways, urban/ suburban arterials, and (using draft HSM Part C materials) freeways. IHSDM includes a CPM Calibration Utility to assist agencies in implementing the calibration procedures described in the Appendix to HSM Part C.
- My agency wants to calibrate HSM Part C Predictive Models. How can IHSDM assist this effort?
  - A Calibration Utility is available in the IHSDM Administration Tool to assist agencies in implementing the calibration procedures described in the Appendix to HSM Part C. The Crash Prediction panel of the Administration Tool contains three sections:
    - Calibration Data Sets
    - Crash Distribution Data Sets
    - Model Data Sets

    The Calibration Data Sets interface provides a mechanism for users to enter, edit and organize the site data to be used to calculate the calibration factors for the various crash prediction models available in the IHSDM Crash Prediction Module (and, thus, in HSM Part C). In addition to containing the user-entered site data, each Calibration Data Set is also linked to a Crash Distribution.

    Within the Calibration Data Set interface, the user can choose to either "Calibrate Using Site Data" or "Manually Specify a Calibration Factor" for each of 26 crash prediction models (covering rural two-lane highways, rural multilane highways, urban/suburban arterials, and freeways).

    When running a Crash Prediction Module (CPM) evaluation, the user indicates which Calibration Data Set to use in that particular evaluation. The CPM then applies the appropriate calibration factors from the user-selected Calibration Data Set.

IHSDM Tutorial Lesson 11 (CPM Calibration) provides step-by-step instructions and hands-on exercises related to the calibration process.

- Can calibration factors from SafetyAnalyst be used in HSM calculations?
  - Calibration factors from SafetyAnalyst cannot be used in applying the HSM Part C procedures, and calibration factors from HSM Part C procedures cannot be used in applying SafetyAnalyst, because calibration is performed differently in SafetyAnalyst and HSM Part C. In SafetyAnalyst, the calibration procedure addresses the calibration of SPFs by themselves. In the HSM Part C procedures, the entire predictive method, including both SPFs and crash modification factors (CMFs), is calibrated.

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Appendix A – Overview of the Interactive Highway Safety Design Model (IHSDM) and *SafetyAnalyst*

Interactive Highway Safety Design Model (IHSDM at http://www.ihsdm.org)

The Interactive Highway Safety Design Model (IHSDM at http://www.ihsdm.org) is a tool developed, using HSM Part C predictive models, to assist in the process of planning and design decisions during a typical road project. IHSDM is a product of FHWA's Safety Research and Development Program. It entails a suite of software tools that support project-level geometric design decisions by providing quantitative information on the expected safety and operational performance. There are six modules in IHSDM; they are Crash Prediction module, Design Consistency module; Policy Review module; Intersection Review module, Traffic Analysis module, and Driver/Vehicle module. The crash prediction module is relevant to this Guide.

IHSDM includes a Crash Prediction Module (CPM) Calibration Utility to assist agencies in implementing the calibration procedure described in the Appendix A of HSM Part C. The calibration procedure provides a mechanism for users to enter, edit and organize the project site data to be used to calculate calibration factors for the relevant SPF. It is noted that the IHSDM Administration Tool allows agencies to enter their own SPFs, provided they have same functional form to those SPFs found in HSM Part C. IHSDM also enables users to modify the HSM default crash severity and crash type distribution values. An IHSDM Tutorial provides step-by-step instructions and hands-on exercises related to the CPM evaluation process and calibration utility (www.ihsdm.org/). The calibration utility was developed and released in 2011 to help the agencies in implementing Appendix A to HSM Part C. An interface is presented to the user to enter site data to be used to calculate the calibration factors for the various crash predictive models. The user has the option to calibrate using site data entered into IHSDM or manually specify a calibration factor developed outside the tool. When the CPM is used, the user can specify which one of the calibration factors is to be used in the prediction assignment.

The calibration utility has a panel that includes three sets: 1) calibration data sets; 2) crash distribution data sets; and 3) model data sets. The calibration data sets interface provides a way for users to enter, edit and organize the site data to be used to calculate the calibration factors. The interface allows the user to enter the required and desirable crash, traffic and site data. The desirable is not optional and it is needed either with local values or using the default values found in the HSM, and equally in the IHSDM. These are provided via a dropdown list for the user to select. Each calibration data set is linked to a crash distribution data set and a model data set. The user interface crash type distribution and severity level proportions can be updated and the relevant CMFs recalculated accordingly prior to the calibration factor estimation procedure. Lesson 11 of the IHSDM is dedicated to the calibration utility.

SafetyAnalyst software (http://www.aashtoware.org/Safety/

While this Guide and the FHWA's IHSDM tool focus on Part C of the HSM (2010), another tool namely, *SafetyAnalyst* software (http://www.aashtoware.org/Safety/) incorporates methodologies set forth in Part B of the HSM (2010). This software supports the Road Safety Management Process through the identification of safety improvement needs and the decision-making process for developing a system-wide program of safety improvement projects. *SafetyAnalyst* addresses site-specific safety improvements. The road safety management process can be described in six main steps (and respective chapters in the HSM (2010)), as follows:

Step 1: Identification of sites with potential for safety improvement (Chapter 4 – EB applications only)
Step 2: Diagnosis of the nature of safety problems at specific sites (Chapter 5)
Step 3: Selection of countermeasures at specific sites (Chapter 6)
Step 4: Economic appraisal for sites and countermeasures under consideration (Chapter 7)
Step 5: Priority rankings of improvement projects (Chapter 8)
Step 6: Safety effectiveness evaluation of implemented countermeasures (Chapter 9)

SafetyAnalyst comprises four modules that implement the six main steps, as follows:

Module 1 - Network screening
Module 2 - Diagnosis and countermeasure selection
Module 3 - Economic appraisal and priority-ranking
Module 4 - Countermeasure evaluation

SafetyAnalyst is packaged with default safety performance functions, countermeasures, site diagnosis, and crash distribution data used by the analytical algorithms. Furthermore, *SafetyAnalyst* provides an Administration Tool that enables users to modify the default data or to provide their own values. *SafetyAnalyst* also provides a Data Management Tool to import an agency's highway inventory, traffic count, and crash data and to convert those data into a format usable by the Analytical Tool for conducting safety analyses.

The SPFs developed for use in *SafetyAnalyst* are valid only for application to the states and time periods for which they were developed. To enable users to adjust the SPFs to their conditions, *SafetyAnalyst* includes a calibration procedure that allows SPFs developed for one particular state and one particular time period to be adjusted to other states and time periods. The method used in *SafetyAnalyst* develops calibration factors annually and adjust the SPF expected crash estimates accordingly. The SPFs in *SafetyAnalyst* are based on a) AADT and segment length (L) for roadway segments; or b) entering AADT $_{major}$ and AADT $_{minor}$ for intersections. They have the following format:

$$N_{spf\ seg} = L \times \exp(B_O) \times AADT^{B1}$$

$$N_{spf\ int} = \exp(B_O) \times AADTmaj^{B1} \times AADT\min^{B2}$$

The SPFs currently available in the *SafetyAnalyst* are:

Roadway Segments

1. Rural two-lane highway segments
2. Rural multilane undivided highway segments
3. Rural multilane divided highway segments
4. Rural freeway segments—4 lanes
5. Rural freeway segments—6+ lanes
6. Rural freeway segments within an interchange area—4 lanes
7. Rural freeway segments within an interchange area—6+ lanes
8. Urban two-lane arterial segments
9. Urban multilane undivided arterial segments
10. Urban multilane divided arterial segments
11. Urban one-way arterial segments
12. Urban freeway segments—4 lanes
13. Urban freeway segments—6 lanes
14. Urban freeway segments—8+ lanes

15. Urban freeway segments within an interchange area—4 lanes
16. Urban freeway segments within an interchange area—6 lanes
17. Urban freeway segments within an interchange area—8+ lanes

Intersections

18. Rural three-leg intersections with minor-road STOP control
19. Rural three-leg intersections with signal control
20. Rural four-leg intersections with minor-road STOP control
21. Rural four-leg intersections with all-way STOP control
22. Rural four-leg intersections with signal control
23. Urban three-leg intersections with minor-road STOP control
24. Urban three-leg intersections with signal control
25. Urban four-leg intersections with minor-road STOP control
26. Urban four-leg intersections with all-way STOP control
27. Urban four-leg intersections with signal control

Ramps

28. Rural diamond off-ramps
29. Rural diamond on-ramps
30. Rural parclo loop off-ramps
31. Rural parclo loop on-ramps
32. Rural free-flow loop off-ramps
33. Rural free-flow loop on-ramps
34. Rural direct or semidirect connection ramps
35. Urban diamond off-ramps
36. Urban diamond on-ramps
37. Urban parclo loop off-ramps
38. Urban parclo loop on-ramps
39. Urban free-flow loop off-ramps
40. Urban free-flow loop on-ramps
41. Urban direct or semidirect connection ramps

In *SafetyAnalyst*, the SPFs are not supplemented with CMFs, as per Part C, to adjust for condition other than base conditions. The application of the SPFs for the screening of a highway / road network uses more "generic groupings of facilities." For example, SPFs for rural two-lane highways include lanes and shoulders of different width, a variety of vertical grades and horizontal curvature, etc. Thus, the data assembling effort toward SPF development for the purpose of network screening is potentially simpler than for project-specific (HSM Part C) as it requires a less differentiated set of data elements for any given facility type. On the other hand, the completeness of the network database for screening sites with highest potential for safety improvements is key; in other words, sites not found in the network screening database will not be included in the process and their expected crash frequency and severity (and potential for improvement) will remain unknown.

Appendix B - How Many Crashes Are Needed to Estimate the Calibration Factor to a Given Accuracy. – A Working Paper by Dr. Ezra Hauer

The main purpose of this working paper is to determine how accurate is the estimate of C obtained by the method suggested in the HSM and how it depends on the number of observed crashes or the number of (representative) sites.

B-1 Analysis

I will denote by N_u the unadjusted $N_{predicted}$ which is based on the SPF & the CMFs which are in the HSM for which C=1. The purpose of the calibration factor C is to adapt the N_u to a different location and time[1]. I will denote the adjusted $N_{predicted}$ by N_a. Thus,

$$N_a = N_u \times C \qquad \textbf{Eq. B1}$$

The N_u in equation B1 is an estimate of the number of crashes expected on an average unit of specified type, with a certain length and traffic volume, with traits implied by the CMFs used, and using the SPF now in the HSM. When N_u is multiplied by C it makes the N_a which is the number of crashes expected on an average unit of a certain type, length, traffic volume and traits implied by the applicable CMF pertaining to the time and place where it is to be used.

The HSM suggests estimating C by

$$\hat{C} = \frac{\sum_{\text{all j}} \text{observed crashes at site j}}{\sum_{\text{all j}} N_{u\ at\ site\ j}} \qquad \textbf{Eq. B2}$$

The summation is overall sites in the sample which represents the population of interest. The question is how many crashes must be in the numerator of equation B2 or, equivalently, how many sites must be in the sample, for the estimate of C to be sufficiently accurate.

Let then V{.} denote the variance of the random variable for which the dot is the placeholder. Only the numerator of equation B2 is a random variable and source of variance; the denominator is a constant. It follows that

$$V\{\hat{C}\} = \frac{V\{\sum_{\text{all j}} \text{observed crashes at site j}\}}{\left(\sum_{\text{all j}} N_{u\ at\ site\ j}\right)^2} \qquad \textbf{Eq. B3}$$

[1]'Time' is not mentioned as a factor on the top of page A-2 (HSM Part C, Appendix A).

Thus, we must inquire about the $V\{\sum_{\text{all j}} \text{observed crashes at site j}\}$. One can justly assume that the observed crashes at one site are statistically independent of the crashes observed at every other site. Therefore, for the numerator of equation B3

$$V\left\{\sum_{\text{all j}} \text{observed crashes at site j}\right\} = \sum_{\text{all j}} V\{\text{observed crashes at site j}\} \qquad \textbf{Eq. B4}$$

The variances in the right-hand-side of equation B4 are computed around the N_a, the number of crashes expected on an <u>average</u> unit. With the usual Poisson-Gamma assumptions leading to the negative binomial distribution, and denoting the overdispersion parameter for site j by k_j, as in the HSM,

$$\sum_{\text{all j}} V\{\text{observed crashes at site j}\} = \sum_{\text{all j}} (N_{a\ at\ site\ j} + k_j N^2_{a\ at\ site\ j}) \qquad \textbf{Eq. B5}$$

Use of equation B5 in equation B3 yields three results usable in computation.

(a) If the analyst has information about segment length, AADT, and crash counts then $V\{\hat{C}\}$ can be estimated by equation B6.

$$V\{\hat{C}\} = \frac{\sum_{\text{all j}}(N_{a\ at\ site\ j} + k_j N^2_{a\ at\ site\ j})}{(\sum_{all\ j} N_{u\ at\ site\ j})^2} \qquad \textbf{Eq. B6}$$

In estimation, the N_a at site j is replaced by the number of observed crashes at site j and for N_u one uses the HSM estimates.

(b) If information about AADT is missing or is incomplete then equation B7 which uses only data about observed crashes can be used. In this case one has to guess what C might be and check the sensitivity of the result to the guess.

$$V\{\hat{C}\} = \frac{\sum_{\text{all j}}(N_{a\ at\ site\ j} + k_j N^2_{a\ at\ site\ j})}{(\sum_{all\ j} N_{a\ at\ site\ j}/C)^2} = \frac{C^2}{\sum_{all\ j} N_{a\ at\ site\ j}} + \frac{C^2 \sum_{all\ j} k_j N^2_{a\ at\ site\ j}}{(\sum_{all\ j} N_{a\ at\ site\ j})^2} \qquad \textbf{Eq. B7}$$

In estimation, the N_a at site j is replaced by the number of observed crashes at site j.

(c) If information about segment length and AADT is available but crash counts are missing one could rewrite equation B6 as a function of N_u instead of N_a as follows:

$$V\{\hat{C}\} = \frac{\sum_{\text{all j}}(C N_{u\ at\ site\ j} + k_j C^2 N^2_{u\ at\ site\ j})}{(\sum_{all\ j} N_{u\ at\ site\ j})^2} = \frac{C}{\sum_{all\ j} N_{u\ at\ site\ j}} + \frac{C^2 \sum_{all\ j} k_j N^2_{u\ at\ site\ j}}{(\sum_{all\ j} N_{u\ at\ site\ j})^2} \qquad \textbf{Eq. B8}$$

To estimate $V\{\hat{C}\}$ by equation B8, the N_u at site j is replaced by the HSM estimate, one has to guess what C might be, and check the sensitivity of the result to the guess. This would give a smoother estimate of $V\{\hat{C}\}$ than equation B6 or B7 but requires the computation of N_u based on the HSM instead of using observed crashes available from data.

B-2 A Lower limit

The first term of the sum in equations B6, B7, and B8 is what the variance would be if there was no overdispersion. This can serve as a lower limit. Thus, for the standard deviation of the estimate of C to be σ the number of crashes must exceed C/σ^2. This number is shown in Table B.1.

Table B.1 - Lower limit of the required number of crashes

σ	C										
	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
0.01	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000
0.02	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750
0.03	556	667	778	889	1000	1111	1222	1333	1444	1556	1667
0.04	313	375	438	500	563	625	688	750	813	875	938
0.05	200	240	280	320	360	400	440	480	520	560	600
0.06	139	167	194	222	250	278	306	333	361	389	417
0.07	102	122	143	163	184	204	224	245	265	286	306
0.08	78	94	109	125	141	156	172	188	203	219	234
0.09	62	74	86	99	111	123	136	148	160	173	185
0.1	50	60	70	80	90	100	110	120	130	140	150
0.11	41	50	58	66	74	83	91	99	107	116	124
0.12	35	42	49	56	63	69	76	83	90	97	104
0.13	30	36	41	47	53	59	65	71	77	83	89
0.14	26	31	36	41	46	51	56	61	66	71	77
0.15	22	27	31	36	40	44	49	53	58	62	67
0.16	20	23	27	31	35	39	43	47	51	55	59
0.17	17	21	24	28	31	35	38	42	45	48	52
0.18	15	19	22	25	28	31	34	37	40	43	46
0.19	14	17	19	22	25	28	30	33	36	39	42
0.20	13	15	18	20	23	25	28	30	33	35	38

<u>NOTE: an Excel File accompanies this Guide; it contains the working tables for the next sub-section B-3, B-4, B-5 and B-7</u>

B-3 Illustration of use for equation B6

Suppose that a jurisdiction has data about segment length, AADT and number of crashes on each segment and that these are arranged in random order (RND computer generated numbers as shown in column B). Using such data and equation B6 one can compute the standard error of the estimate of C as a function of the number of segments used for calibration. To illustrate, I generated data for fifty (j=1, 2, ...50) segments of rural two lane roads as shown columns C to F of Figure B.1. The total length of these segments is 0.94 miles on which 34 crashes occurred. The N_u in column G is based on HSM equation 10-6 (page 10-15). The sum of Nu is 25.84 crashes. Therefore,

$\hat{C} = \frac{34}{25.84} = 1.3.$

Segment length is needed to compute the value of the overdispersion parameter for segments in column I (HSM equation 10-7,page 10-16).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	For Illustration Purposes - Equation 6 - Made up data for fifty segments of two-lane, two-way rural roads												
2	Data						Computations					Results	
3						Observed		Cumul Nu		Crashes+	Cum k_j*Crashes^2	Estimate of	Estimate of
4	Site j	RND	Site J ID	L	AADT	Crashes	N_u	0	k_j	k_j*Crashes^2	0	V{C}	σ{C}
5	1	0.966173801	R2 023	0.08	3715	0	0.07	0.07	3.14	0.00	0.00	0.000	
6	2	0.956428133	R2 054	1.14	220	1	0.07	0.14	0.21	1.21	1.21	60.259	7.76
7	3	0.95286274	R2 043	0.94	2133	3	0.54	0.68	0.25	5.25	6.46	14.007	3.74
8	4	0.949927362	R2 065	0.66	2569	0	0.45	1.13	0.36	0.00	6.46	5.054	2.25
9	5	0.90983927	R2 032	1.13	1451	0	0.44	1.57	0.21	0.00	6.46	2.626	1.62
50	46	0.030682154	R2 291	0.13	3980	0	0.13	23.33	1.87	0.00	51.23	0.094	0.31
51	47	0.02445264	R2 440	1.43	1177	0	0.45	23.78	0.16	0.00	51.23	0.091	0.30
52	48	0.01810682	R2 204	0.86	2542	0	0.58	24.36	0.27	0.00	51.23	0.086	0.29
53	49	0.015413493	R2 185	1.93	2219	1	1.14	25.51	0.12	1.12	52.35	0.080	0.28
54	50	0.010747759	R2 452	0.40	3186	0	0.34	25.84	0.60	0.00	52.35	0.078	0.28
55	Sum			0.93641	2284.17	34	25.84						

Figure B.1- Illustration of Equation B6

The results are in columns L and M. With these data for fifty sites one may expect the standard error of $\hat{C}$ to be about ± 0.28.

B-4 Illustration of use for equation B7

Here only data about segment length (column D in Figure B.2) and observed crashes (column E) is used.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	For Illustration Purposes - Equation 7 - Made up data for fifty segments of two-lane, two-way rural roads												
2			Data				Computations					Results	
3			C=	1.3	Observed		Sum Crashes	k_j*Crashes^2	Sum	First term	Second Term	Estimate of	Estimate of
4	Site j	RND	Site J ID	L	Crashes	k_j	0		0			V{C}	σ{C}
5	1	0.966174	R2 023	0.08	0	3.14	0	0.00	0.00				
6	2	0.956428	R2 054	1.14	1	0.21	1	0.21	0.21	1.69	0.35	2.04	1.43
7	3	0.952863	R2 043	0.94	3	0.25	4	2.25	2.46	0.42	0.26	0.68	0.83
8	4	0.949927	R2 065	0.66	0	0.36	4	0.00	2.46	0.42	0.26	0.68	0.83
9	5	0.909839	R2 032	1.13	0	0.21	4	0.00	2.46	0.42	0.26	0.68	0.83
50	46	0.030682	R2 291	0.13	0	1.87	33	0.00	18.23	0.05	0.03	0.08	0.28
51	47	0.024453	R2 440	1.43	0	0.16	33	0.00	18.23	0.05	0.03	0.08	0.28
52	48	0.018107	R2 204	0.86	0	0.27	33	0.00	18.23	0.05	0.03	0.08	0.28
53	49	0.015413	R2 185	1.93	1	0.12	34	0.12	18.35	0.05	0.03	0.08	0.28
54	50	0.010748	R2 452	0.40	0	0.60	34	0.00	18.35	0.05	0.03	0.08	0.28
55	Sum			46.82	34								

Figure B.2 - Illustration of Equation B7

The two terms making up the estimate of $V\{\hat{C}\}$ in equation B7 are in columns J and K. These values depend on what C might be. In this computation I used C=1.3 (cell D3). How various values of C affect the result can be ascertained by placing different values in cell D3. Going down column L, it can be seen that the larger the number of sites used the smaller is $V\{\hat{C}\}$. The standard error of the estimate of C obtained using these 50 sites is ± 0.28 as shown in the last row. If the desired standard error of the estimate of C is to be less than 0.28 then more than 50 segments (and more than 34 crashes) need to go into the calibration. If the user has data about crashes and length for a representative set of sites the spreadsheet can be used to see how far down the list one must go to attain the desired accuracy assuming a certain C.

Comment: When calibration is done for intersections and similar units for which the value of the overdispersion parameter does not depend on length, only the count of crashes is needed here.

B-5 Illustration of use for equation B8.

Suppose that a jurisdiction has data about the AADT and segment length of many representative sites and these are arranged in random order. Using such data and equation 8 one can compute the standard error of the estimate of C as a function of the number of segments used for calibration. To illustrate, I generated data for fifty (j=1, 2, ...50) segments of rural two lane roads, as shown in columns D and E of Figure B. 3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	For Illustration Purposes - Equation 8 - Made up data for fifty segments of two-lane, two-way rural roads													
2			Data				Computations						Results	
3			C=	1.3				Cum N_u	$k_j*N_u^2$	Cum $kj*N_u^2$	First term	Second Term	Estimate of	Estimate of
4	Site j	RND	Site J ID	L	AADT	N_u	k_j	0		0			V{C}	σ{C}
5	1	0.966174	R2 023	0.08	3715	0.07	3.14	0.07	0.02	0.02	17.45	5.31	22.762	4.77
6	2	0.956428	R2 054	1.14	220	0.07	0.21	0.14	0.00	0.02	9.19	1.55	10.738	3.28
7	3	0.952863	R2 043	0.94	2133	0.54	0.25	0.68	0.07	0.09	1.91	0.33	2.247	1.50
8	4	0.949927	R2 065	0.66	2569	0.45	0.36	1.13	0.07	0.16	1.15	0.22	1.367	1.17
9	5	0.909839	R2 032	1.13	1451	0.44	0.21	1.57	0.04	0.20	0.83	0.14	0.969	0.98
50	46	0.030682	R2 291	0.13	3980	0.13	1.87	23.33	0.03	3.88	0.06	0.01	0.068	0.26
51	47	0.024453	R2 440	1.43	1177	0.45	0.16	23.78	0.03	3.91	0.05	0.01	0.066	0.26
52	48	0.018107	R2 204	0.86	2542	0.58	0.27	24.36	0.09	4.01	0.05	0.01	0.065	0.25
53	49	0.015413	R2 185	1.93	2219	1.14	0.12	25.51	0.16	4.17	0.05	0.01	0.062	0.25
54	50	0.010748	R2 452	0.40	3186	0.34	0.60	25.84	0.07	4.24	0.05	0.01	0.0610	0.25
55	Sum			0.93641	2284.17	25.84								

Figure B. 3 - Illustration of Equation B8

The N_u in column F is based on HSM equation 10-6 (page 10-15). The k_j in column G is based on HSM equation 10-7 (page 10-16). Columns H to J contain various preparatory computations. The two terms making up the estimate of $V\{\hat{C}\}$ in equation B8 are in columns K and L. These values depend on what C might be. In this computation I used C=1.3 (cell D3). How various values of C affect the result can be ascertained by placing different values in cell D3. The standard error of the estimate of C obtained using these 50 sites is ±0.25 as shown in the last row. If the desired standard error of the estimate of C is to be less than 0.25 then more than 50 segments need to go into the calibration. If the user has data for a representative set of sites the spreadsheet can be used to see how far down the list one must go to attain the desired accuracy assuming a certain C.

B6- A possible approximation

Let $\bar{L}$ and $\overline{AADT}$ be the length and AADT of an average segment and let $\bar{N}_u$ and $\bar{k}$ be the average values computed using $\bar{L}$ and $\overline{AADT}$. With n such sites

$$V\{\hat{C}\} = \frac{C}{\sum_{all\ j} N_{u\ at\ site\ j}} + \frac{C^2 \sum_{all\ j} k_j\, N^2_{u\ at\ site\ j}}{\left(\sum_{all\ j} N_{u\ at\ site\ j}\right)^2} \cong \frac{C}{n\bar{N}_u} + \frac{C^2 n\bar{k}\bar{N}_u^2}{(n\bar{N}_u)^2} = \frac{C}{n\bar{N}_u} + \frac{C^2\bar{k}}{n} \quad \textbf{Eq. B9}$$

From this,

$$n \cong \frac{C}{\sigma^2 \bar{N}_u} + \frac{C^2\bar{k}}{\sigma^2} \quad \textbf{Eq. B10}$$

Numerical example:

In Figure B. 3, $\bar{L}$=0.936 miles and $\overline{AADT} = 2284$. With these $\bar{N}_u = 2284 \times 0.936 \times 365 \times 10^{-6} \times e^{-0.312} = 0.571$ and $\bar{k} = \frac{0.236}{0.936} = 0.252$. With C=1.3 to get $\sigma^2 = 0.061$ (the value in the last row of Figure B. 3) the required n≅1.3/(0.061×0.571)+ 1.3^2×0.252/0.061 =44. This is an approximation to the n=50 segments in Figure B. 3.

With the same conditions($\bar{L}$=0.936 miles and $\overline{AADT} = 2284$) to get σ=±0.05, n≅1.3/(0.0025×0.571)+1.3^2×0.252/0.0025 =910+170≅1080 segments. With C=1.3 and N_u=0.571 and 1080 segments, one expects about 1080×0.571=617 crashes. As per Table B.1, when C=1.3 and σ=0.05, one must have more than 520 crashes; 617>520. Thus, this is a reasonable approximation.

B-7 What variance to select for the sample size

The calibration sample size depends on what V{Ĉ} we want to get. But on this we have no guidance. The purpose here is to see what guidance can be provided relatively simply.

$$\mathrm{N_a = CN_u} \quad \textbf{Eq. B11}$$

Using statistical differentials:

$$\mathrm{V\{\hat{N}_a\} \cong C^2 V\{\hat{N}_u\} + N_u{}^2 V\{\hat{C}\}} \quad \textbf{Eq. B11}$$

Dividing by N_a^2,

$$\mathrm{\frac{V\{\hat{N}_a\}}{N_a{}^2} \cong \frac{C^2 V\{\hat{N}_u\}}{(CN_u)^2} + \frac{N_u{}^2 V\{\hat{C}\}}{(CN_u)^2} = \frac{V\{\hat{N}_u\}}{N_u{}^2} + \frac{V\{\hat{C}\}}{C^2}} \quad \textbf{Eq. B12}$$

Notation: Let X be a random variable and μ{X}, σ{X} its mean and standard deviation. The ratio σ{X}/μ{X} is called the coefficient of variation, cv{X}. Thus, e.g., if σ{X} is ±10% of μ{X} then cv{X}=0.1 and $(cv\{X\})^2$=0.01.

Equation B12 ($\frac{V\{\widehat{N}_a\}}{{N_a}^2} \cong \frac{V\{\widehat{N}_u\}}{{N_u}^2} + \frac{V\{\widehat{C}\}}{C^2}$) can be written as

$$\left(cv\{\widehat{N}_a\}\right)^2 = \left(cv\{\widehat{N}_u\}\right)^2 + \left(cv\{\widehat{C}\}\right)^2 \qquad \textbf{Eq. B13}$$

For the practical purposes in HSM we use $\widehat{N}_a$ and it is its accuracy that matters. The accuracy of $\widehat{N}_a$ is determined, in part, by the accuracy of the SPFs & CMFs that go into the calculation of the $\widehat{N}_u$. The $cv\{\widehat{N}_u\}$.is unknown. Recent work completed by Dr. Dominique Lord has studied how to estimate the variance of the SPFs and the contribution of the product of CMFs to this variance (Lord (2008; Lord et al (2010). The HSM (2010) Part C SPFs do not include their variances. For our purposes, equation B13 shows that the accuracy with which C is estimated contributes to the accuracy of the $\widehat{N}_a$ in the same way as does the accuracy of the SPFs & CMFs. This may provide a common-sense yardstick. It would make little sense to estimate C much more accurately than that of the estimate of N_u. Thus if, e.g., $cv\{\widehat{N}_u\} = 0.22$ then whether $cv\{\widehat{C}\} = 0.15$ (thus: $cv\{\widehat{N}_a\} = \sqrt{0.22^2 + 0.15^2} = 0.27$) or $cv\{\widehat{C}\} = 0.05$ ($thus$: $cv\{\widehat{N}_a\} = \sqrt{0.22^2 + 0.05^2} = 0.23$) really does not matter much. On the other hand if $cv\{\widehat{C}\} = 0.22$, the same as $cv\{\widehat{N}_u\}$, then $cv\{\widehat{N}_a\}$ would be increased by a factor of 1.4 It seems that aiming for a $cv\{\widehat{C}\}$ that is larger than $0.5 \times cv\{\widehat{N}_u\}$and less than $0.75 \times cv\{\widehat{N}_u\}$ is reasonable. Since we do not know what are the $cv\{\widehat{N}_u\}$ of the values now in the HSM, one may argue that a $cv\{\widehat{N}_u\} = 0.2$ is a reasonable goal for the future and therefore one should aim for a $cv\{\widehat{C}\}$ in the 0.10-0.15 range.

B-8 The effect of time

The observed number of crashes in the numerator of equation B4 changes over time while the N_u in the denominator remains unchanged. For this reason, the C of a given facility type and SPF must be assumed to change over time. Considering that the crash rate is steadily declining, it is sensible to assume that this holds for C as well. The implication for calibration is that C ought to be thought of a function of time. For our purposes time is best measured in years. Let y stand for year. We are interested in the time series:

$$\widehat{C}(y) = \frac{\sum_{\text{all j}} \text{observed crashes at site j in year y}}{\sum_{\text{all j}} N_{u\ at\ site\ j}}, y = 1,2, \ldots \qquad \textbf{Eq. B14}$$

The $V\{\hat{C}(y)\}$ can be estimated, e.g., by

$$\hat{V}\{\hat{C}(y)\} = \frac{\sum_{\text{all j}}\left(\text{Crashes}_{at\ site\ j\ in\ year\ y} + \text{k}_\text{j}\text{Crashes}^2_{at\ site\ j\ in\ year\ y}\right)}{\left(\sum_{all\ j} N_{u\ at\ site\ j}\right)^2} \qquad \textbf{Eq. B15}$$

Suppose that for the calibration effort, we have annual crash counts for, say, each of five years. Instead of using the sum of these in equation B2, it would make sense to estimate five C(1), C(2),…,C(5) and, using the corresponding $V\{\hat{C}(y)\}$), fit a function to this time series. This would enable the agency to use the appropriate C for each year or period, and to extrapolate the time series into the near past or future. It would also be the basis to which future calibration results can be added.

Appendix C - Traffic Volume (AADT) Ranges Applicable to HSM SPFs by Facility Type

The HSM (2010) SPFs were developed for a given range of AADT volumes. These are summarized in the Table C1. HSM (2010) notes that "*Application to sites with AADTs significantly outside this range may not provide reliable results*" (e.g., HSM page10-15 (2010)).

Table C1 – Traffic Volume (AADT) ranges applicable to HSM SPFs by facility type

Facilities and HSM Prediction Models	*SPFs*	*Traffic Volume (veh/day)*
Rural undivided two-lane, two-way - roadway segments (2U)	(A1)Predicted total (KABCO) crash frequency (HSM Eq. 10-6)	(A1) AADT from zero to 17,800 veh/day
Rural two-lane, two-way three-leg (3ST) <u>or</u> four-leg STOP (4ST) controlled on minor-road approach <u>or</u> four-leg signalized (4SG) intersections	Predicted total (KABCO) crash frequency for: (B1)3ST(HSM Eq. 10-8) (B2)4ST(HSM Eq. 10-9) (B3)4SG(HSM Eq.10-10)	(B1)For 3ST - AADTmaj from zero to 19,500 veh/day and and AADTmin from zero to 4,300 veh/day (B2) For 4ST - AADTmaj from zero to 14,700 veh/day and AADTmin from zero to 3,500 veh/day (B3)For 4 SG - AADTmaj from zero to 25,200 veh/day and AADTmin ranges from zero to 12,500 veh/day
Rural four-lane undivided – Roadway segment (4U)	(C1)Predicted total (KABCO) crash frequency (C2)Predicted fatal and Injury (KABC) crash frequency (C3)Predicted fatal and injury (KAB) crash frequency (HSM Eq. 11-7 and Table 11-3)	(C1), (C2) and (C3) AADT from zero to 33,200 veh/day

Facilities and HSM Prediction Models	*SPFs*	*Traffic Volume (veh/day)*
Rural four-lane divided – Roadway segment (4D)	(D1)Predicted total (KABCO) crash frequency (D2)Predicted fatal and Injury (KABC) crash frequency (D3)Predicted fatal and injury (KAB) crash frequency (HSM Eq. 11-9 and Table 11-5)	(D1), (D2) and (D3)– AADT from zero to 89,300 veh/day
Rural multilane highway three-leg (3ST) <u>or</u> four-leg STOP (4ST) controlled on minor-road approach <u>or</u> four-leg signalized (4SG) intersection	(E1)3ST(HSM Eq. 11-11 and HSM Table 11-7): (E1.1)Predicted total (KABCO) crash frequency (E1.2)Predicted fatal and Injury (KABC) crash frequency (E1.3)Predicted fatal and injury (KAB) crash frequency (E2)4ST(HSM Eq. 11-11 and HSM Table 11-7): (E2.1)Predicted total (KABCO) crash frequency (E2.2)Predicted fatal and Injury (KABC) crash frequency (E2.3)Predicted fatal and injury (KAB) crash frequency (E3)4SG(HSM Eq. 11-11 and HSM Table 11-8): (E3.1)Predicted total (KABCO) crash frequency (E3.2)Predicted fatal and Injury (KABC) crash frequency (E3.3)Predicted fatal and injury (KAB) crash frequency	(E1)For 3ST - AADTmaj from zero to 78,300 veh/day and and AADTmin from zero to 23,000 veh/day (E2) For 4ST - AADTmaj from zero to 78,300 veh/day and AADTmin from zero to 7,400 veh/day (E3)For 4SG - AADTmaj from zero to 43,000 veh/day and AADTmin ranges from zero to 18,500 veh/day

Facilities and HSM Prediction Models	*SPFs*	*Traffic Volume (veh/day)*
Urban and suburban arterial two-lane undivided (2U) or three-lane including a TWLTL (3T) or four-lane undivided (4U) or four-lane divided (4D) or five-lane including a TWLTL (5T) - Roadway Segments	For (F1) and (F2) and (F3) and (F4) and (F5) (HSM Eq.12-2 and Eq.12-3) and: a)Multiple-vehicle nondriveway collisions (HSM Eq. 12-10 and HSM Table 12-3) b)Single-vehicle crashes (HSM Eq. 12-13 and HSM Table 12-5) c)Multiple-vehicle driveway-related collisions (HSM Eq. 12-16 and HSM Table 12-7) d)Vehicle-pedestrian collisions (HSM Eq. 12-19 and HSM Table12-8) e)Vehicle-bicycle collisions (HSM Eq. 12-20 and HSM Table12-9) Each facility i from 1 to 5 have three predicted values: (Fi.1)Predicted total (KABCO) crash frequency (Fi.2)Predicted fatal and Injury (KABC) crash frequency (Fi.3)Predicted PDO (O) crash frequency	(F1)For 2U- AADT from zero to 32,600 veh/day (F2) For 3T – AADT from zero to 32,900 veh/day (F3)For 4U – AADT from zero to 40,100 veh/day (F4)For 4D – AADT from zero to 66,000 veh/day (F5)For 5T – AADT from zero to 53,800 veh/day

Facilities and HSM Prediction Models	*SPFs*	*Traffic Volume (veh/day)*
Urban and suburban arterial three-leg (3ST) or four-leg (4ST) STOP controlled on the minor-road approaches or three-leg (3SG) or four-leg (4SG) signalized intersections	For (G1) and (G2) and (G3) and (G4) and (G5) (HSM Eq.12-5 and Eq.12-6) and: a)Multiple-vehicle collisions at intersections (HSM Eq. 12-21 and HSM Table 12-10) b)Single-vehicle crashes at intersections (HSM Eq. 12-24 and HSM Table 12-12) c)Vehicle-pedestrian collisions at signalized intersections (HSM Eq. 12-28 and HSM Table12-14) d)Vehicle-pedestrian collisions at STOP-controlled intersections (HSM Eq. 12-30 and HSM Table12-16) e)Vehicle-bicycle collisions at intersections (HSM Eq. 12-31 and HSM Table12-17) Each facility i from 1 to 4 have three predicted values: (Fi.1)Predicted total (KABCO) crash frequency (Fi.2)Predicted fatal and Injury (KABC) crash frequency (Fi.3)Predicted PDO (O) crash frequency	(G1)For 3ST - AADTmaj from zero to 45,700veh/day and and AADTmin from zero to 9,300 veh/day (G2) For 4ST - AADTmaj from zero to 46,800 veh/day and AADTmin from zero to 5,900veh/day (G3)For 3SG - AADTmaj from zero to 58,100veh/day and AADTmin ranges from zero to 16,400 veh/day (G4)For 4SG - AADTmaj from zero to 67,700 veh/day and AADTmin ranges from zero to 33,400veh/day AND for 4SG pedestrian models: AADTmaj from zero to 80,200 veh/day and AADTmin ranges from zero to 49,100 veh/day or PEDvol = 0 to 34,200 ped/day crossing all four legs combined

Appendix D - When to Estimate Separate C's - A Working Paper by Dr. Ezra Hauer

The HSM suggest that *"For large jurisdictions, such as entire states, with a variety of topographical and climate conditions, it may be desirable … (to) develop separate calibration factors for each specific terrain type or geographical region."*[2] The underlying rationale is that the C's may differ from terrain to terrain, region to region or, more generally, from condition to condition. Thus, e.g., if there was a large difference between $C_{statewide}$ and $C_{mountainous}$ then applying the $C_{statewide}$ to a site located in the mountainous terrain would cause significant bias in the estimate of the number of crashes expected at that site. Inasmuch as having good estimates of the expected number of crashes is the kingpin of evidence-based road safety management, it is important that in each case when one computes the $N_{predicted}$ [3] for a site the C used in the computation is close enough to the C for the conditions of that site.

It stands to reason (and will also be shown by data) that C depends on many factors, not only 'Terrain Type' and 'Region'. However, there is a practical limit to the number of factor combinations for which separate C's can be estimated. Guidance on how many separate C's to estimate depends on two considerations:

1. How close is close enough. Do we need to insist that the difference between the C used to compute the $N_{predicted}$ be within $\pm$10% of the C for the conditions of the site or can we live with, say, $\pm$50%?
2. How different are the C's in different conditions. Thus, e.g., is the ratio $C_{mountainous}/C_{statewide}$ 1.5 or only 1.05?

The first consideration involves knowing how evidence-based decisions would be affected by the error (the bias) in C. The second consideration requires knowledge of fact and availability of the data. Within the limited resources available in this project an attempt will be made to provide useful, albeit limited, guidance.

[2] HSM Volume 2, page A-3.

[3] See equation C-1 on page C-4 of HSM Volume 2

D-1 How close is close enough?

Road safety management is about making various decisions. The decision may be about whether the safety of the site requires attention, whether some improvement is worthwhile, whether some design or standard change is justified, etc. When road safety management is evidence-based all such decisions depend on an estimate of the expected number of crashes per year. In the HSM notation decisions depend on $N_{expected}$. Also, using the HSM notation[4], $N_{expected}=w\times N_{predicted}+(1-w)\times N_{observed}$. When the number of observed crashes ($N_{observed}$) is not known, the w is 1; otherwise w is a number between 0 and 1[5].Thus, $N_{expected}$ is fully or partly determined by $N_{predicted}$. $N_{predicted}$, in turn, is the product of the predicted value from the SPF, the applicable CMFs and the calibration factor C (equation C-1 on page C-4 of HSM Volume 2). In this manner any inaccuracy in C is passed onto $N_{expected}$ and through it into decision making (Figure D.1).

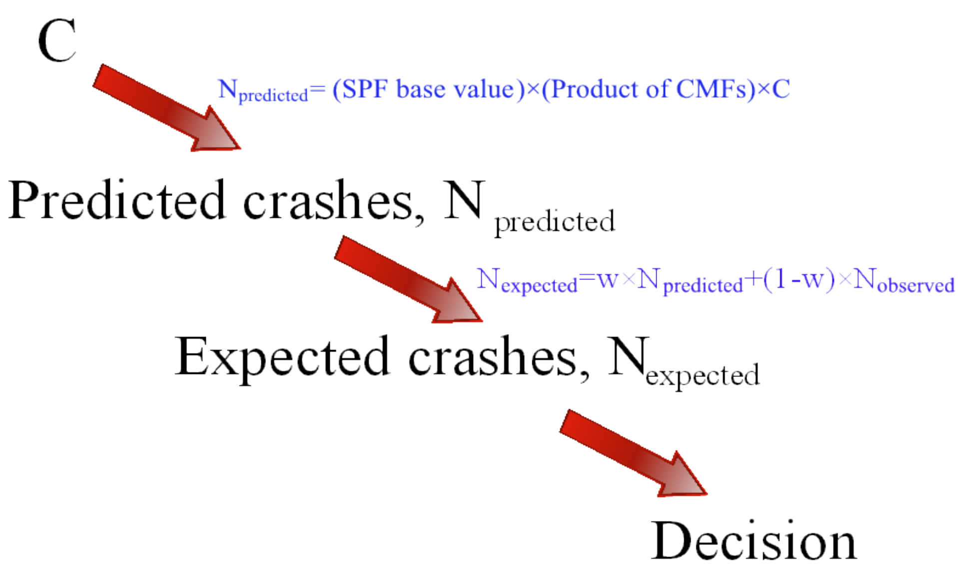


Figure D.1 - How C affects decisions

To illustrate, suppose that at a site the SPF predicts 12.3 crashes/year, the product of applicable CMFs is 1.27, the statewide estimate of C is 1.25 whereas the C for the conditions of this site is 1.37. Were the $N_{observed}$ not known the analyst would estimate $N_{expected}$= 12.3×1.27×1.25 =19.53 crashes/year while the correct value is 12.3×1.27×1.37=21.4 crashes/year. In this case, the

[4] Equation A-4 on page A-19, HSM Volume 2

[5] 1The weight w depends on the overdispersion parameter, years of data and on $N_{predicted}$.

difference of about 10% in the C's (1.37/1.25=1.096) is passed directly into the same 10% error in the estimate of $N_{expected}$. Were the $N_{observed}$ known to be, say, 16 crashes and if w=0.7 then, using the estimate of C=1.25, $N_{expected}$=0.7×19.53+0.3×16=18.47. Using the correct C=1.37, 0.7×21.4+0.3×16 =19.78 crashes/year. Now the error is 7% (19.78/18.47=1.07).

An inaccurate $N_{expected}$ may result in an inferior decision. Inferior decisions have costs. The cost may be that of investing in projects with insufficient benefits, not investing in projects when doing so is justified, choosing inferior designs or treatments, etc. In this sense the inaccuracy in C has real costs. A substantive research project would be needed to learn about how often inaccuracies of this kind would lead to inferior decisions and what might be the cost of such inaccuracies. This knowledge would provide the necessary guidance to agencies on defensible investment efforts for the estimation of separate Cs .

Two pathways are explored within the limited guidance provided in this working paper. The first is based on the argument that $N_{predicted}$ is the product of three factors: (Predicted base value from the SPF)×(Product of applicable CMFs)×C. Inasmuch as every one of these factors is inaccurate, it would make little sense to seek an accuracy in C which exceeds the accuracy of the two other factors.

The second pathway is based on the consequences of systematic bias. To illustrate, if $C_{statewide}$ was less than $C_{mountainous}$ then systematically applying $C_{statewide}$ to mountainous sites would make their $N_{expected}$ appear smaller than it is and thereby lead to a systematic underinvestment in mountainous sites.

D-1.1 The first pathway: Accuracy of C relative to other factors

Call the 'Predicted base value of SPF' by 'A' and the 'Product of applicable CMFs' by 'B'. With this notation

$$N_{predicted} = A \times B \times C \qquad \textbf{Eq. D1}$$

In what follows V{.} will denote the variance of the estimate for which the dot is the placeholder. Using statistical differentials:

$$V\{N_{predicted}\} \cong (B \times C)^2 V\{A\} + (A \times C)^2 V\{B\} + (A \times B)^2 V\{C\} \qquad \textbf{Eq. D2}$$

Dividing by $N_{predicted}^2$,

$$\frac{V\{N_{predicted}\}}{N_{predicted}{}^2} \cong \frac{V\{A\}}{A^2} + \frac{V\{B\}}{B^2} + \frac{V\{C\}}{C^2} \qquad \textbf{Eq. D3}$$

These expressions are squared 'coefficients of variation'. The coefficient of variation is the standard deviation of a random variable divided by its mean. Thus, e.g., if the standard deviation of a random variable is 10% of its mean then the coefficient of variation is 0.1.
Now equation D3 can be rewritten as:

$$\begin{aligned}\left(cv\{N_{predicted}\}\right)^2 &= (cv\{\text{Predicted base value from SPF}\})^2 + \\ &+ (cv\{\text{Product of applicable CMFs}\})^2 + (cv\{C\})^2\end{aligned} \qquad \textbf{Eq.D4}$$

To further explain the meaning of the coefficient of variation, suppose that for some site $N_{predicted}$ is 12.3 crashes/year. If the cv was 0.1, the standard deviation of $N_{predicted}$ would be $0.1\times12.3=\pm1.2$ crashes per year. The approximate rule of thumb is that the true value is within about two standard deviations of the estimate. With cv=0.1 it would be somewhere between $12.3\pm2\times1.2$, that is between 9.9 and 14.7. However, should the cv be 0.3 the range would be $12.3\pm2\times0.3\times12.3$ that is between 4.9 and 19.7.

I do not know how large are the cv's of the 'Predicted base value from SPF' and of the 'Product of applicable CMFs' on the right-hand-side of equation D4. Lord(2008)[6] shows how these values could be estimated and provides some numerical examples[7]. However, we were not able to find any publication providing these estimates for the SPFs and CMFs in the HSM Part C. The CMFs in the HSM Part D are mostly with standard errors of less than or equal to 0.1 with some companion CMFs with standard errors less than 0.3. We can assume that the CMFs extracted from Part D to Part C have standard errors of less than 0.1 to possibly 0.2. Exceptions to this assumption are those CMFs that are given in a functional form (e.g., safety effect of different lane width for two-

[6] D. Lord, (2008). Methodology for estimating the variance and confidence intervals for the estimate of the product of baseline models and AMFs. Accident Analysis and Prevention 40, 1013–1017.

[7] In one example based on data about signalized intersections in Toronto for an intersection with 35,500 vehicle/day on the major approach and 5000 vehicle/day on the minor approach mean number of crashes was estimated to be 1.30 crashes/year. After adjusting for the presence left and right turning lanes on the major approach (CMF = 0.90± 0.05 and CMF = 0.95± 0.10) the estimate of the mean changed to 1.112 crashes/year. Using Lord's methodology, the estimate of the standard deviation was ±1.084 and the cv 1.084/1.112=0.97.

lane, two-way roads) and CMFs developed by an expert panel, for which their standard errors were not calculated.

Equation D4shows that the accuracy with which C is estimated contributes to the accuracy of $N_{predicted}$ in the same way as does the accuracy of the 'Predicted base value' and the 'Product of CMFs'. It would therefore make little sense to estimate C much more accurately than what can be done for the other two factors. Thus, e.g., if cv{Predicted base value of SPF} = 0.1 and cv{Product of applicable CMFs}=0.2 then whether cv{C} = 0.15 or 0.05 really does not matter much. With cv{C}=0.15 $cv\{N_{predicted}\} = \sqrt{0.1^2 + 0.2^2 + 0.15^2} = 0.27$ whereas with cv{C}=0.05 the $cv\{N_{predicted}\} = \sqrt{0.1^2 + 0.2^2 + 0.05^2} = 0.23$. The conclusion is that the magnitude of $cv\{N_{predicted}\}$ is dominated by the largest of the three cv's. Based on this observation, the following conservative guideline is offered for consideration:

Conservative Guideline[8]. The coefficient of variation of C does not need to be less than, say, half the cv{Product of applicable CMFs}.

I do not know what is the typical cv{Product of CMFs}. Assuming that the average value of CMFs is close to 1, based on the logic of equations D3 and D4,

$$cv\{CMF_1 \times CMF_2 \times CMF_3 \times \dots\} \cong \sqrt{V\{CMF_1\} + V\{CMF_2\} + V\{CMF_3\} + \cdots} \qquad \textbf{Eq. D5}$$

Were the variances $V\{CMF_i\}$ of the CMFs listed in the HSM known, the cv for the combinations of CMFs could be computed.

D-1.2 The second pathway: Fairness and efficiency

As will be shown in Section D-2, the magnitude of C depends on various conditions. Thus, e.g. using calibration data collected in a certain State, the estimate of C for all rural multilane roads is 1.32. However, for those rural multilane road segments with ADT<10,000 and which are shorter than 1 mile the estimate of C is 1.65 whereas for rural multilane roads with 10,000<ADT<20,000 and segment length between 1 and 2 miles, the estimate is 1.03. Were the $C_{statewide}$ (=1.32) used everywhere, the lesser volume & shorter segments would appear safer than they really are.

[8] Embedded in this guideline is the assumption that the coefficient of variation of the Product of CMFs is larger than that of the Predicted base value from the SPF.

Conversely, the higher volume & longer segments would seem less safe than they are. The systematic distortions which would result from always using $C_{statewide}$ could be manifold. Thus, e.g., project money might go to the higher volume longer segments because they appear to be less safe than they really are; higher standards of reconstruction, maintenance and policing might be applied there; the results of corrective action when evaluated may seem to be more beneficial than it really is and so on. Similar concern about distortions and inefficiencies arise when a C is used that does not differentiate between kinds of terrain, between jurisdictional regions, between crash severities, etc.

In view of such concerns, how large a difference between C's can be tolerated? If differences between the C used and the C that should be used is set at 10% or more, very many C's will have to be estimated. On the other hand, if only differences of 50% or more are of concern, chances are that only few C's will need to be estimated.

How to settle on that value, somewhere between 10% and 50%, which is a reasonable compromise between keeping a lid on the cost of studies to estimate C's and the need to be fair in budgeting, efficient in decision making, and correct in the evaluation of benefits? As noted earlier, without the conduct of a substantive research project one cannot come to a defensible opinion. My guess is that the difference between the C which is used and the C which should be used should not be larger than 20%. Whether this is a reasonable choice depends, among other things, on how many C's would have to be estimated if 20% is the target. The answer to this depends on knowing how C varies from condition to condition. This is at this time largely unknown. A way to find out and some partial answers will be described in the next section.

D-2 How different are the C's and what are the conditions that matter

As per Section 6 and Appendix B, N_u stands for the $N_{predicted}$ when C=1; the u stands for '<u>u</u>nadjusted by C'. That is, N_u= (Crash frequency predicted by the SPF for base conditions) × (Product of applicable CMFs). The estimate of C is the ratio Observed crashes/N_u. To obtain an estimate of C one has to have information about both the number of observed crashes numerator and about N_u. The information needed to compute the N_u is acquired in the course of a calibration process, as shown in Section 6 of this Guide. Thus, to examine how the Cs differ from condition to condition one needs the data assembled for the development of SPF calibration factors. The results of one such calibration study conducted by the OHIO DOT will be used to illustrate how the variability in C can be examined.

D2.1 How C depends on Variables

The data used are in Figure D.2. It consists of 350 segments of rural multilane roads totalling 149.9 miles in length. Based on these data, one can examine only whether C depends on Crash Severity, Segment Length and ADT. If variables such as Terrain, Region, etc. were in the data, one could check whether C depends on these too.

	A	B	C	D	E	F	G	H	I
1–2	Rural Multilane Road Segments - Predicted and Observed Crashes by Severity								
3–5	Segment	Predicted average crash frequency with C=1 (crashes/year)			Observed crashes, $N_{observed}$ (crashes in 3 years)				
6–8		N_u (TOTAL)	N_u (FI)	N_u (PDO)	$N_{observed}$ (TOTAL)	$N_{observed}$ (FI)	$N_{observed}$ (PDO)	Length in miles	ADT
9	1	0.372	0.191	0.182	0	0	0	0.2	12185
10	2	0.790	0.405	0.385	3	1	2	0.3	12120
11	3	0.194	0.110	0.084	0	0	0	0.2	4135
12	4	0.394	0.210	0.184	0	0	0	0.3	7808
354	346	0.094	0.047	0.047	0	0	0	0.0	14830
355	347	0.013	0.009	0.004	0	0	0	0.1	640
356	348	0.665	0.359	0.306	7	1	6	0.5	6906
357	349	0.286	0.146	0.140	0	0	0	0.1	12825
358	350	1.859	0.991	0.868	5	1	4	1.2	7935

Figure D.2 – Excerpt from data assembled for the development of calibration factors

Based on the sums of the columns in Figure D.2 (similarly to Table 6-10), Table D.1 has been produced. It is evident that there is a major difference between $C_{fatal\ \&\ injury}$ and C_{PDO}. In this jurisdiction, on rural multilane roads, more than twice as many PDOs and less than half the injury crashes are reported than what the HSM predicts[9]. One may conclude that, in this jurisdiction, separate Cs are needed by crash severity.

[9] For two lane roads in the same jurisdiction the estimate are $C_{Total=1.16}$, $C_{Fatal\ \&\ Injury}$=0.88, and C_{PDO}=1.29.

Table D.1 – C estimate values by crash severity

	Total	*Fatal & Injury*	*PDO*
Observed/year	413.7	67.3	346.3
Predicted	314.0	160.6	153.4
Estimate of C	1.32	0.42	2.26

To check whether the C depends on ADT, one has to stratify to data into cells. This is easy to do using the Excel Pivot Table. Because not all are familiar with this useful tool, the steps of the analysis will be described in detail.

In Excel 2007, click on the 'Pivot Table' icon in the 'Insert' tab as shown in Figure D.3.

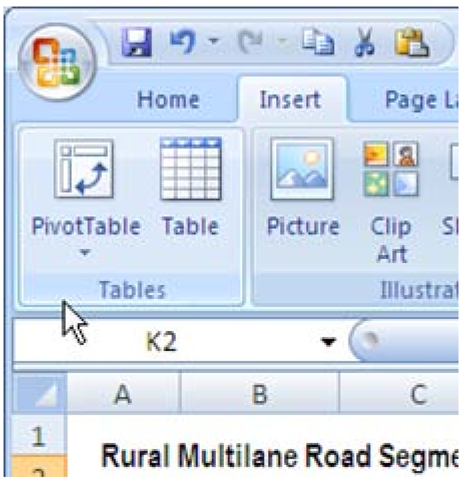


Figure D.3 - Excel 2007 Pivot Table icon

In the window that opens (Figure D.4), select the range of the data. Make sure to include in the selection to row of heading (row 6 in Figure D.2) and select the location for the 'Pivot Table Report'.

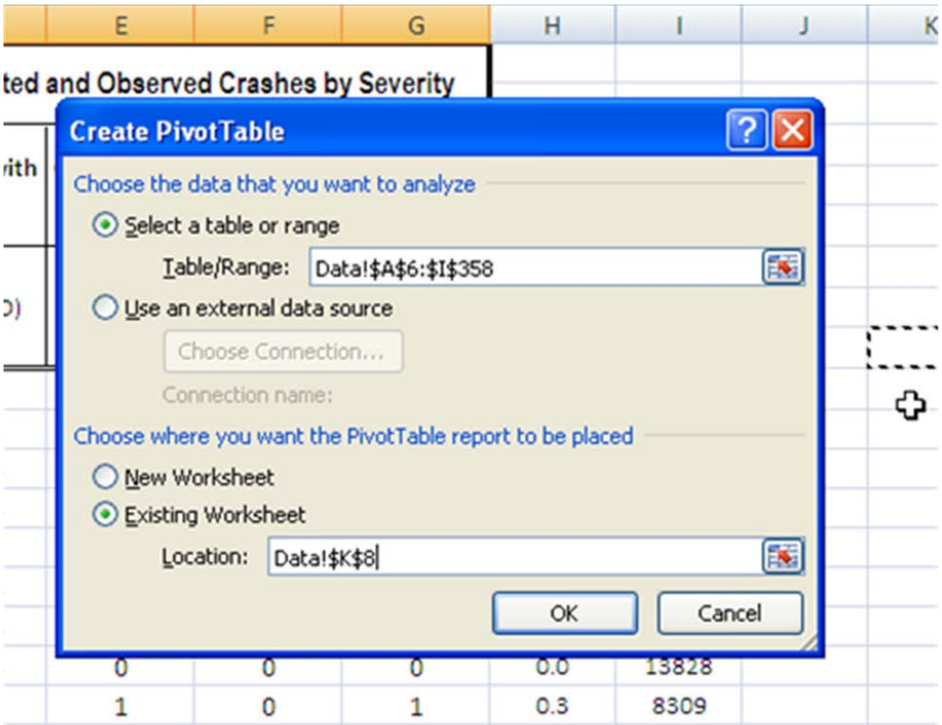


Figure D.4 – Selection of data/ table range for the pivot table

After clicking 'OK', one should see a screen similar to Figure D.5.

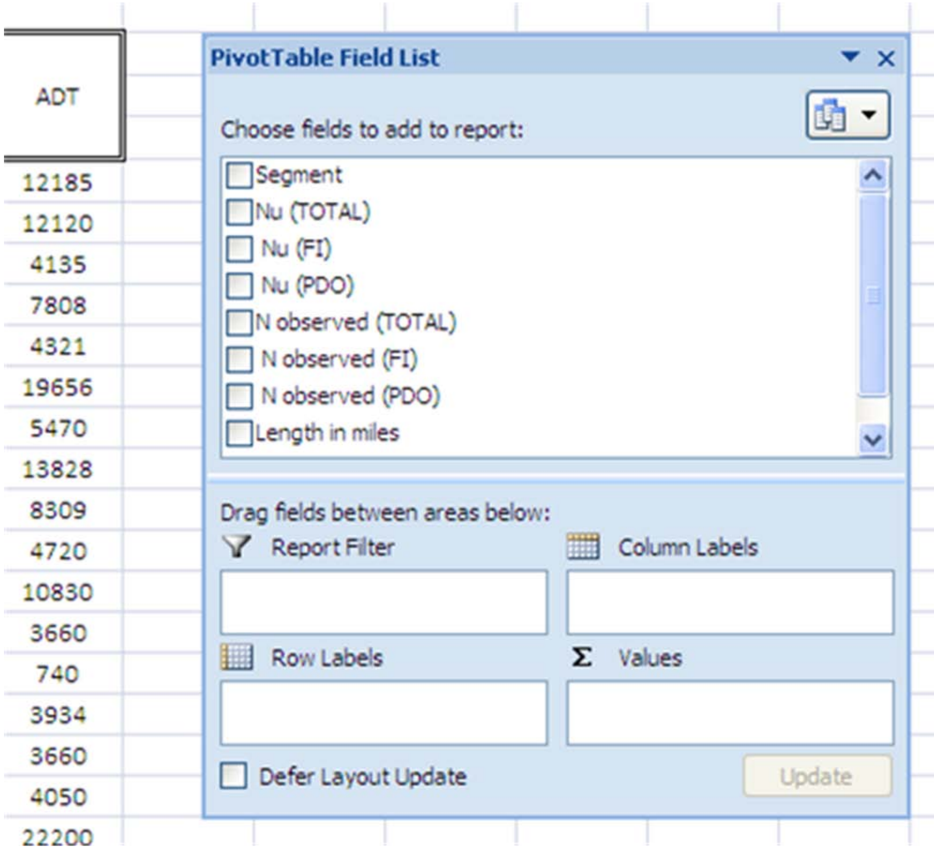


Figure D.5 – Pivot table field list based on data range selected

ADT Groupings

Click on the down arrow of the slider to reveal the ADT field on the Pivot Table Field List and then drag the ADT field into the Row Labels window, as shown in Figure D.6. The Row Labels column appears on the right. The rows are the ADT values. However, we want to create ADT groupings or bins. To do so, right click on any entry in the Row Labels column and choose Group from the menu that appears as shown in Figure D.7.

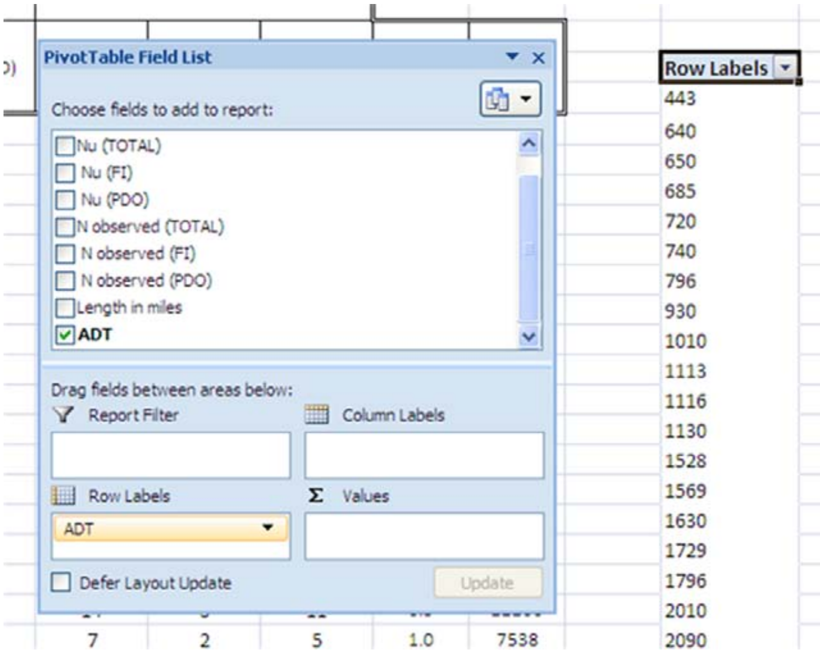


Figure D.6 – Adding ADT to Row Labels

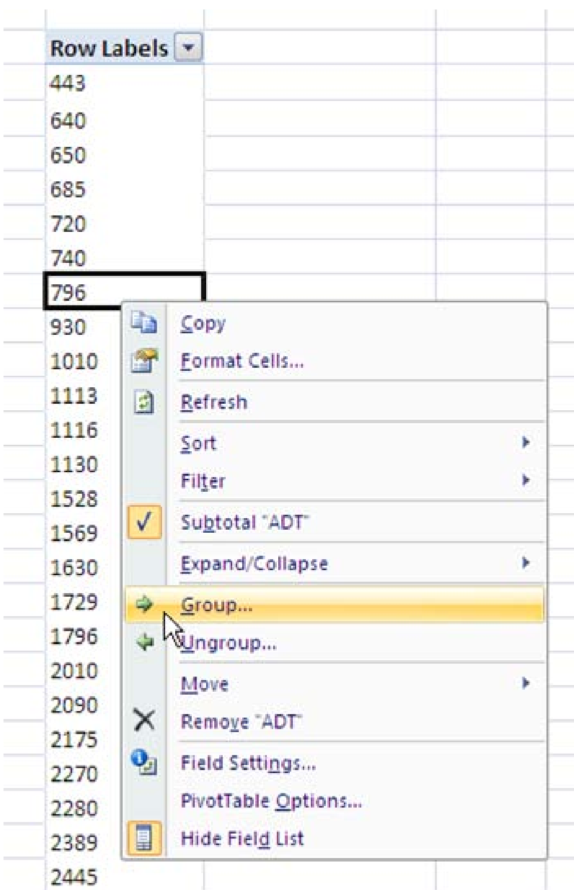


Figure D.7– Creation of ADT groupings or bins

After 'Group' is clicked, the window in Figure D.8 will show.

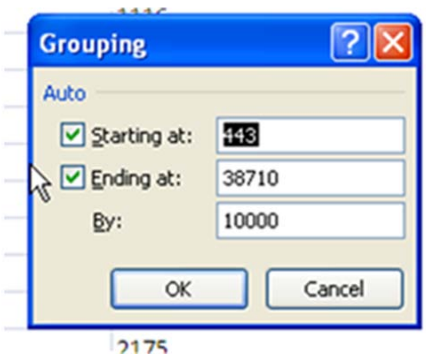


Figure D.8 – Defining the ADT groupings

For reasons that will become obvious shortly, change the starting value to 0, the ending value to 20,000, and the increment to 5,000. After OK, the row labels column is as shown in Figure D.9.

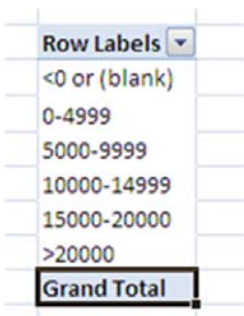


Figure D.9 – ADT grouping

The next step is to drag the N_u(Total) field into the window under the 'Σ Values' heading. In doing so, a list of the count of segments in each ADT group is created, as shown in Figure D.10.

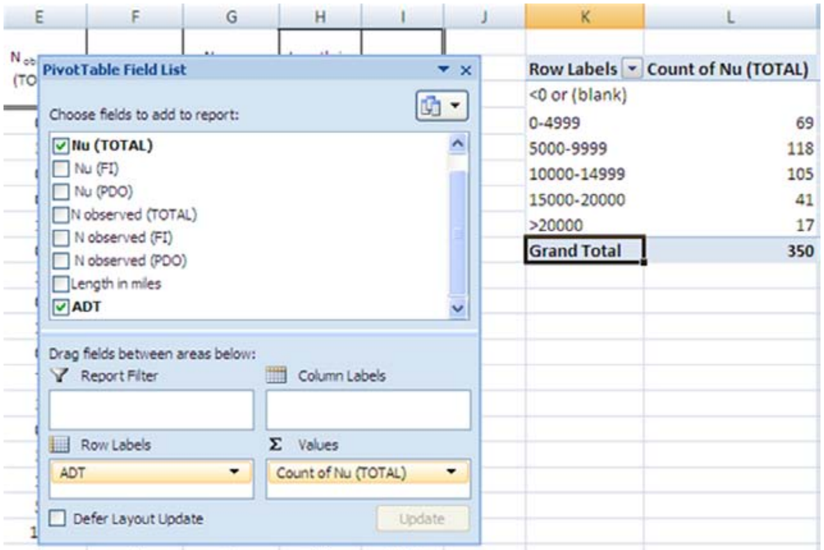


Figure D.10 – Count of N_u (Total) for each ADT grouping

There are 69 segments with 0<ADT<4999, 118 with 5000<ADT<9999 etc. There are too few segments with ADT>20,000 to produce sufficiently accurate C estimates which is why I chose this as the upper limit.

To produce a different summary, click on the 'Count of Nu(Total)' to produce the menu in Figure D.11. Choosing the 'Value of Field Setting' gives various summary options, as shown in Figure D.12.

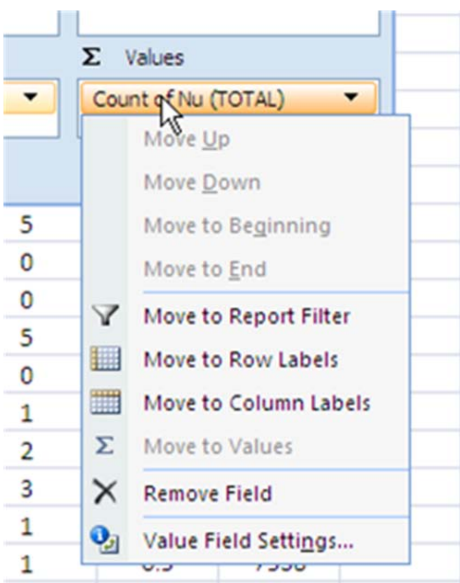


Figure D.11 – Getting access to the menu for different data summaries

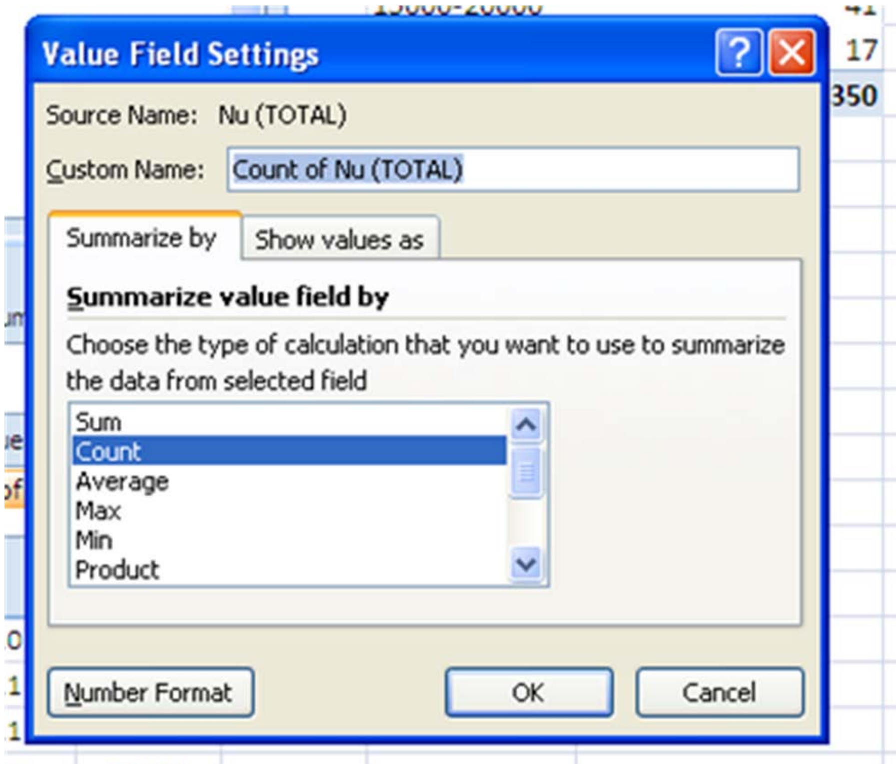


Figure D.12 – Value field options menu

Choosing 'Sum' yields the sum of N_u in each ADT grouping, as shown in Figure D.13

Row Labels	Sum of Nu (TOTAL)
<0 or (blank)	
0-4999	14.47085009
5000-9999	67.93898804
10000-14999	104.7809792
15000-20000	72.12075458
>20000	54.72739939
Grand Total	**314.0389713**

Figure D.13 – Sum of Nu (total) for ADT groupings

To compute a C for each ADT grouping, we also need the number of observed crashes in each grouping. To get these, drag the '$N_{observed}$ (Total)' field into the window under the 'Σ Values' heading (as shown in Figure D.10). Click on it to get the menu with the 'Value of Field Setting' and choose 'Sum' (as shown in Figure D.12). The result is the pivot table in Figure D.14 .

Recall that $N_{observed}$ corresponds to three years of data. Using the numbers in Figure D.14, the estimates of C for each ADT grouping can be found in Table D.2.

	Values	
Row Labels	Sum of Nu (TOTAL)	Sum of N observed (TOTAL)
<0 or (blank)		
0-4999	14.47085009	82
5000-9999	67.93898804	330
10000-14999	104.7809792	369
15000-20000	72.12075458	237
>20000	54.72739939	223
Grand Total	**314.0389713**	**1241**

Figure D.14 - Sum of 3-year $N_{observed}$ (Total) for ADT groupings

Table D.2 - C as a function of ADT

ADT Bins	N_u	$N_{observed}$	C
0-4999	14.47	82	1.89
5000-9999	67.94	330	1.62
10000-14999	104.78	369	1.17
15000-20000	72.12	237	1.1
Grand Total	314.04	1241	1.32

The results in Table D.2 indicate that for the Ohio data, C depends on ADT. Applying the overall C=1.32 to segments with 0<ADT<4999 (where C is 1.89) would make them appear safer than they really are and may lead to the aforementioned inefficiencies.). The agency, having established that C is a function of ADT, may choose to fit a function C = f(ADT) to the data. A function would provide a calibration factor for each segment on the basis of its ADT.

Segment Length Groupings

An entirely analogous analysis can be done for the segment length variable. It begins by placing 'Length in miles' into the 'Row Labels' window, grouping the segment length into groupings of 0.5 miles wide between 0 and 2 miles, placing N_u(Total) and $N_{observed}$(Total) into the ΣValues window, and choosing 'Sum' from the "Value Field Settings'. The result is in Figure D.15.

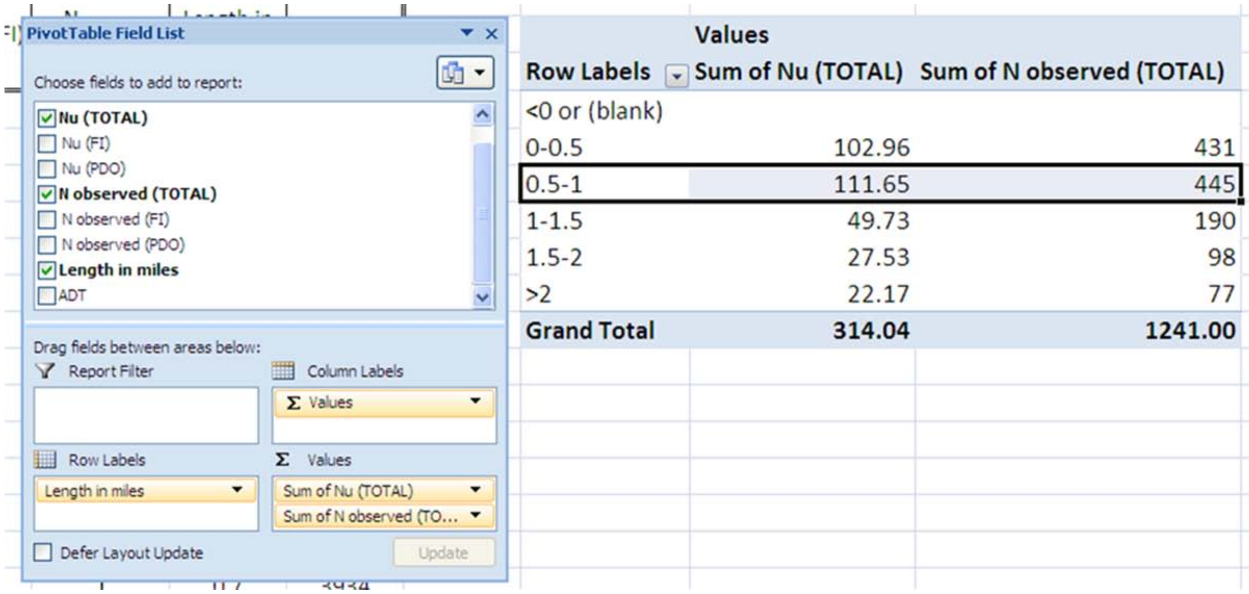


Figure D.15 - Sum of 3-year $N_{observed}$ (Total) for Segment Length groupings

The estimates of C for each segment length grouping can be found in Table D.3.

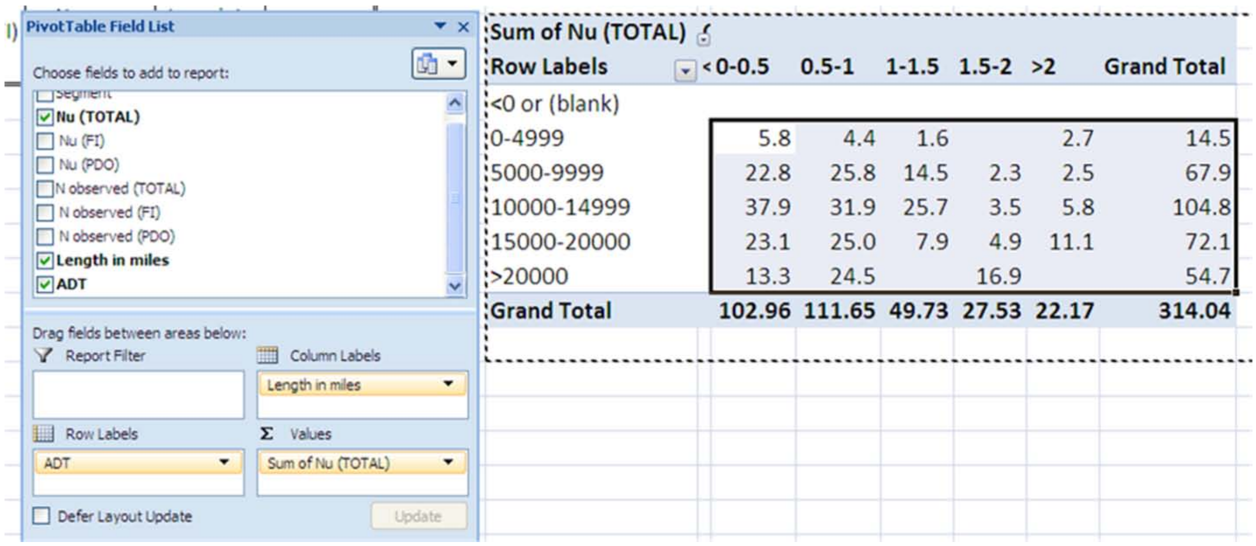
Table D.3 - C as a function of Segment Length

Segment Length in miles	*Sum of N_u*	*Sum of $N_{observed}$*	*C*
0-0.5	103.0	431	1.40
0.5-1	111.6	445	1.33
1-1.5	49.7	190	1.27
1.5-2	27.5	98	1.19
Grand Total	314.0	1241	1.32

Table D.3 shows that C varies systematically as a function of segment length. Were the average C=1.32 applied to a segment which is 1.5 to 2 miles long, it would seem less safe than it really is.

A Two-Dimensional Pivot Table

One could, of course, build a two dimensional pivot table with ADT as rows and Segment Length as columns. To do so, drag 'Length in miles' into the window under 'Column Labels' as shown in Figure D.16. The grouping is done as explained earlier.



Row Labels	<0-0.5	0.5-1	1-1.5	1.5-2	>2	Grand Total
<0 or (blank)						
0-4999	5.8	4.4	1.6		2.7	14.5
5000-9999	22.8	25.8	14.5	2.3	2.5	67.9
10000-14999	37.9	31.9	25.7	3.5	5.8	104.8
15000-20000	23.1	25.0	7.9	4.9	11.1	72.1
>20000	13.3	24.5		16.9		54.7
Grand Total	102.96	111.65	49.73	27.53	22.17	314.04

Figure D.16 - Two dimensional pivot table

A second such table with $N_{observed}$ (Total) under ΣValues would enable one to produce a table of Cs. One can show both N_u(Total) and $N_{observed}$ (Total) in the same table by dragging both into the window under *Σ Values* labels. A part of such a pivot table is shown in Figure D.17.

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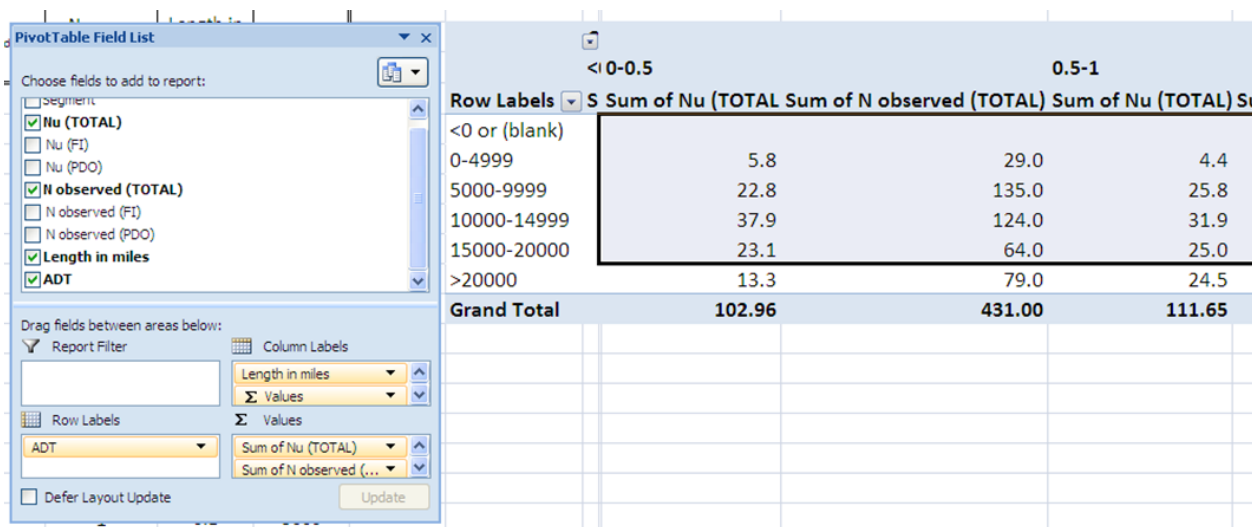

	<0-0.5		0.5-1
Row Labels	Sum of Nu (TOTAL	Sum of N observed (TOTAL)	Sum of Nu (TOTAL)
<0 or (blank)			
0-4999	5.8	29.0	4.4
5000-9999	22.8	135.0	25.8
10000-14999	37.9	124.0	31.9
15000-20000	23.1	64.0	25.0
>20000	13.3	79.0	24.5
Grand Total	102.96	431.00	111.65

Figure D.17 - Sum of 3-year $N_{observed}$ (Total) and N_u (Total) for ADT and segment length combined groupings

A similar two-dimensional table could be used to examine how C depends jointly on major and minor approach ADTs of intersections.

As is evident, in Ohio where the calibration data were collected, C depends systematically on crash severity, ADT and also, to a lesser extent, on segment length.

The reasons for this systematic dependence of C on various variables are rooted in some assumptions which the HSM makes. The N_u in the HSM corresponds to that population of units which was used to estimate the SPF; it also reflects the many other populations of units which served to provide the CMFs. The C is supposed to account for differences between these populations and the population of interest. These differences may be related to factors such as climate, crash reporting practices, passage of time, road use culture, income, demography, terrain, wildlife, etc. The belief that when N_u is multiplied by C one obtains an unbiased estimate of $N_{predicted}$ for the population of interest rests on two assumptions.

The first assumption is that were one to estimate an SPF from data in the population of interest, one would obtain the same SPF as in the HSM save for a multiplication constant. In other words, that the SPF has the same functional form and the same parameter everywhere and that these are identical to what the HSM provides. The second assumption is that the CMFs for the site of interest are identical to the CMFs in the HSM. Judging by the diversity of published SPFs and CMFs these assumptions do not seem to be approximately true.

D.2.2 Regression of C on variables

In the preceding section, the question was whether C depends on the variables for which data are available. In the dataset used, C was seen to depend on crash severity, ADT, and segment length. Because segment length and ADT are continuous variables, the use of C estimated for discrete bins leads to inaccuracy; a continuous representation is preferable. Accordingly, with the data available, it would be better to fit a regression model to:

$$N_{observed} = N_u C(\text{segment length}, ADT) \qquad \textbf{Eq. D6}$$

To illustrate, one could replace the function C(segment length, ADT) by $C = \beta_o e^{\beta_1(\text{segment length})} e^{\beta_2 ADT}$. With this, the model equation would be

$$N_{observed} = N_u C$$

and **Eq. D7**

$$C = \beta_o e^{\beta_1(\text{segment length})} e^{\beta_2 ADT}$$

The parameters β_0, β_1, and β_2 can then be estimated from the 350 data points (Figure D.2) in the usual manner.

D.3 Attempting to summarize

Two questions were asked:

1. How close should be the C used to compute the $N_{predicted}$ to the C that is correct for the conditions of the site under consideration?
2. How different are the Cs in different conditions?

Two pathways were explored on first question. The first pathway was based on the argument that $N_{predicted}$ is the product of three factors: (Predicted base value from the SPF)×(Product of applicable CMFs)×C and it would make little sense to seek an accuracy in C which far exceeds the accuracy of the Product of the CMFs. The accuracy of this product can be assumed but cannot be ascertained from available information. If the typical coefficient of variation of the Product of CMFs is about 0.1 to 0.2 then the coefficient of variation of C need not be less than, say 0.05 to 0.10.

The second pathway was motivated by the desire for fairness in budgeting and efficiency in action. The consistent use of an incorrect C could result in systematic misallocation of resources. How large an error in C can be tolerated from this perspective is a matter of opinion. Our opinion is that a coefficient of variation larger than 0.2 is undesirable. There is a hitch with setting the bar at $cv(C) \leq 0.1$. The hitch stems from the fact that the Cs seem to vary considerably from condition to condition.

Our analysis of just one data set led us to conclude that C depends very significantly on crash severity, ADT, and to a lesser extent on segment length. We did not have data to examine its dependence on terrain, region, alignment, etc. However, even if there were additional data at our disposal, one must ask whether it is feasible to conduct calibration studies for all the conditions which seem to significantly affect the magnitude of C. The apparent dependence of C on a host of variables calls into question the need to prioritize which variables to consider based in their impact on calibration factors, and the feasibility of developing jurisdiction-specific SPFs.