TRC1503

Safety Performance Functions for Arkansas

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Final Report

2017

Safety Performance Functions for Arkansas

Arkansas Department of Transportation TRC 15-03

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November 2017

Technical Report Documentation Page

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle **Safety Performance Functions for Arkansas**	5. Report Date **November 2017** 6. Performing Organization Code
7. Author(s) **J. L. Gattis, Justin Chimka, James Newton, Andrew Evans**	8. Performing Organization Report No.
9. Performing Organization Name and Address **4190 Bell, Department of Civil Engineering** **University of Arkansas** **Fayetteville, AR 72701-1201**	10. Work Unit No. (TRAIS) 11. Contract or Grant No. **TRC 15-03**
12. Sponsoring Agency Name and Address **Arkansas Department of Transportation** **P.O. Box 2261** **Little Rock, AR 72203-2261**	13. Type of Report and Period covered **Final Report** **Nov 2014 – Nov 2017** 14. Sponsoring Agency Code
15. Supplementary Notes **Conducted in cooperation with U.S. Department of Transportation, Federal Highway Administration**	

16. Abstract

The 2010 *Highway Safety Manual* (HSM) contains a number of safety performance functions, i.e., equations that predict the expected number of crashes on a roadway segment or intersection of the specified type. The HSM authors suggest that the various safety performance functions presented therein "be calibrated for application in each jurisdiction". This document reports the methods and outcomes of calibrating the following rural types on the state system to the Arkansas crash database: two-lane segments, four-lane divided segments, intersections on two-lane roads, and intersections on four-lane divided roads. In order to better reflect a truly rural highway environment, the calibration was restricted to locations with speeds of 50 mph or more. For all four types, the actual numbers of crashes in the database were less than those predicted by the HSM equations.

17. Key Words **safety performance functions, calibration**	18. Distribution Statement **no restrictions**

19. Security Classification (of this report) **(none)**	20. Security Classification (of this page) **(none)**	21. No. of Pages	22. Price

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

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INTRODUCTION

The publication of the 2010 *Highway Safety Manua*l (HSM) by the American Association of State Highway and Transportation Officials (AASHTO) ushered in a new era for assessing the safety implications associated with roadway planning, design, or operations decisions. Two of the main HSM computations in safety assessment are safety performance functions (SPF) and crash modification factors (CMF). Due to varying characteristics among jurisdictions (such as crash reporting practices), the HSM states that, "it is important that the SPFs … be calibrated for application in each jurisdiction" (HSM, p. C-18).

The objective of this project was to develop SPF calibration factors for rural two-lane and multilane (excluding freeways) roadway segments and intersections on the state-numbered system in Arkansas. To do this, the following activities were undertaken.

Task 1 – Review Sources

Review relevant literature from a variety of sources, and contact some of the neighboring states to ascertain their experiences. A main focus of this review is to identify problems encountered and lessons learned by others developing state-based SPFs.

Task 2 – Assemble and Review State Data

Request crash data, road inventory, roadway volume, and construction time-period data for the state network in the most recent three years for which data are available. Also request records defining the route/section/log mile for highway segments, and any recent changes in these designations during the same time period. At the beginning of the project, the most recent crash data were for 2010, 2011, and 2012, but before progressing to far, the 2013 crash data became available, so the three years of crash data used are from 2011 through 2013.

Task 3 – Finalize Research Plan

This provides the Subcommittee with the opportunity to review the project and request any redirection.

Task 4 – Analyze Data

During this task, the Contractor examines and tests relationships among the different attributes for which reliable data are available.

Task 5 – Implementation Meeting

Discuss implementation with the subcommittee.

Task 6 – Develop and Assess Final Models

Finalize the calibration factors, and apply them to a sample of road segments to assess how well they perform.

Task 7 – Documentation

Prepare a final report and a guidebook for users.

This report mentions various software products, such as Google Earth™. Such product names may be registered trademarks. Exhibit 1-1 provides a partial list of abbreviations used in this report.

EXHIBIT 1-1 Partial list of abbreviations

Abbreviation	Meaning
AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	average daily traffic
ArDOT	Arkansas Department of Transportation
CMF	crash modification factor
DOT	Department of Transportation
FHWA	Federal Highway Administration
ft	foot or feet
HSM	*Highway Safety Manual*
MMHIS	Multimedia Highway Information System
NHTSA	National Highway Transportation Safety Administration
RHR	roadside hazard ratings
SPF	safety performance function

CHAPTER 2: PERTINENT INFORMATION FROM RELATED SOURCES

Task 1 of this research project included a review of sources that contain information related to the objectives of this project. These sources include:

1. the 2010 *Highway Safety Manual* (HSM);
2. recently published research papers and reports;
3. conversations with and documents from surrounding states' departments of transportation (DOT).

A main focus of this review was the experiences of other states, identifying problems encountered and lessons learned by others developing state-based safety performance functions (SPFs) and calibration factors.

INDICATORS OF THE PROBLEM

In 2012, 53% of all national fatal crashes occurred in rural areas; 52% of these rural fatal crashes happened during the daytime (NHTSA, p 3). The rural fatality crash rates decreased by 27% between 2003 and 2012 (NHTSA, p 1). The number of fatalities per one million vehicle mile traveled dropped from 2.30 to 1.86 within this time frame, but the rural fatality rate was still significantly higher than the fatality rate in urban areas.

In rural locations, speed was considered a causal factor for 31% of the fatal crashes in vehicles (NHTSA, p 2). For rural areas, 40% of passenger vehicle occupants killed were in rollover crashes (NHTSA, p 4).

Alcohol was another major factor in crash fatalities. Crashes in which the driver's blood alcohol concentrations were 0.08 grams per deciliter killed over 5,700 persons in rural areas nationwide. Over half of drivers involved in rural alcohol related crashes had at least one prior driving-while-intoxicated (DWI) offense (NHTSA, p 3).

The data show a relationship among the type of vehicle involved in a crash, restraint device use, and crash fatalities (NHTSA, p 4). Although overall, 54% of those rural passenger vehicle occupants who were killed were unrestrained, this proportion jumps to 65% for pickup truck occupants.

The University of Michigan (Sivak) conducted a study of national crash data in 2014. Using 2012 data for each state, they computed total number of fatalities, fatalities per distance driven, and fatalities per population. Developing rates for amount of travel and for population somewhat helps normalize data to account for the great differences among states, but obviously does not account for the effects of different congestion levels on numbers of crashes. After compiling the data for each state, they then ranked each state, with lower numbers indicating the least amount of fatalities or "best"; i.e., the first-ranked state performed better than all other states. They also computed the percentage increase or decrease in each category from 2005 to 2012, with a negative sign indicating a decrease or improvement. Exhibit 2-1 presents their numbers for Arkansas.

EXHIBIT 2-1 Fatality rates for Arkansas

Type	Fatality Data 2012	Fatality Rank 2012	Difference 2005 - 2012	Difference Rank 2005 - 2012
Total Fatalities	552	28th	-14.8 %	42nd
Fatalities/distance driven	16.47/billion miles	47th	-18.8%	33rd
Fatalities/population	18.72/100,000 persons	47th	-19.7%	39th

Source: Sivak

HIGHWAY SAFETY MANUAL

The first edition of the *Highway Safety Manual* (HSM), published in 2010, includes a wide range of both qualitative and quantitative information related to roadway safety. Part C of the HSM provides methods to calculate estimated crash frequency. Crash frequencies are calculated separately for roadway segments and for intersections.

The present HSM has predictive models for three types of rural roadway segments: two-lane two-way, four-lane undivided, and four-lane divided. Rural intersections are divided into three types: three-leg STOP controlled, four-leg STOP controlled, and four-leg signal controlled. Chapter 10 addresses rural two-lane segments and intersections, Chapter 11 addresses rural four-lane segments and intersections, and Chapter 12 is devoted to urban and suburban arterials. There are a total of 18 predictive facility types, eight for segments and 10 for intersections.

Explaining Safety Performance Functions

The *Highway Safety Manual* contains a variety of equations to examine and evaluate highway crashes and safety. One of these is called a safety performance function (SPF). The SPFs are models used to predict the number of crashes on a given roadway segment or near an intersection. Safety performance functions can be used in a variety of ways, including evaluating design impacts at a project level, determining potential improvement areas in the network, and for comparison between before and after situations (Srinivasan, p 6).

The core of the equation assumes what is called “base conditions”; this is subsequently adjusted for site-specific characteristics with the use of “crash modification factors” (CMF). The form of a generic equation is:

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

where $N_{predicted}$ is the predicted number of crashes, N_{spf} is the HSM base value for the given roadway, and C_x is a calibration factor. CMFs and C_x are discussed later.

Explaining Base Conditions

Base conditions are what the HSM authors considered to be a starting point – typical or normal values for characteristics of each facility type. Exhibit 2-2 lists the base conditions for rural facility types.

EXHIBIT 2-2 Base conditions for facility types

Characteristic	R2 rural 2-lane	R4U rural 4-lane undivided	R4D rural 4-lane divided	3ST 3-leg STOP	4ST 4-leg STOP
Lane Width (Ft)	12	12	12	-	-
Shoulder Width (ft)	6	6	8 (right side)	-	-
Shoulder Type	paved	paved	-	-	-
Roadside Hazard Rating	3	-	-	-	-
Driveway Density	5 per mile	-	-	-	-
Horizontal Curvature	none	-	-	-	-
Vertical Curvature	none	-	-	-	-
Centerline Rumble Strips	none	-	-	-	-
Passing Lanes	none	-	-	-	-
Two-Way Left-Turn Lanes	none	-	-	-	-
Lighting	none	none	none	none	none
Automated Speed Enforcement	none	none	none	-	-
Grade Level (%)	0	-	-	-	-
Intersection Skew Angle (degrees)	-	-	-	0	0
Intersection Left Turn Lanes	-	-	-	none	none
Intersection Right Turn Lanes	-	-	-	none	none
Sideslope	-	1V:7H or flatter	-	-	-
Median Width (ft)	-	-	30	-	-

Source: HSM, p 10-14, 10-18, 11-14, 11-17, and 11-20

Explaining Crash Modification Factors

To reflect conditions other than "base conditions", the number of crashes initially predicted by the SPFs are then adjusted with the application of crash modification factors (CMFs). For a given characteristic (e.g., lane width), when the actual condition of a segment matches the base condition (e.g., lane width equals 12 ft), the CMF will be 1.0. A CMF greater than 1.0 indicates that for the particular situation, more crashes are expected than there would be if base conditions were present.

Some important elements on high risk rural roads are not addressed by the HSM CMFs. The Federal Highway Administration's (FHWA, p 1) *Safety Improvements to High Risk Rural Roads* presents CMFs to address nine elements: horizontal curves, signalized intersections, unsignalized intersections, non-motorized users, pavement and shoulder resurfacing, pavement markings, roadside signing, vertical curves, and other treatments. For each category, the document lists potential safety improvements. Examples include installing advanced warning signs, providing center line rumble strips, and installing a safety edge. Each improvement is accompanied by a CMF, benefit/cost ratio, and a short description or diagram. For example, installing advanced warning signs merits a CMF of 0.66; this conveys there is a 34% decrease in crashes associated with this improvement.

Explaining Calibration

The SPF models presented in the HSM were derived from crash data taken from only a few states. Due to factors such as variations among the states in the quality of crash data, requirements for omission or inclusion of certain crash types, terrain, weather, or other causal factors, computations from these models may not correctly represent outcomes in any given state or locale. Therefore, to more accurately predict crash numbers in a state or region, the HSM authors strongly suggest that calibration factors (C_x) be applied to the SPF equations. A calibration factor is calculated as follows:

$$C_x = \frac{\sum_{all\ sites} N_{observed}}{\sum_{all\ sites} N_{predicted}}$$

where C_x is the calibration factor, $N_{observed}$ is the observed crash frequency of each site, and $N_{predicted}$ is the unadjusted predicted crash frequency of each site.

The HSM suggests using three consecutive years of crash data for proper calibration. For each roadway or intersection type (e.g., rural multilane undivided), a randomly selected sample of a minimum of between 30 and 50 sites is required, and more sites may be added if there is an ample pool from which to choose. For each type, the sum of the number of crashes should be at least 100 per year (HSM, p A-8). When, for a given type, the minimum number of sites or crashes is not available, then the entire population is to be used for calibrating that type.

HSM Assumptions

Those who developed the HSM models of necessity made certain choices and decisions. HSM users must be aware of these to avoid misapplication of the procedures.

Definition of Rural

The location of a roadway and the surrounding land use affect driver behavior and crash occurrence. The HSM authors adopted the FHWA definition of "rural," places outside of an urban area where the population is less than 5,000 (HSM, p C-12).

Definition of Intersection Related

The HSM process considers any crash that takes place at or within 250 feet of an intersection to be an intersection-related (IR) crash (Neuman, p V-8). As one aspect of a broader research effort, other researchers examined crashes near 73 Oregon signalized intersections to test this assumption (Avelar). They studied the relationship between the distance from the intersection (along with other variables) and whether a crash was intersection-related. A shorter threshold is more likely to correctly exclude crashes not related to an intersection, but also overlooks some IR crashes. Per intersection, a 200 ft threshold averaged 0.6 false positives (classifying a crash as IR when it was not), but also had 4.5 false negatives (excluding what should have been an IR crash). At a 300 ft threshold, the number of false positives was about the same as the number of false negatives, thus the two canceled out each other. They concluded "If the intent is to identify IR crashes for crash frequency prediction, as when developing a safety performance function …. a threshold of 250 ft tends to yield fewer IR crashes than actually exist", and suggested using a 300 ft threshold for some purposes. Another finding was that also considering other codes in the crash database, such as a code showing the presence of intersection traffic control devices, improved the quality of the classification of IR crashes.

Guidelines for SPF Calibration

The National Cooperative Highway Research Program (NCHRP) developed a guide to explain why calibration is needed, how to implement the calibration process, how to assess the results of calibration, and how to prepare for future calibration updates (Bahar, p 21). The guide explains each type of roadway and characteristics required or desired. These facility characteristics can be obtained from highway agencies, aerial and ground photography, roadway plans, intersection diagrams, and estimation techniques.

An appendix recommends methods to determine an adequate sample size for each facility type. The publication refers to a procedure listed in the HSM to calibrate the SPF models for a specific region. Calibration is divided into five steps (Bahar, p 55):

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

The guide explains each step, and provided worksheets to help organize the data. For states that have experience with calibration, it lists details about site selection, sample size, data collection and management, data analysis and findings, future recommendations, and documentation. The guide also addresses frequently asked questions.

ROADSIDE HAZARD RATINGS

Given the significance of run-off-the-road crashes in rural environments, and the challenges some states encountered in quantifying this aspect of safety performance functions, the topic of roadside hazard ratings deserves special attention. Roadside Hazard Ratings (RHR) are safety ratings for a roadway based adjacent land features. The rating consists of a scale ranging from 1 to 7, with 1 being the safest and 7 being most dangerous. This scale is determined by observing three aspects of the land adjacent to the roadway: clear zone width, sideslope, and other roadside features. Exhibit 2-3 presents a table of rating definitions.

EXHIBIT 2-3 Definitions of roadside hazard ratings

<table>
<tr><th>Rating</th><th>Clear Zone Width</th><th>Sideslope</th><th>Roadside</th></tr>
<tr><td>1</td><td>Greater than or equal to 30 ft</td><td>Flatter than 1V:4H; recoverable</td><td rowspan="2">N/A</td></tr>
<tr><td>2</td><td>Between 20 and 25 ft</td><td>About 1V:4H; recoverable</td></tr>
<tr><td>3</td><td>Between 10 and 20 ft</td><td>About 1V:3H; marginally forgiving, increased chance of reportable roadside crash</td><td>Rough roadside surface</td></tr>
<tr><td>4</td><td>Between 5 and 15 ft</td><td>About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash</td><td>May have guardrail (offset 5 to 6.5 ft)
May have exposed trees, poles, other objects (offset 10 ft)</td></tr>
<tr><td>5</td><td>Between 5 and 10 ft</td><td>About 1V:3H; virtually non-recoverable</td><td>May have guardrail (offset 0 to 5 ft)
May have rigid obstacles or embankments (offset 6.5 to 10 ft)</td></tr>
<tr><td>6</td><td rowspan="2">Less than or equal to 5 ft</td><td>About 1V:2H; non-recoverable</td><td>No guardrail
Exposed rigid obstacles (offset 0 to 6.5 ft)</td></tr>
<tr><td>7</td><td>1V:2H or steeper; non-recoverable with high likelihood of severe injuries from roadside crash</td><td>No guardrail
Cliff or vertical rock cut</td></tr>
</table>

Note: Clear zone width, guardrail offset, and object offset measured from edge line.
N/A = no description of roadside is provided (HSM, p 13-25)

The clear zone, located in the space adjacent to the traveled way, is measured from the outer edge of the traveled way to the edge of potential hazards, such as a tree line. It is desirable that this area be made as safe as feasible, in case a vehicle runs off the road, by reducing or eliminating objects such as utility poles.

The slope of the land adjacent to the traveled way affects the chances of being able to recover, or correct, a vehicle and return to the roadway. A steeper slope makes it less likely that a driver will be able to recover once the vehicle leaves the roadway, meriting a higher RHR.

Roadside characteristics affect the RHR, because a roadway's safety may be affected by either natural or manmade roadside characteristics. Guardrails placed within the clear zone may improve safety conditions by diverting a vehicle back onto the roadway or stopping the vehicle before it can leave the road. Cliffs and rock cuts are common on the roadside in mountainous terrain, and may define the outer edge of the clear zone. Cliffs and rock cuts generally create a greater safety risk than a tree line, and therefore merit special consideration when assigning a RHR.

When all three aspects are considered, the roadway in question is then given the appropriate rating. Terrain of the area plays a large role in determine the roadside hazard rating. A national study collected random samples of roadside data (Zegeer, pg. 119) found that in general, flat terrain was associated with a lower RHR than roadways in mountainous topography, as Exhibit 2-4 conveys.

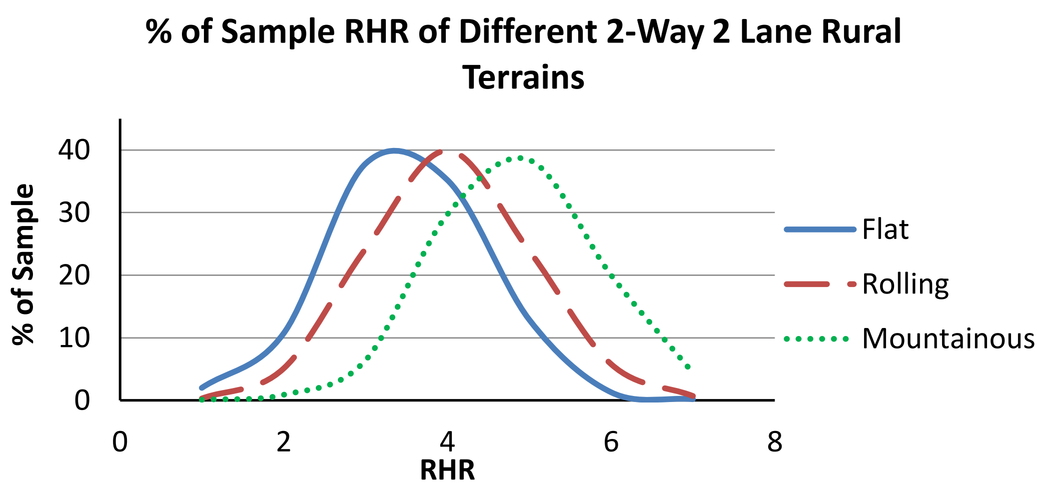

EXHIBIT 2-4 Roadside hazard rating of different terrain

When determining RHRs for a many roadways, the resources are usually not available for individual site visits to collect the clear zone width and sideslope. Therefore, most ratings are derived from photographs or video logs, and requires that an assessor use their subjective judgement when rating the roadway. The HSM recognizes that roadside features may gradually change and defined location of change may not be notable. To counter this dilemma, The HSM allows roadside hazard ratings to be average together as long as the adjacent ratings have a difference less than two (HSM, p 10-13).

One of the most common factors in run-off-road crashes is tree collisions. As Exhibit 2-5 shows, 32% of fatal run-off-road crashes in 2013 involved trees, the highest percentage of objects hit in fatal run off road crashes in Arkansas (NHTSA, 2013).

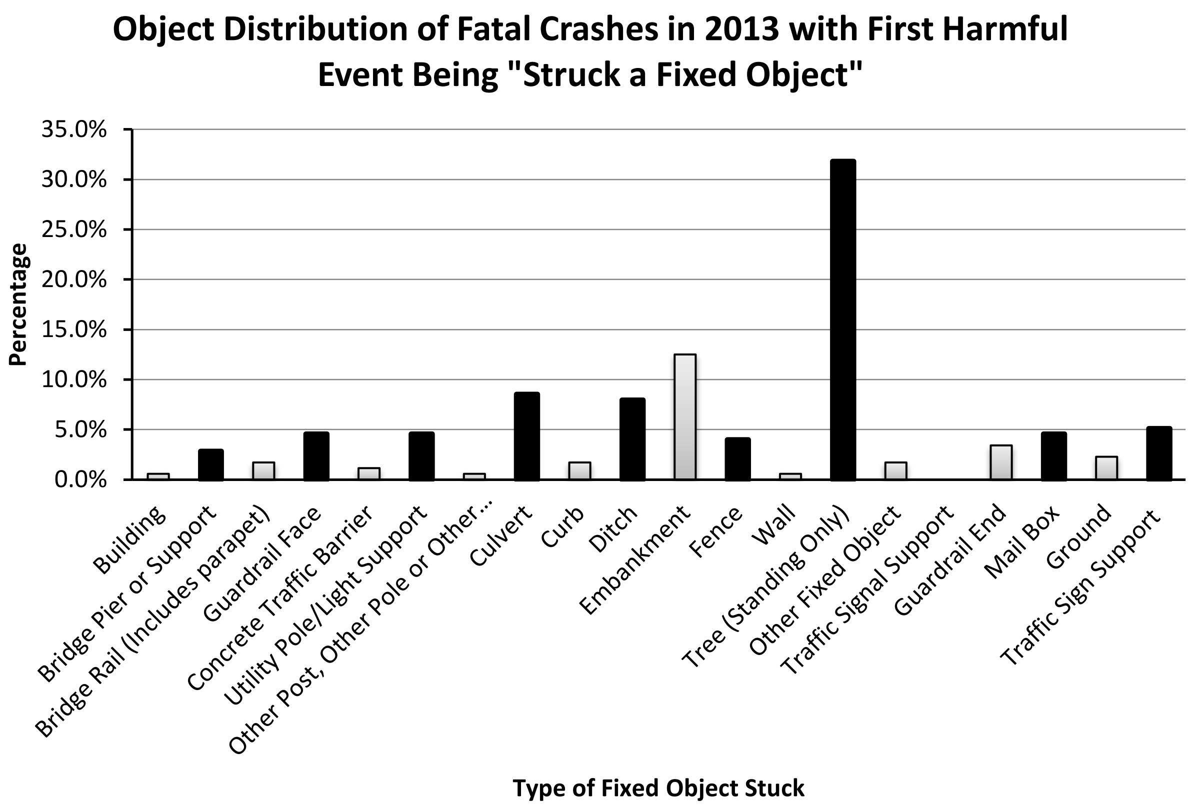

EXHIBIT 2-5 Percentages of objects struck in 2013 Arkansas fatal crashes

INSIGHTS FROM STATES' EXPERIENCES

A recent Maryland SPF calibration project, discussed later, stated "data collection and compilation were the most challenging tasks", and noted that other previous studies "used alternative data collection methods" to compensate for omissions in the normal databases (Shin). To gain insight into data collection challenges and to learn from the experiences of previous studies, documents pertaining to the calibration of safety performance functions by selected states were reviewed.

Virginia

The Virginia DOT employed the University of Virginia to study SPF calibration factors for some facility types, using data from 2003 to 2007 (Garber and Rivera, Garber et al.).

Site Selection

Only sites on state routes were eligible for selection. Sites selected were then separated into segments. Virginia separated a roadway segment when any of the baseline factors deviated from the base conditions, or upon approach to an intersection (Garber and Rivera, p 4). All segments were less than one mile in length to eliminate unnecessary site variance. If data to describe one of the HSM characteristics was not available, then the site was eliminated from selection (Garber and Rivera, p 32).

Data Collection

The Virginia Department of Transportation (VDOT) was able to access the Highway Traffic Records Information System (HTRIS) for all data collection needed. The HTRIS is an online database composed of three smaller databases in the state: a roadway inventory database, an accident report database, and a highway performance monitoring system (HPMS). The HPMS was used to determine traffic volumes for both major and minor approaches. The methodology of collected data for sideslope and vertical grade was not explained in the report.

Geographical Areas

VDOT has five geographic regions defined within the state (Garber et al., p 10). For each region, HSM calculations were performed separately.

Developing Equations

Virginia compared their roadway segment SPF models to those of Ohio, Minnesota, North Carolina, and Washington (Garber et al., p 24-28). SPF models for the total amount of statewide crashes were compared to the Minnesota SPF models (Garber and Rivera, p 27-33) for intersections. Minnesota was selected because the HSM based national models on Minnesota roadway data.

The Virginia research compared their SPF models to other states. Ohio, Minnesota, North Carolina, and Washington SPF models were compared to the Virginia SPF models for roadway segments (Garber et al., p 24-28). SPF models for the total amount of statewide crashes were compared to the Minnesota SPF models (Garber and Rivera, p 27-33) for intersections. Minnesota was selected because the HSM based national models on Minnesota roadway data.

Utah

The state of Utah contracted with Brigham Young University to calibrate the HSM SPF models for rural two-lane roadways in their state. They used crash records from 2005 through 2007.

Site Selection

Only straight sections were considered for the study. Segments with daily volumes in excess of 10,000 or speed limits below 50 mph were excluded, as they were not considered to be representative of typical Utah rural two-lane highways (Saito, p 31). Exhibit 2-6 describes the characteristics of the 157 sites.

Data Collection

The researchers found the numerical values describing these characteristics in a variety of sources. They utilized a statewide network of street-view cameras to assist in counting volume. In places where cameras were not located, a statewide equation was created from existing data, and the volumes were estimated from this equation. The study collected truck percentage from records kept by the state (Brimley, p 84).

EXHIBIT 2-6 Characteristics of Utah rural, two-lane sites

Characteristics	Minimum	Median	Mean	Maximum
Segment length (mi)	0.20	0.64	0.97	5.85
Longitudinal grade (%)	0	0.76	1.11	7.13
Number of driveways	0	0	1.38	14
Driveway density (driveways per mile)	0	0	1.8	21.2
Speed limit (mph)	55	65	64	65
Lane width (ft)	10.2	12.1	12.1	16.6
Shoulder width (ft)	0	4.1	4.7	11.4
AADT (vpd)	287	2739	2787	8270
Single-unit truck (%)	3	10	12.6	32
Multiple-unit trucks (%)	4	16	21.9	60

Source: Brimley

Geographical Areas

The study did not subdivide Utah by geographic regions (Brimley, p 83).

Developing Equations

A group of model equations were then created for both 75% and 95% confidence intervals of each characteristic. Using the Bayesian test, the best fit model was chosen to produce the appropriate SPF equations for Utah's two-lane rural roads. The calibration factor found was 1.16, indicating that 16% more crashes occur on rural roads in the state than what the HSM predicted (Brimley, p 88).

Florida

Florida DOT contracted with the University of Florida to calibrate the HSM SPF models. They used 2005 through 2008 crash data.

Site Selection

The Florida study only used state-owned roadways for the study. The decision was based on the availability of characteristic data for each facility type.

After selecting a site, they were divided into homogenous segments. A change in any of the characteristics prompted the start of a new segment. These caused most segments to be less than 0.5 miles long. The study discarded any segment of roadway that was shorter than 0.1 mile (S Srinivasan, p 9).

Data Collection

Data sources included the Crash Analysis Reporting System, the Roadway Characteristics Inventory (RCI), and satellite images (S Srinivasan, p 27). Because state owned roads were the only roads analyzed, the volumes for minor roads at intersections were available through the state DOT. Some data was not recorded within these data points and had to be manually recorded from Google Maps or a default value from the HSM was assumed. Default values were assumed for characteristics such as vertical grade and sideslope measurements (S Srinivasan, p 8, 27). Such assumptions were made due to the relatively flat terrain throughout the state.

Geographical Areas

Florida DOT has existing geographic regions to account for different land use, weather patterns, and terrain. In addition to a statewide calibration factors, each region was calibrated only using crash data within the respected region (S Srinivasan, p 16).

Developing Equations

Florida DOT only has crash reports on record for injury and fatal crashes. Because property damage only (PDO) crashes are listed as "short-term" reports in the state databases, they are no longer filed for the years studied. Due to the necessary lack of crash report information, the only crash severity levels calibrated were fatal and injury crashes for each facility type.

North Carolina

In 2010, the University of North Carolina Highway Safety Research Center (HSRC) conducted a study for North Carolina DOT (NCDOT) to calibrate the SPF models for the state's roadways. Since for some facility types, those creating the "national" SPF models in the *HSM* had in part based their models on North Carolina roadway data, the researchers assumed C_x to be 1.0 for such facility types. For the other facility types for which North Carolina data had not been used when developing the HSM models, the researchers developed calibration factors (R Srinivasan, p 24).

Site Selection

A sample of sites with similar characteristics was selected from the statewide roadway network. Segments with railroad crossings were removed from consideration.

NCDOT developed a pool for each facility type. Sites were then selected from this pool to create a sample collection of each roadway segment and intersection type. Sites were chosen randomly, but care was taken to include an equal number of sites from the three geographic regions (R Srinivasan, p 25).

Data Collection

Once each site was selected, the coordinates were recorded and the characteristics data was collected primarily using the Highway Safety Information System, Traffic Engineering Accident Analysis System, and aerial imagery.

Pedestrian counts were not critical to create the model and pedestrian data was not available at all sites. As a result, pedestrian counts were not used in the intersection calibration.

Geographical Areas

After the sites were selected and the data gathered, the study assigned the sites to one of three geographic regions: coast, piedmont, and mountains. Counties were assigned to a region, based on the dominant terrain, but counties were not split between two regions (R Srinivasan, p 25). Each region's crash data was then used to develop geographic-specific calibration factors. In many circumstances, the number of observed crashes per region fell well below the 100-crash minimum, resulting in less-reliable calibration factors.

Developing Equations

Once the calibration factors were calculated for each roadway segment and intersection type, the researchers also created new SPF models. The calibration factors and new state SPF models were compared and proved to complement one another.

Oregon

The Oregon Department of Transportation (ODOT) contracted with Oregon State University to develop calibration factors for the national HSM SPF models for the state.

Site Selection

All sites for the project were chosen randomly, but the samples were stratified in order to achieve geographical diversity. The samples were separated into groups based on similar characteristics, and then further split into segments of equivalent length. Exhibit 2-7 lists the numbers of sites of each type.

One objective of segment selection was to produce a sample of segments with similar lengths. Any roadway that did not meet the length criteria was discarded from the eligible pool. The selected rural two-lane roads all had lengths of approximately two miles, and the chosen multilane roadway segment lengths varied from 0.5 miles to 2.5 miles (Dixon, p 9,10). Each site was further divided into 0.1 mile segments; each segment was analyzed with the appropriate HSM equation.

Data Collection

The supporting data can be described as being basic, geometric, or crash. Basic data came from different databases created by ODOT. The databases did not have all of the needed roadway volume and pedestrian activity data. Major roadway ($AADT_{major}$) and minor roadway ($AADT_{minor}$) volumes were both needed to complete the intersection calibrations. A model was created to estimate $AADT_{minor}$. Another characteristic required was pedestrian activity. For pedestrian activity level, a default value was assumed.

Exhibit 2-7 Number of sites in Oregon study

Type	Code	Sample Size
Two-lane roads	R2	75
Multilane undivided	MRU	50
Multilane divided	MRD	19
Intersection: 3-way, STOP controlled	3ST	200
Intersection: 4-way, STOP controlled	4ST	200
Intersection: 4-way, SIGNAL controlled	4SG	25
Multilane intersection: 3-way, STOP controlled	M3ST	100
Multilane intersection: 4-way, STOP controlled	M4ST	107
Multilane intersection: 4-way, SIGNAL controlled	M4SG	34

Source: Dixon, p 1, 8

Geometric data was obtained from ODOT Reports for State Highway Lanes, other publications, and digital video logs. Some information could not be collected from these reports, such as land use, and intersection turning lanes. In these cases, aerial photography and Google Streetview were used to acquire data.

Crash data were compiled using historical records from 2004-2006. These records were transcribed from the Statewide Crash Data System (CDS). Each crash indicated in the CDS included a unique ID number as well as the type, the severity, the location, and the direction of each crash (Dixon, p 5).

Some of the characteristics collected from each category can be seen in Exhibit 2-8. Along with each characteristic, the data source is also noted.

Geographical Areas

Due to geographical differences throughout the state, nine different regions were created by the research team within the state. Crash modification factors were created separately for each region. The crash counts for each region were well below the 100 crash minimum recommended by the HSM. Both the statewide calibration factor and the geographic calibration factors were compared to each other.

Developing Equations

The study showed a full example of a site analysis and adjoining calculations. Then, the site was compared to the national HSM models and a calibration factor for the state was found. Each facility type was calibrated per year and compared to the annual HSM values. Finally, one calibration number was found for each facility type from averaging each of the three years' calibration factors. This final calibration factor for each facility type is the calibration factor used to predict crash numbers throughout Oregon.

Exhibit 2-8 Data sources for Oregon calibration

Characteristics	Sources
AADT of Major Road	ODOT Traffic Volumes and Vehicle Classification Report and County Public Works Departments
AADT of Minor Road	ODOT Traffic Volumes and Vehicle Classification Report, Local County Public Works Departments, and AADT Estimate Model
Segment Length	Defined as part of the site selection process
Lane Width	ODOT State Highway Lane Report
Shoulder Width	ODOT State Highway Lane Report
Shoulder Type	ODOT State Highway Lane Report
Horizontal Curve Data	ODOT State Highway Horizontal Curve Report and Field Verification
Vertical Grades	ODOT State Highway Vertical Grade Report
Driveway Density	ODOT Digital Video Log
Centerline Rumble Strips	ODOT Digital Video Log
Passing Lanes	ODOT State Highway Lane Report and Aerial Photography
TWLTLs	ODOT Digital Video Log and Aerial Photography
Roadside Hazard Rating	ODOT Digital Video Log
Sideslope	ODOT Digital Video Log
Roadside Fixed Object Density	ODOT Digital Video Log
Average Offset to Fixed Objects	ODOT Digital Video Log and Aerial Photography
Median Type and Width	ODOT State Highway Lane Report
Lighting	ODOT Digital Video Log (Roadways), Aerial Photography (Intersections)
Speed Category	ODOT State Highway Lane Report
Automated Speed Enforcement	ODOT TransGIS
Intersection Skew Angle	Aerial Photography
Left-Turn Signal Phasing	ODOT Digital Video Log, Google Streetview (major legs)
Right-Turn Signal Phasing	ODOT Digital Video Log, Google Streetview (major legs)
Intersection Left-Turn Lane	Aerial Photography
Intersection Right-Turn Lane	Aerial Photography
Right-turn-on-red Prohibited	ODOT Digital Video Log, Google Streetview (major legs)
On-Street Parking Type	Aerial Photography
Maximum lanes for pedestrian crossing	Aerial Photography
Pedestrian Volumes	Default assumed-"Medium"
Bus stops within 1000 ft	Aerial Photography
Schools within 1000 ft	Aerial Photography
Alcohol sales establishments within 1000 ft	Aerial Photography

Source: Dixon, p 24

Maryland

The Maryland State Highway Administration (SHA) contracted with Morgan State University to calibrate both rural and urban HSM SPF models. They relied on crash data from 2008 through 2010. Those performing the study chose to slightly modify the HSM letter-number codes used to designate facility types, to improve the "understandability" of the codes.

Site Selection

The study included only SHA-maintained roadways and intersections; it excluded Baltimore city. The researchers collected data from 30 different sites for each facility type; if the minimum number of crashes was under 100, more sites were added until the 100 crash requirement was met. The study authors commented about the difficulty in achieving the suggested 0.1 mile segment length, noting that over 60% of Maryland's rural roadway homogeneous segments were shorter than 0.1 mile (Shin p 13). Types for which the minimum numbers could not be achieved were rural 4-lane undivided road segments, rural multilane 3-leg STOP controlled intersections, and rural multilane 4-leg STOP controlled intersections.

Each site was then subdivided into segments based on homogenous characteristics. The minimum segment length on rural roadway segments was 0.1 miles (Shin, p 43).

Data Collection

The Maryland research team utilized 60 characteristics to determine the number of predicted crashes; the HSM requires 41 of these characteristics, and the other 19 characteristics are considered optional (Shin, p 17). The databases provided by the SHA did not contain information for some of these characteristics. These data had to be manually collected or assumed using the HSM default values (Shin, p 20).

With such large amounts of data to locate, the program ArcGIS was used to derive a number of characteristics not listed in the SHA. For instance, sideslope was not recorded in the database, so GIS was deployed to determine the terrain. In other cases, where the characteristics such as vertical grade could not be obtained, the study used the HSM default values. Data sheets were collected from the SHA to obtain other needed information, while Google Earth was used to complete the data and double check SHA information, such as vertical grade (Shin, p 32,33).

Some characteristics were found independently by the research team. They assumed pedestrian activity levels, based on surrounding land use (Shin, p 32). Because it was not uncommon for minor road volumes to be absent from available databases (this was missing for almost 2/3 of stop-controlled intersections), Maryland used multiple regression models to estimate unavailable minor road volumes, in a manner similar to that of the Oregon study (Shin, p 39). When grade data were unavailable, the research team made use of the Google Earth Elevation Profile to determine an average slope, and from this, the terrain categories that Exhibit 2-9 shows (Shin, p 33). For the Maryland study, five students spent four months collecting and measuring additional attributes (Shin, p 31).

Geographical Areas

The study did not mention subdividing Maryland by geographic regions.

Exhibit 2-9 Maryland terrain categories

Average Slope	Terrain Category	CMF	Value of Grade Maryland Used
> 6%	Mountainous	1.16	6%
From > 3% to ≤ 6%	Rolling	1.10	3%
≤ 3%	Level	1.00	0%

Note: CMFs from the HSM are added to this table for informational purposes

Source: Shin, p 33, from AASHTO HSM, p 10-28

SURROUNDING STATES

In addition to reviewing documents that presented various states' experiences with developing SPF calibration factors, inquiries were made to ascertain what steps each of the six states that border Arkansas had taken to develop or calibrate safety performance functions.

Louisiana

The Louisiana Department of Transportation and Development (LaDOTD) contracted with Louisiana State University to calibrate the HSM SPF models for rural roadways and intersections. The researchers referenced the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors* (Bahar) in their calibration study.

In a phone conversation with LaDOTD, it was mentioned that the study estimated the sideslope of roadway segments using ground pictures and video recordings of each site.

Mississippi

As of February 2015, the state of Mississippi has not calibrated the HSM SPF equations or created state specific SPF models.

Missouri

Missouri Department of Transportation (MoDOT) contracted with the University of Missouri to calibrate HSM SPFs for rural road segments and intersections.

Site Selection

When possible, Missouri took five random samples of each type of roadway and intersection from each of their seven districts; this was done to keep an equal geographic diversity in their sample (Sun, p 18). The selections were made only from segments longer than 0.5 mile. These segments were then subdivided into homogeneous subsegments; even if the resulting subsegment length was less than 0.5 mile, it was still included (Sun, p 19).

The resulting maximum subsegment length for rural two-lane sites undivided was 7.52 miles, and for rural four-lane divided sites was 7.59 miles (Sun, p 42, p 52).

Data Collection

To obtain required data for each selected segment, MoDOT researchers relied on sources such as their Transportation Management System (TMS) and the Automated Road Analyzer (ARAN). Crash information came from a Statewide Traffic Accident Records System (STARS). When information was not available, aerial/street photographs and default values were used. Vertical grade was one of these assumptions, defaulting to 0% on all roadway segments (Sun, p 24).

For intersections, they chose only sites at which ADT_{minor} volumes were available from the TMS. This resulted in the total number of crashes for the intersection facility types falling below the required 100 crash minimum (Sun, p 248).

Geographical Areas

The study did not subdivide Missouri by regions to create separate calibration factors based on geography.

Developing Equations

To assist with the calibration of the HSM SPF models, the researchers used the Interactive Highway Safety Design Model (IHSDM) (Sun, p 30). The IHSDM calculated a calibration factor for every facility type with the three years of data that was input.

Oklahoma

The Oklahoma Department of Transportation (ODOT) is currently developing their own SPF models, independent from the HSM, for their roadways and intersections. ODOT collects the data, and sends it to the University of Oklahoma for storage and processing by an in-house program called Safe-T. Safe-T will automatically run the SPF models on all roadways in the system to predict the number of crashes.

Tennessee

As of February 2015, the state of Tennessee has not calibrated the HSM SPF equations or created state specific SPF models.

Texas

The Texas Department of Transportation developed their own equations to predict crash numbers for their rural roadways and intersections, independent of the HSM equations. Chapter 3 of the *Roadway Safety Design Workbook*, by the Texas A&M Transportation Institute, presents a procedure to use the state SPF models, along with examples (Bonneson).

SUMMARY

The different states have developed a number of practices to address the real-world problems encountered when trying to implement HSM procedures. These include the following.

1. Geographic differences within state. To account for differences across the breadth of a given state, practices ranged from dividing the state into parts and developing functions for each part, to having only one function but stratifying the pool so that samples were drawn equally from different parts of the state.
2. Segment length – Some states restricted the lengths of segments used in calibration to be greater than a certain minimum and less than a certain maximum. The HSM mentions a minimum segment length of 0.1 mi (HSM, p 10-13).
3. Segment sideslope - It is not uncommon for state databases to not include sideslope information, forcing states to take one of a number of approaches to compensate for this absence, such as entering 0 for the grade.
4. Intersection minor road AADT

   Volume data for legs of an intersection not on the state system (i.e., the minor volume, $AADT_{minor}$) may not exist. Some states chose to examine intersection crash frequency only at locations for which the side road volume data were available, which may mean excluding some intersecting roads from possible selection. States such as Florida, North Carolina, and Virginia relied on their databases to produce $AADT_{minor}$.

   Decades ago, Mohamad, et al. developed a multiple linear regression model for Indiana county traffic prediction based on significant effects in locale, access, population, and total arterial mileage. They initially fit a full, main effects model including two significant and nine insignificant independent variables, which explained approximately 46% of the variation in annual average daily traffic (AADT). However, after transforming the response and employing model selection procedures, the authors found a better fitting, more efficient model of $\log_{10}$ (AADT), with $R^2 = 0.75$. Note that this R^2 applies to the log of the volume, not the actual volume.

   Less commonly, some states, such as Oregon, estimated $AADT_{minor}$ volumes through statistical analysis. Other states, such as Maryland, used this method, citing Oregon's report as a reference. Oregon researchers created a model for each facility type to estimate roadway volumes without actual traffic counts provided. The statistics were analyzed through multiple linear regression using ten variables, as seen in Exhibit 2-10. The coefficient of determination (R^2) value in the analysis should be greater than 0.60 for the model to be considered adequate.

Exhibit 2-11 shows a summary of select characteristic sources for certain states.

EXHIBIT 2-10 Independent variables for minor AADT estimation models

Variable	Description
CtPop	County population
CityPop	Population of nearest city
Income	Average per capita income of the region
Distance	Distance to the nearest freeway (miles)
MIA	Is the cross street a minor arterial? (1=yes, 0=no)
MAC	Is the cross street a major collector? (1=yes, 0=no)
CityLimit	Is the intersection located within a city limit? (1=yes, 0=no)
Right	Is a right-turn lane present on the minor road? (1=yes, 0=no)
RightCross	Does the major road have a right-turn lane? (1=yes, 0=no)
LandUse	Is the adjacent land developed? (1=yes, 0=no)
Centerline	Is a centerline present on the minor road? (1=yes, 0=no)
Edgeline	Does the minor road have striped edgelines? (1=yes, 0=no)

Source: Dixon, p 28

EXHIBIT 2-11 Methods to find values for characteristics

State	$AADT_{minor}$	Minimum Segment Length	Sideslope	Grade
Florida	database	0.1 mi	use HSM default = 1V:7H or flatter	use HSM default = 0%
Louisiana[2]	not explained	not explained	estimated from photographs and videos	not explained
Maryland	model	0.1 mi	manually gathered from eGIS of SHA	Google Earth profile average, one of 3 groups (<3%, 3%-6%, >6%)
Missouri	database	0.5 mi	use HSM default = 1V:7H or flatter	use HSM default = 0%
North Carolina	database	0.01 mi	not explained in report	not explained in report
Oregon	model	0.1 mi	ODOT digital video log	ODOT state highway vertical grade report
Utah	N/A[1]	0.2 mi	not explained in report	Google Earth
Virginia	database	0.25 mi	not explained in report	not explained in report

[1] Utah did not calibrate intersections

[2] Information from Louisiana was obtained through a phone conversation with LaDOTD

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CHAPTER 3: RESEARCH METHODOLOGY

The *Highway Safety Manual* (HSM) provides predictive methods to examine traffic collision data and develop Safety Performance Functions (SPFs) for the following six rural roadway categories.

2-lane undivided,

4-lane undivided,

4-lane divided,

3-leg STOP controlled intersections,

4-leg STOP controlled intersections, and

4-leg SIGNAL controlled intersections.

Note that the HSM does not at this time have a procedure to deal with rural roadways having flush medians, either painted or with two-way left-turn lanes (TWLTL) (HSM, 11-3). After reviewing the available number of samples and eliminating categories with sample size is too small, we proceeded to examine data for the categories presented in the following Exhibit 3-1 matrix.

EXHIBIT 3-1 Types which were calibrated

	2-lane undivided	4-lane divided
Rural Segments	✓	✓
Rural 3-leg STOP controlled intersections	✓	✓
Rural 4-leg STOP controlled intersections	✓	✓

The roadway inventory file from which segments were selected contained 135 homogenous rural segments categorized as multilane undivided roadways. These 135 segments were located using Google Maps and MMHIS data (if available). Some segments listed as multilane undivided were found to be segments of 2-lane roadways with passing lanes in both directions, or segments where the passing lanes would overlap for a short time. These segments were noted as “Passing Lanes” and removed from consideration.

With the remaining segments, the posted speed limit was identified. Those segments with a speed limit below 50 mph were tagged as “Speed Limit ##mph” and discarded.

Each segment was viewed to identify those that were not truly undivided. Segments found to have a narrow (e.g., 4 ft) painted median or a TWLTL were tagged and removed from consideration.

Once the segments with passing lanes, low-speed roadways, or median treatments were discarded, only 14 segments suitable for SPF calibration purposes remained. The breakdown of segment properties can be seen in Exhibit 3-2. With the HSM suggesting a minimum of 30 sites and 100 annual crashes a year, this type falls far short of the minimum site requirements, so calibration was not performed for multilane undivided segments.

Exhibit 3-2 Multilane undivided segments discarded for various reasons

Factor under consideration	Number of segments in category
Passing lanes	28 discarded
Speed limit ##mph	47 discarded
4 ft painted median	27 discarded
TWLTL	8 discarded
Other non-homogenous segments	11 discarded
Usable segments	*14 retained*
Total segments	**135**

While using Google Maps and MMHIS video to investigate the 135 segments in the multilane undivided pool, some 4-lane undivided roadways not in this pool were encountered that may be categorized as “urban” but appear to be in rural areas. Perhaps these rural areas are categorized as urban due to their proximity to the city limit boundaries; these were parts of US 79 in the Pine Bluff area.

DATA ANALYSIS PROCEDURE OVERVIEW

The HSM requires that a site must maintain specified homogenous factors throughout the entire segment. In defining a two lane roadway and differentiating from a four-lane roadway, the HSM considers roadways having the following features to be a rural two lane segment (HSM, p C-13).

- passing lanes in one or both directions, if less than 2 miles in length
- two-way left-turn lanes (TWLTLs), if less than 2 miles in length

In either case, the presence of the extra lane(s) calls for applying a CMF to the 2-lane SPF calculations.

Obviously, the HSM exerts a major influence on efforts to calibrate safety performance functions. Volume 2 of the HSM (p A-3) contains the following guidance.

- “For each facility type, the desirable minimum sample size … is 30 to 50 sites
- the entire group … should represent a total of at least 100 crashes per year
- If … fewer than 30 sites for a particular facility type … use all of those available sites
- it may be desirable to … develop separate calibration factors for each … geographical region
- calibration periods longer than three years are not recommended”

However, a few procedures unique to this particular study were developed.

- Speed. The Federal Highway Administration (FHWA) categorizes roadways within an incorporated city of less than 5000 population as rural, and it is our understanding that the HSM rural safety performance functions reflect this definition; i.e., crash histories from roadways in small towns were included in the development of "rural" functions. This definition of "rural" areas encompasses smaller towns in which the driving environment is considerably different than that of the open road, as Exhibit 3-3 depicts. Because of this difference between environments, we thought it unwise to combine crash experience from a 55 mph truly rural highway with that of say, a 40 mph roadway in a town of 1500. *A Policy on Geometric Design of Highways and Streets* defines a high-speed road as any roadway designed to equal or exceed a 50 mph speed limit (AASHTO, 2-58). Combining these considerations, we employed a criterion of excluding any segment categorized as "rural" having a posted speed limit of less than 50 mph. Based on Arkansas speed signing practices, this will produce a truer rural environment.

  For the purposes of this analysis, the posted speed limit must remain constant. The point at which the speed limit changes defines where a new segment begins.

EXHIBIT 3-3 Traffic characteristics in a town with 1500 population not rural

- Segment length. Chapter 10 of the HSM (p 10-13), addressing rural two-lane roads, states "There is no minimum roadway segment length …", then proceeds to state that a minimum length of 0.10 mile will not affect results. Given that either faulty crash location information in the original crash report or coding error can result in inaccurate location of a crash, we were more comfortable with a minimum segment length of 0.20 of a mile. However, when working with the file for two-lane rural segments, we realize that the longer the minimum segment length, the greater likelihood of excluding horizontal curves. The final resolution of this was a 0.2 mile minimum length for four-lane segments, and a 0.15 mile minimum length for two-lane segments. In those instances where it was noted that all of the critical attributes (e.g., lane width) for a short segment were equal to those of an adjacent segments, opportunities were found to salvage segments that were otherwise too short by combining them to create one of sufficient length.

- Vertical alignment. For rural two-lane roads, the HSM procedure calls for creating a new segment at each point of vertical intersection (HSM p 10-12). However, the roadway information ArDOT provided did not define these vertical alignment points.

Based on this guidance, the following general procedure evolved. The Appendix explains the procedures in much greater detail.

- Obtain roadway network descriptive data.
- Select segments and intersections to analyze.
- Obtain crash data for selected segments and intersections.
- Obtain videos of selected segments from ArDOT.
- Check segment data bases for confounding factors, such as change in log mile numbering or construction during period of analysis.
- Check for factors that can either affect calibration or eliminate a location, e.g., speed limit, intersection traffic control devices, etc.
- Make adjustments of delete segments and intersections, as required.
- Identify and code the crashes within the limits of the segment or intersection.
- Compare the actual number of crashes with that predicted by HSM equations to derive the calibration factor.

SPECIFIC DATA ANALYSIS ISSUES

This section provides more detail about selected data analysis procedures.

Dividing the State Topographically

We divided the state into two topographic regions, designated as “flatter” and “hilly”. The Ozark and Ouachita areas were considered hilly, with the south and east parts of the state, as well as the River Valley, considered flat. The dashed dividing line Exhibit 3-4 shows was defined visually with the aid of QGIS software and “hillshaded” maps, supplemented by telephone conversations with ArDOT district offices. Based on this division, separate calibration factors were developed for segments in the two regions.

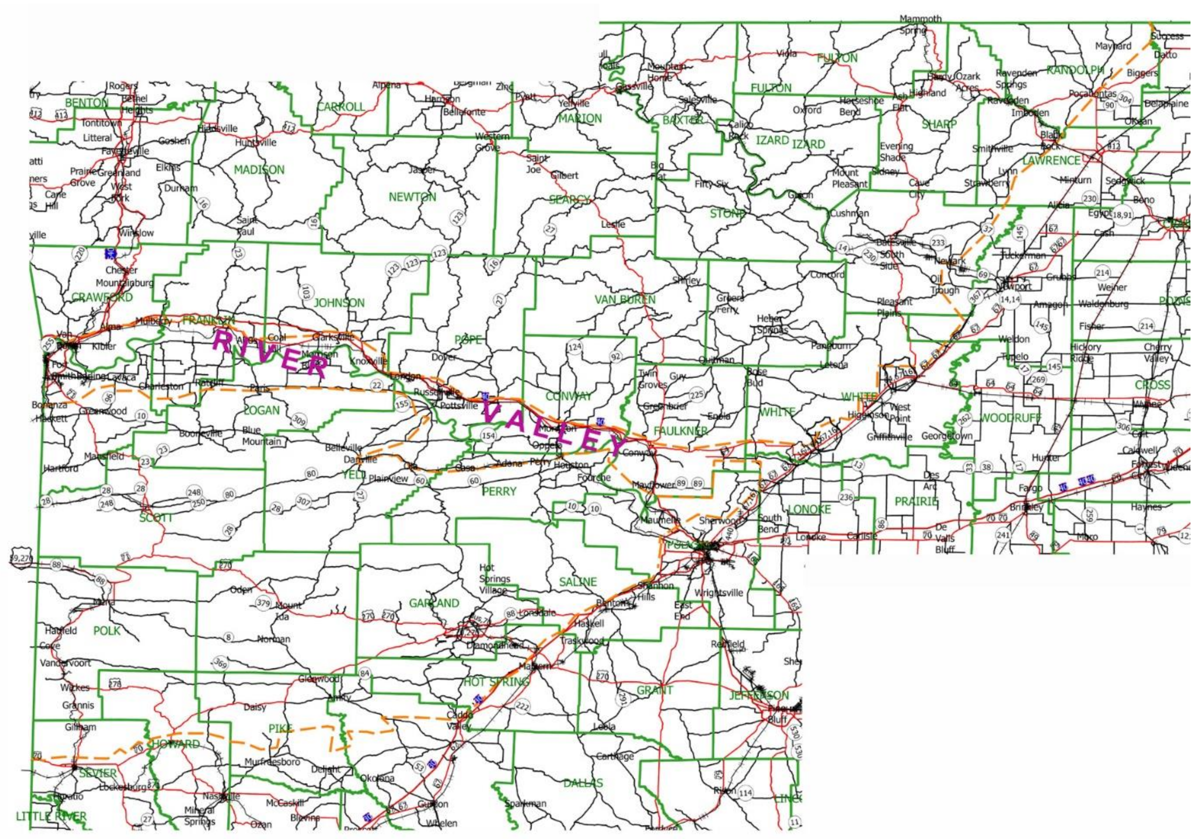

EXHIBIT 3-4 Dashed line dividing the hilly from the flatter regions

Ascertaining the Speed

As videos were viewed to ascertain the speed limit at a location, it was not uncommon to not find a posted speed limit near the site. In such cases, if the area appeared to be rural, then the speed limit was assumed to be acceptable.

Where horizontal curves were present, we determined speed based on advance curve warning speed plaques found and on estimates of the curve radius.

Determining the Intersection Skew Angle

At a skewed-angle intersection where the approach lane of the side or minor road is considerable wider than a typical lane, drivers are offered a range of possible positions at which they may orient their vehicles. In such cases, determining the effective intersection angle is somewhat subjective.

Determining Intersection Approach Volumes

For a given intersection, the approach volume was taken from the state traffic count database, supplemented by numerous special counts conducted on county roads at intersections with state highways. The following Exhibit 3-5 depicts a case in which determining the volume involves guesswork.

At the southeast edge of the city of Hope, the ADT equals 4100. The sum of the volumes of the two roadways that combine further to the southeast is 3100. This creates the appearance of 1000 unaccounted for vehicles. One reasonable explanation is that as one proceeds in a southeasterly direction from Hope, volume gradually decreases. The volume on the northwest approach to the intersection probably falls somewhere within the range of 3100 to 4100, but the exact number is a guess, with a possible error of up to roughly 25%.

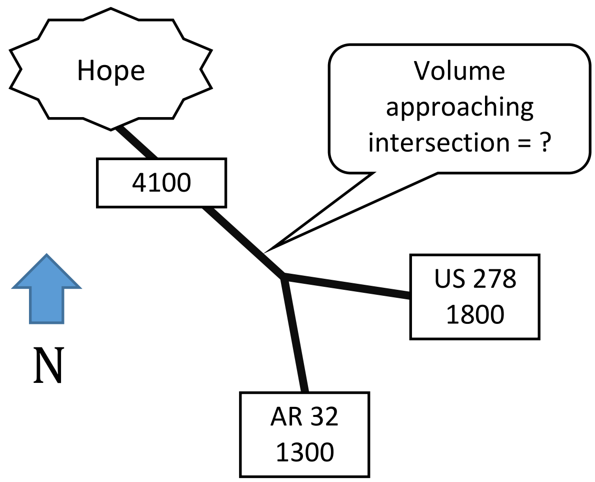

EXHIBIT 3-5 The problem with determining intersection volume

Low Volume Intersections

While working with the data and gaining familiarity with its nuances, we became aware of the obvious: in general, side roads leading to intersections in rural, uninhabited areas tend to have low volumes.

As the initial pool of rural intersections was expanded more and more, in an attempt to have a pool with a greater number of crashes, we seemed to have reached the point of diminishing returns, in that we were adding more intersections but not increasing the number of crashes. In spring of 2017, a new threshold criterion was established for adding intersections to the pool: main road volume at least 800, side road volume at least 200, some of both at least 1300.

Crash Underreporting

As we compiled and worked with the data, we encountered unexpected patterns (see Exhibits 3-6 and 3-7), which in turn raised suspicions that local crash reports from some counties were not making their way into the statewide crash database. According to *Arkansas 2013 Traffic Crash Statistics*, by the Arkansas State Police, 26.2% of all crashes statewide are reported by the state police, 7.4% by the county sheriffs', and 66.1% by city police. Overall, the State Police submitted about 3.5 times the number of crash reports as did sheriffs.

EXHIBIT 3-6 Examining crash percentages from selected counties

County and Year	% of VMT on state routes	% of crashes on state route	% of crashes in state database investigated by State Police	% of crashes in state database investigated by county sheriff
Bradley 2011	69%	68%	64%	0%
Bradley 2012	68%	96%	100%	0%
Bradley 2013	67%	96%	100%	0%
Cleveland 2011	79%	98%	100%	0%
Cleveland 2012	79%	99%	100%	0%
Cleveland 2013	77%	97%	100%	0%
Conway 2011	90%	82%	59%	27%
Conway 2012	90%	84%	69%	20%
Conway 2013	89%	88%	69%	24%
Izard 2011	66%	95%	95%	1%
Izard 2012	65%	97%	100%	0%
Izard 2013	60%	98%	98%	0%
Lafayette 2011	73%	74%	56%	38%
Lafayette 2012	71%	84%	55%	32%
Lafayette 2013	69%	94%	97%	0%
Nevada 2011	87%	97%	97%	0%
Nevada 2012	88%	99%	99%	0%
Nevada 2013	89%	98%	98%	1%
Newton 2011	77%	98%	100%	0%
Newton 2012	78%	98%	100%	0%
Newton 2013	78%	99%	100%	0%

Inspecting Exhibit 3-6, note the following patterns that suggest a disconnect between crash reporting at the local level and the statewide database.

- In Conway County, which includes an Interstate highway, about 9/10 of the estimated countywide vehicle miles of travel occurs on state routes; slightly over half of the recorded crashes were reported to be on state routes. About 70% of reported crashes were investigated by the State Police, with another 25% by the sheriff's office. For the most part, nothing in these numbers raises a suspicion. However, one might suspect that some crash reports from municipal law enforcement agencies are missing from the statewide database.

- Contrast the numbers from Conway County with those of Cleveland and Newton Counties. In none of these counties is there a single crash report from a sheriff's office in any of the three years. In all but one year from one county, the State Police were the source of all reported crashes. Either all local roads are extraordinarily free of reportable crashes, or local crash reports are missing. The pattern from Izard County was similar.
- Bradley County presents an interesting pattern. In 2011, about 1/3 of reported crashes were from local law enforcement, but none came from the sheriff's department. In the following two years, none of the crash reports were from local agencies. During all three years, the estimated proportions of vehicle miles of travel on state numbered routes remained fairly constant.
- Lafayette County presents a pattern similar to that of Bradley County. In 2011 and 2012, over 1/3 of reported crashes were from the sheriff's department, and the sheriff's department combined with the State Police accounted for roughly 90% of reported crashes. While the estimated vehicle miles of travel on state roads within this county remained fairly constant, there was an abrupt change in the source of crash reports in 2013. The sheriff's department reported no crashes, and only 3% were from other local agencies.

EXHIBIT 3-7 Contrasting statewide and county database crash totals

County and Year	Crashes in state database investigated by State Police	Crashes in state database investigated by county sheriff	Crashes NOT in state database investigated by county sheriff	Crashes NOT in state database on Dept roads investigated by county sheriff	Crashes NOT in state database on eligible Rural 2-Ln investigated by county sheriff
Boone 2011	202	0	9	3	0
Boone 2012	196	2	4	2	2
Boone 2013	202	2	10	4	2
Cleveland 2011	65	0	20	20	8
Cleveland 2012	70	0	12	11	3
Cleveland 2013	76	0	23	23	9

Prompted by these concerns, we requested and received crash data from the sheriff's departments in two counties. Exhibit 3-7 displays crash totals that contrast numbers in the statewide database with information held within a county. This comparison raises the possibility that some local agencies either occasionally or completely fail to submit crash reports.

Crash Variability Over Time

For this calibration effort, we employed the latest available annual crash data at the time the project was underway, that from 2011, 2012, and 2013. One issue of interest to users of the calibration factors is how well the crash history of this three-year period relates to the present. To investigate this, we examined trends in crash totals from Arkansas State Police annual reports over recent years.

We first compared total numbers of crashes from 2006 through 2014 (see Exhibit 3-8). Preliminary indications are that the number of crashes in 2015 increased from 2014. The statewide numbers of crashes were at their lowest during the 2011-2013 interval used for calibration. The numbers of crashes per year in 2008 and later were considerably less than those in 2006 in 2007. It may be that the years 2008, 2009, 2010, and 2014 better reflect current experience, although this will be known only in hindsight. The average of the numbers of crashes per year during these four years exceeded the 2011-2013 average by 5.6%. The outcome of this analysis directed us to confine our comparisons to the 2008 through 2014 interval.

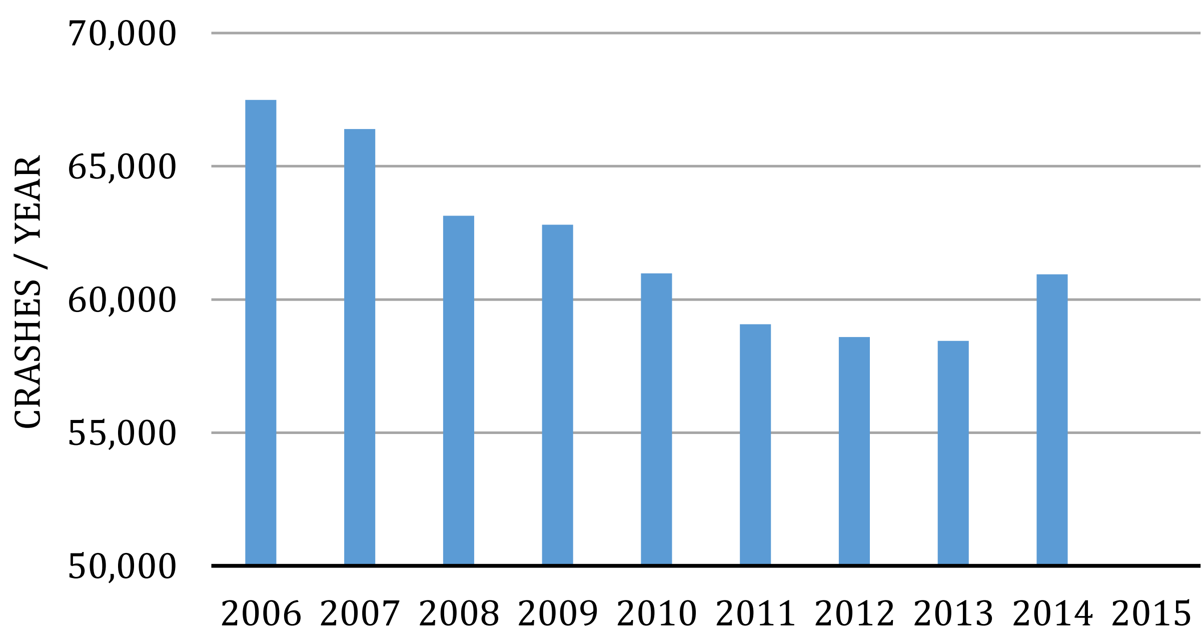

EXHIBIT 3-8 Total number of crashes in statewide database

Exhibit 3-9 presents the relative proportions of property damage only (PDO), injury, and fatal crashes. Note that the proportions vary only slightly from year to year. On average in 2008, 2009, 2010, and 2014, about 68% of crashes are PDO, about 31% involve injury, and 0.8% are fatal. The 2011-2013 averages were very close to these.

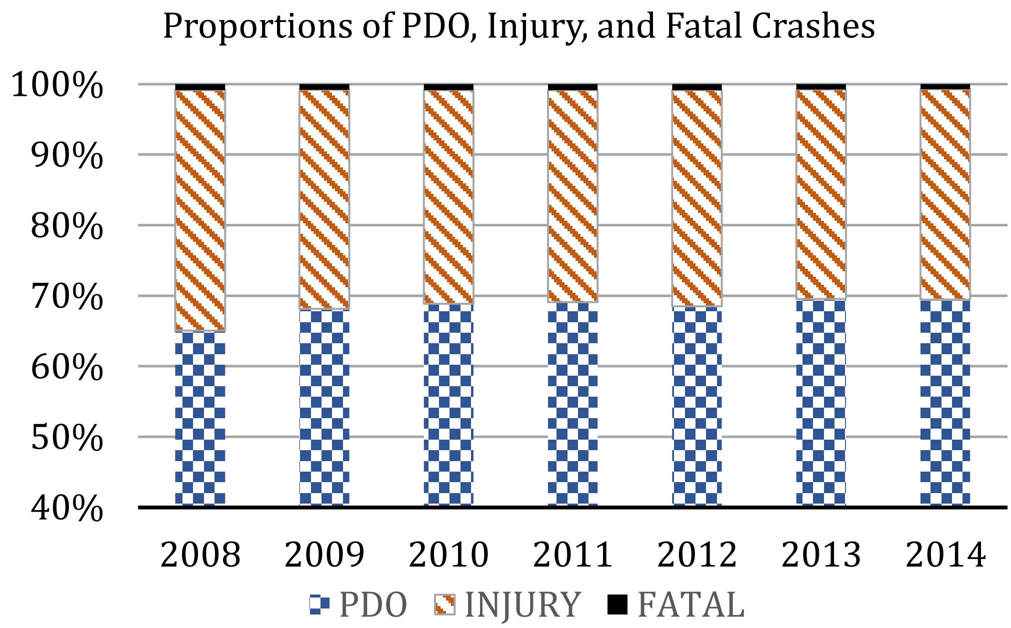

EXHIBIT 3-9 Proportions of PDO, injury, and fatal crashes

Exhibit 3-10 shows the proportions of crashes reported as occurring in daylight and in dark. The totals do not add to 100%, since a few crashes are categorized as "other" or as "unknown". On average, in both the three-year calibration period and in the surrounding four years, about 75% of crashes are reported as occurring in daylight and 22% in dark conditions.

In summary, these examinations show that in recent years, the relative proportions of reported PDO, injury, and fatal crashes have remained constant, as have the proportions of crashes reported in daylight or in dark conditions. This suggests that adjustments are not called for when applying these recent historical trends to present day crash numbers by severity or light condition. However, the calibration factors based on 2011-2013 data may underpredict the numbers of crashes in subsequent years by approximately 5% to 6%. Exhibit 3-11 compares Arkansas crash severity proportion with portions found in the HSM.

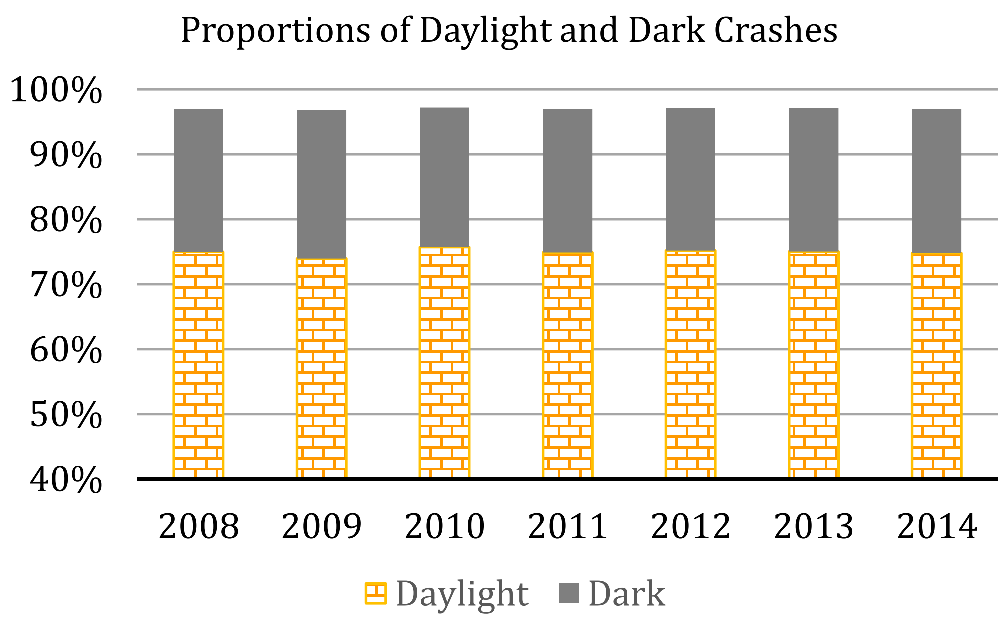

EXHIBIT 3-10 Proportions of daylight and dark crashes

EXHIBIT 3-11 Comparing Arkansas and HSM crash proportions

	Arkansas proportion	HSM proportion R 2-Lane segments (Washington)	HSM proportion R 2-Lane 4-leg STOP intersections (California)
Fatal	0.8%	1.3%	1.8%
Injury – incapacitating	4.2%	5.4%	4.3%
Injury – all	31.3%	30.8%	41.3%
Property damage only	67.9%	67.9%	56.9%
Dark	~23%	37.0%	--

ATTRIBUTES OF DATABASE USED IN CALIBRATION FACTORS

The following tables (Exhibits 3-12 and 3-13) describe the data populations that serve as the basis for the safety performance function calibrations; note that C is the calibration factor.

The number of potential segments and intersections on rural four-lane divided roads is limited by the relatively few miles of rural multilane divided roadways in Arkansas. The initial pool of rural intersections on two-lane roadways consisted of 618 locations, but almost 40% of these were removed from consideration for reasons ranging from the presence of large islands to the close proximity of other intersections or commercial driveways.

EXHIBIT 3-12 Attributes of database for segment calibration

	Flatter Terrain	Hilly Terrain
Rural 2-Lane segments	# of segments = 322 # of crashes 3 yrs = 343	# of segments = 244 # of crashes 3 yrs = 318
Rural 4-Lane Divided segments	# of segments = 106 # of crashes 3 yrs = 256	# of segments = 36 # of crashes 3 yrs = 224

EXHIBIT 3-13 Attributes of database for intersection calibration

	3 Leg	4 Leg
Rural 2-Lane intersections	# of intersections = 207 # of crashes 3 yrs = 240 average C = 0.68	# of intersections = 172 # of crashes 3 yrs = 231 average C = 0.43
Rural 4-Lane Divided intersections	# of intersections = 36 # of crashes 3 yrs = 37 average C = 0.8	# of intersections = 49 # of crashes 3 yrs = 96 average C = 0.93

Prediction Equations

Exhibit 3-14 presents safety performance function equations in the 2010 *Highway Safety Manual*.

Calibration Factor Statistical Analyses

In addition to determining the calibration factors for different categories, it is also of interest to know the standard error of such factors. Given information about segment length, volume, N number of crashes at site j, and calibration factor C = $N_{actual}/N_{predicted}$, one can find the variance of calibration factor estimate V(C') with the following equation (Bahar and Hauer, p 152).

$$V\{C'\} = \frac{\sum_{all\ j}\ (\ N_{actual\ at\ site\ j}\ +\ k_j\ N^2_{actual\ at\ site\ j}\ )}{(\ \sum_{all\ j} N_{predicted\ at\ site\ j}\ )^2}$$

Standard error of calibration factor is the square root of V(C'). This standard error allows one to say that the true calibration factor lies within plus-or-minus a certain number, with a certain degree of probability. To illustrate this, if the mean is 0.80 and the standard error is 0.15, then the true value of the mean will be 0.80 $\pm$ 0.15, 90% of the time.

To respond to a request, we also calibrated the coefficient of determination (R^2) for the calibration factors. Recall that while a safety performance function may reasonably well predict the aggregate number of crashes for a number of similar locations, due to the randomness of crash occurrence, the functions are not as well suited to closely predicting numbers of crashes at a single location over a short time span, especially one with a low frequency of crash occurrence.

Numbers of Crashes

The numbers of crashes found in the state database for these rural locations were less than expected. In response to concerns expressed about this, we recounted crashes on one of the types, the intersections on rural multilane divided roadways. The student workers had tallied 142 crashes. The Principal Investigator checked 123 out of a total of 255 entries. From this spot check, the decision was made to revise numbers for 12 entries, creating a revised total of 133 crashes for these sites, even fewer than before.

EXHIBIT 3-14 Safety performance functions employed in this report

Type	$N_{predicted}$ =	over-dispersion parameter k
Rural segment 2-lane, 2-way	$L \times AADT \times 365 \times 10^{-6} \times e^{-0.312}$	$k = 0.236 / L$
Rural segment 4-lane divided	$e^{[-9.025 + 1.049 \ln(AADT) + \ln(L)]}$	$k = 1 / e^{[1.549 + \ln(L)]}$
Rural intersection 2-lane, 3-leg STOP control	$e^{[-9.86 + 0.79 \ln(AADT_{major}) + 0.49 \ln(AADT_{minor})]}$	k = 0.54
Rural intersection 2-lane, 4-leg STOP control	$e^{[-8.56 + 0.60 \ln(AADT_{major}) + 0.61 \ln(AADT_{minor})]}$	k = 0.24
Rural intersection 4-lane, 3-leg STOP control	$e^{[-12.526 + 1.204 \ln(AADT\ major) + 0.236 \ln(AADT\ minor)]}$	k = 0.460
Rural intersection 4-lane, 4-leg STOP control	$e^{[-10.008 + 0.848 \ln(AADT_{major}) + 0.448 \ln(AADT_{minor})]}$	k = 0.494

AADT = volume L = segment length

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CHAPTER 4: CALIBRATION FACTORS AND THEIR APPLICATION

Exhibits 4-1 and 4-2 present the safety performance function calibration factors computed for rural segments and rural intersections on the state highway system; Exhibit 4-3 explains the meanings of some of these statistical terms. The equations in the 2010 HSM overpredicted the numbers of crashes recorded on both segments and intersections of these rural roadways in Arkansas with speed limits equal to or above 50 mph.

In addition to the calibration factors (C), the tables include their standard errors, 95% confidence intervals (CI), squared correlation coefficients (R^2) between crashes predicted and recorded, and mean absolute deviations (MAD) between crashes predicted and recorded. For sample sizes, see numbers of segments and intersections in Exhibits 3-12 and 3-13, respectively.

EXHIBIT 4-1 SPF calibration factors for rural segments

	Flatter Terrain	Hilly Terrain
Rural 2-Lane segments	Calibration factor C = 0.54 Standard error = 0.17 95% CI = (0.204, 0.872) R^2 = 0.45 MAD = 1.364	Calibration factor C = 0.73 Standard error = 0.32 95% CI = (0.107, 1.357) R^2 = 0.33 MAD = 1.198
Rural 4-Lane Divided segments	Calibration factor C = 0.66 Standard error = 0.17 95% CI = (0.337, 0.992) R^2 = 0.42 MAD = 2.248	Calibration factor C = 0.75 Standard error = 0.23 95% CI = (0.303, 1.205) R^2 = 0.67 MAD = 3.379

EXHIBIT 4-2 SPF calibration factors for rural intersections

	3 Leg	4 Leg
Rural 2-Lane intersections STOP control	Calibration factor C = 0.65 Standard error = 0.19 95% CI = (0.278, 1.031) R^2 = 0.31 MAD = 1.104	Calibration factor C = 0.46 Standard error = 0.12 95% CI = (0.218, 0.693) R^2 = 0.29 MAD = 1.929
Rural 4-Lane Divided intersections STOP control	Calibration factor C = 0.70 Standard error = 0.29 95% CI = (0.129, 1.265) R^2 = 0.14 MAD = 1.103	Calibration factor C = 0.74 Standard error = 0.22 95% CI = (0.304, 1.180) R^2 = 0.11 MAD = 1.806

EXHIBIT 4-3 Explaining statistical measures

Symbol	The following information is meant to clarify statistics presented in Exhibit 4-1 with calibration factors and standard errors that are explained in detail elsewhere.
CI	The confidence interval (CI) about the calibration factor C is a function of standard error (SE), where the coefficient 1.96 is a value from the standard normal distribution associated with 95% confidence. CI = [C – 1.96 (SE), C + 1.96 (SE)]
MAD	Mean absolute deviation (MAD) is the average absolute difference between crashes predicted and recorded within each sample. MAD = AVERAGE |crashes recorded – crashes predicted|
R^2	The R^2 is the coefficient of determination between crashes predicted and recorded. Consider a simple linear regression model of crashes recorded. R^2 = Regression Sum of Squares / Total Sum of Squares

CONSIDERATIONS

When considering and applying the calculated calibration factors, keep in mind the discussion from previous chapters.

- The *Highway Safety Manual* rural crash prediction models are based on data that includes roadways in towns under 5000 population. In contrast, the analyses and calibration factors herein are based on only roadways with speed limits of 50 mph or more.
- Available evidence suggests that some municipal and county law enforcement agencies do not forward all crash reports to the statewide database as required. Thus, there is probably some crash underreporting of an unknown magnitude.
- The years on which these calibration factors were based may have been years with a lower than normal crash frequency. There is some indication that numbers of crashes are slightly rebounding from this low.

As the contents of Exhibits 4-1 and 4-2 indicate, the ability of an equation to predict numbers of crashes in the short-term at any one location, especially a location with relatively low volumes and a low probability of a collision in any year, is not strong. What the equations do is predict broader tendencies for an aggregated number of locations with similar attributes.

SUGGESTIONS

This is the first large-scale foray into calibrating HSM safety performance functions to Arkansas recorded crash numbers. From this experience, a number of observations and suggestions have been derived, which may help improve the processes for similar endeavors in the future. Some of these may already be on the path to implementation, or may have even now been implemented.

1. Roadway Inventory

Expand the items catalogued to log locations of both the posted speed and the curve warning speeds, and include those items whose attributes are required to calculate crash modification factors.

2. Crash Coding

The existing database is plagued by the multiple ways in which a single street name can be entered. For instance, if a crash occurred on Main Street, it may be coded as “Main”, “North Main”, “No Main”, or “N Main”; and if Main Street also happens to be a numbered route, the crash may be coded by route number. Implementing a standardized practice could greatly reduce the numbers of crashes on the same road that are filed in different places within the database.

Universal reporting of the coordinates of the first harmful event would be a major contribution toward a more accurate crash database.

3. Crash Data Quality

Modern crash analysis practices call for an improved quality of data.

a. Timeliness. The statewide crash database should not lag more than a few months behind.

b. Completeness. Routines and analyses should be regularly run on the database that will identify agencies suspected of failing to submit crash reports.

c. Quality. Samples of individual crash reports should be drawn, and their coding into the statewide database checked for quality.

4. Future Calibrations

This project was delayed while side road volumes were collected for intersection calibrations. With the benefit of hindsight, we can now see that a better procedure would have been to focus on intersections and obtain side road volumes near the beginning of the project, then address segments during the latter half of the project timeframe.

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APPENDIX A: DATA PROCESSING PROCEDURES

This appendix presents the procedure that evolved to obtain, evaluate, and enter input data to eventually calibrate the selected *Highway Safety Manual* equations.

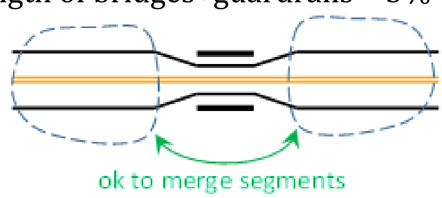
Abbreviations used herein

CL	centerline
Dept	Arkansas Dept. of Transportation
FHWA	Federal Highway Administration
HSM	*Highway Safety Manual*
LM	log mile
MMHIS	Multimedia Highway Information System
Rt	route
Sec	section
SL	speed limit
TWLTL	two-way left turn lane
UA	University of Arkansas

Step	Action	Comments
1.	Divide the state into two topographic regions: a. "Hilly", the northwest and western Ozark and Ouachita Mountain portions. b. "Flatter", the eastern, southern, southwestern, and Arkansas River Valley portions.	Performed visually with the aid of QGIS software and "hillshaded" maps, supplemented by telephone conversations with Dept district offices.
2.	Dept provides Excel file listing rural road segments on the state numbered system; each row of data constitutes 1 segment.	This rural data was defined according to the FHWA "under 5000 population" definition.
3.	Types of segments not suitable for study (e.g., 1-lane, "Special" system within a state institution) are removed from lists.	Acting on advice from Dept, deleted "special system" roadways from consideration; deleted the following categories. 3: Airport 4: Game & Fish 6: Institutional 7: State Park
4.	UA sort the list of state numbered roads into HSM categories, create separate list for each category.	**R2-U** Rural 2-lane undivided: includes TWLTL; passing lanes in one or both directions (HSM p10-2) **R2-3ST** Rural 2-lane intersection: 3-leg, STOP controlled **R2-4ST** Rural 2-lane intersection: 4-leg, STOP controlled **R4-U** Rural multilane undivided: includes 4-lane Excludes: flush, painted median; > 4 lanes; near

	Intersections are selected later. Due to the low number of sites, project will not consider rural signalized intersections.	interchange (HSM p11-2,3); does not address TWLTL. **R4-D** Rural multilane divided: includes 4-lane with restrictive median. Excludes: > 4 lanes; near interchange (HSM p11-2,3). For segments with 2 roadways built at different times, see HSM p11-17. **R4-3ST** Rural multilane Intersection: 3-leg, STOP controlled **R4-4ST** Rural multilane Intersection: 4-leg, STOP controlled
5.	Select segments from each category. Initially selected with random number generator, but soon replaced this method with selection of every n^{th} segment in the list.	Excluded segments from selection list if: • posted speed limit less than 50 mph; • length less than 0.2 mile for **R4-D**, 0.15 mi for **R2-U**. However, if a selected segment is too short but has same attributes (i.e., lane width, etc.) and similar volume as adjacent segment has, then combine adjacent segments into one.

6.	For the selected segments for 2011 through 2013 time period, request additional data from Dept: MMHIS video, Construction dates, Log mile changes, Volumes	The initial file from Dept contains lane width, shoulder width, shoulder type, median width, TWLTL presence.
note	When copying from one Excel file to another, do not assume that rows' numbers in one file match those of another; double check the Rt/Sec/LM for origin and destination files	Note: In Dept Rt/Sec/LM files, "Segment = 010" means Segment 1.
note	When referring to online aerial maps, use images from the project time period (2011-2013) if available.	
note	MMHIS – Google Earth version	CTR (hold), LT to bring list of nearby segments

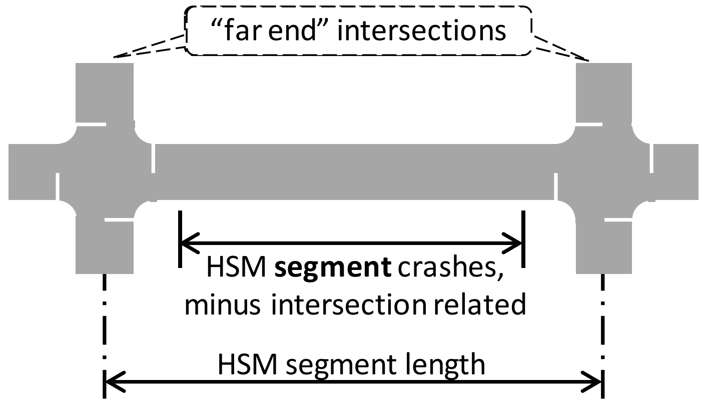
	FOR SEGMENTS …	
8.	After receiving MMHIS videos, check each segment, determine which part of segment is usable. Revise the log mile numbers to reflect only usable portions. If have MMHIS for multiple years, view video closest to time window of crash files.	Use the Dept Rt-Sec-LM map to locate the segment; then use video. Considerations when establishing segments. 1. Constraints on extending through intersections. (1a) New segment at point where intersect with state numbered highway. (1b) Can continue the segment through insignificant intersections, such as where volume to/from side road is so low as to not change volume of the thru road. 2. Bridges. Determine if segment has bridge, including approach guardrails; delete the length of bridge(s) / approach guardrail if: (2a) shoulder is less than that of overall road; (2b) combined length of bridges+guardrails > 5% 
a.	note and make adjustments if **log mile points were changed** during 2011, 2012, 2013	Grad student to either resolve or discard. Import any notes from Dept reply.
b.	determine if any months may need to be removed from consideration due to **construction activity**	Grad student to either resolve or discard. Import any notes from Dept reply. Delete part or all of segment if has construction; if for < 6 mos, omit months.
c.	compare available video sources for **changes in road configuration,** such as different number of lanes; – also, does what you see in the video match the listing in the Excel file, col P & U thru AF ?	View Google Earth™ and MMHIS. If find changes, flag segment, do not proceed unless satisfactory explanation is found.
d.	verify that posted speed limit is **50 mph** or more;	View Google Earth™ and MMHIS. To search for SL sign, begin near edge of town, then drive away from town. Delete if cannot find a speed limit. Delete parts of segment less than 50 mph; enter adjusted log mile numbers to include only those parts with speed limit ≥ 50 mph.

	Can include inside city limit, so long as speed ≥ 50 mph.
e. **ONLY R2-U**: if entire segment not straight, then determine which part to use: straight or curved segment	View Google Earth™ and MMHIS to determine begin and end log miles.
f. For selected segment, determine if it is homogeneous with adjacent segments, so that adjacent parts can also be used	Applies only if the MMHIS video includes the adjacent segment. Change in lane width placed roadway in another 0.5 ft increments category Change in right shoulder width placed roadway in another 1 ft increment category **ONLY R4-D** change in median width places roadway in another 10 ft increments category
g. determine if any **traffic control devices** (i.e., Stop signs or traffic signals) are present on the segment	View Google Earth™ and MMHIS. If present, discuss with Dr Gattis; may delete part/all of segment if has intersection traffic control signal.
h. determine if any **railroad** crossings are present within the segment	View Google Earth™ and MMHIS. If present, discuss with Dr Gattis; may delete part/all of segment if has RR x-ing.
i. determine if any roadway **lighting** fixtures are present to illuminate the subject segment	View Google Earth™ and MMHIS. Code segment.
j. **NOT 4-D**: determine if has CL rumble strip	Compare MMHIS with Dept list.
k. add volume data; flag if volume fluctuates > 20%	Use Excel volume files.
l. **ONLY R2-U**: Rural 2-lane, estimate grade and horizontal curve radius.	Utilize functions of Google Earth™.

	FOR INTERSECTIONS …	
9.	Identify candidate rural 3-leg and 4-leg intersections. All through roads are to be state routes, side roads have STOP control. Attempt to find intersections with side road(s) also a state route, but if necessary, supplement with local roads.	For each county, view Dept state and county maps to identify candidate sites; supplement with online aerial maps. Exclude location if it appears that side road appears to lack any amount of traffic generation; discuss with supervisor. Record name of county road as shown on Google Earth. OK for side road right-turn to be YIELD control.
a.	verify **number of lanes** on through roadway;	Usable categories of THRU roadway: 2-lane; 2-lane with turn lane(s) or TWLTL; 4-lane with raised or depressed median. Exclusions include passing lanes.
b.	check roadway **pavement surface**;	Normally exclude if any of the intersection approaches are gravel or dirt.
c.	check for **turning roadways and traffic islands**;	If the through roadway turning path onto the side road includes a triangular island with a dimension perpendicular to the through road of more than 25 ft, exclude, unless also accompanied by a separate right turn lane on the through roadway. Note the island size in left column.
d.	check **speed or radius** of any curves on through roadway approach;	Record the supplemental advisory speed below the yellow curve warning sign. If do not find curve advisory speed, then measure radius. Exclude if R < 1190 ft, unless advisory plate of no less than 50 mph is present. (Basis: V=50, f=0.14, e=0.00 ⇒ R=1190’; also, V=60, f=0.12, e=0.08 ⇒ R=1200’)
e.	verify that **speed** on through roadway is **50 mph** or more;	If curves are OK, then record the posted speed limit. If cannot find sign, but roadway surroundings appear so that normal highway speed (i.e., 55 mph) is expected, then enter “ok”.
f.	check for presence of other **nearby intersections** along through roadway, or **offset intersections**;	Use online aerial maps. For 3-leg, exclude if, on opposite side of through roadway, other intersecting road or active commercial driveway is within 250 ft. For 4-leg, check with supervisor if other intersecting road or active commercial driveway is within 250 ft. If intersecting side roads are

	offset to the extent that the edge of one side road projected across the intersection does not fall within the limits of the opposite side road, then exclude.
g. determine if any traffic controls (i.e., **signals or All-Way STOP)** are present at intersection;	Use online aerial maps or MMHIS. If present, add note in left column to keep a record of this location, but do not use.
h. determine if any intersection leg crosses **railroad** at grade;	Use online aerial maps or MMHIS. -for THRU rd: If RR xing within 250 ft of intersection, do not use. -for SIDE rd: discuss with supervisor; generally exclude if within 50 ft.
i. determine if any roadway **lighting** fixtures are present over the intersection to illuminate the intersection;	Use online aerial maps or MMHIS. Record the presence.
j. measure intersection **skew angle**;	Use online aerial maps. Record the difference from 90^0.
k. compare available video sources for **changes in road configuration** during the 2011-2013 time frame;	View Google Earth™. If find changes, discuss with supervisor.
l. Send a list of selected sites to Dept. Dept copies any needed MMHIS video files for 2011, 2012 2013 on to hard drive and returns it to UA	Also ask Dept to 1. check for cons't; 2. provide volume; 3. check for LM changes.
m. note and make adjustments if log mile points were changed during 2011, 2012, 2013	**If LM change creates uncertainty, then omit intersection.** All done by Grad student. Import any notes from Dept reply.
n. determine if any months may need to be removed from consideration due to construction activity	**If construction creates uncertainty, then omit intersection.** All done by Grad student. Import any notes from Dept reply. Delete intersection if has construction; if for < 6 months, omit months.

KD 3/17/15, 4/28/16: Most of the HSM contractors considered intersection crashes as those
(a) within the physical limits of the intersection;
(b) within 250 ft of the intersection, if crash was **also** coded as "intersection related";
(c) if within 250 ft of the intersection **and** other crash attributes suggest it was related to intersection – for instance …
-- rear end (queue of vehicles backed up),
-- same direction sideswipe (changing lanes prior to turn).



These intersection crashes are NOT also included in segment crashes; no double counting.

sum of segment crashes + intersection crashes = total number of crashes

10.	**NUMBERS OF CRASHES**	
a.	Ark State Police furnish files listing Ark roadway crashes in 2011, 2012, 2013. Goal is to select sufficient number of sites in each category so that aggregate number of crashes for a category is no less than 100 per year.	For each facility, N_{min} = 30 to 50 sites (HSM Vol 2, p A-3); each drawn group with min 100 crashes/yr. Preferred number of crashes per facility type from National Cooperative Highway Research Program NCHRP 20-07/Task332, p152 ff. If insufficient number of crashes, notify DrG to add segments.
	For each selected site, search 2011, 2012, and 2013 Crash files for crashes falling within the limit of the site; enter the number of crashes in the appropriate column of that row. KD 5/10/16: p A-13 should be 200 crashes/yr. When looking in the crash record files, CAREFULLY check to verify that the descriptions in the crash file agrees with other inputs; if they disagree, there may be an error in location! Also check reference to cross streets – does it make sense?	For each year, enter numbers of "Actual Total", and "Actual 1,2,3,4" crashes (p 10-53, 11-22. Also, for intersections with street lights, enter total crashes during darkness (Col C) for each year. D: Rural or Urban H: Roadway Alignment (Straight, Curve) J : Crash in Cons't Zone K: Traffic Flow (Divided, Not Divided) L: Number of Lanes M: Relation to Junction N: Type of Traffic Control AE: At Intersecting Street AG: Dist from Nearest Intersection

11. Examine your work; have the following been addressed?	
For R2-U Rural 2-lane	
segment length - beginning and ending log mile	
posted speed limit	
ADT / Volume, separately for each year	
lane width	
shoulder width	
shoulder type	
Radius (if a horizontal curve)	All done by Grad student. Record radius when drawing the tangent line; it disappears after saving.
Δ (if a horizontal curve)	All done by Grad student. Record line bearings when drawing the tangent line; they disappear later.
Length of horizontal curve	All done by Grad student. Compare calculated length with difference in LM; adjust as required.
number of driveways	Count from MMHIS
grade	Compute from GoogleEarth elevation profile
presence of CL rumble strip	
presence of passing lanes	
presence of TWLTL	
RHR – roadside hazard rating	All done by Grad student.
number of crashes, separately for each year	
For R4-D Rural 4-lane Divided	
segment length - beginning and ending log mile	
posted speed limit	
ADT/Vol, separately for each year	
lane width	
shoulder width	
shoulder type	
median width	

	presence of lighting	
	presence of automated speed enforcement	
	number of crashes, separately for each year	
For Rural Intersections		Both Undivided and Divided
	ADT / Volume	
	number of intersection legs (3 or 4)	
	type of traffic control	
	intersection skew angle	
	number of approaches with intersection left-turn lanes, not including stop-controlled approaches	
	number of approaches with intersection right-turn lanes, not including stop-controlled approaches	
	presence of intersection lighting	
	number of crashes, separately for each year	

13. Calculate and enter the expected number of crashes.	Enter data into special calculation spreadsheet. For each segment or intersection, save a separate file. NOTE: Some spreadsheets with roadway inventory info may also have the SPF calculation "built in"; if so, will not enter data into a special calculation spreadsheet.

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APPENDIX B: USING THE ARKANSAS CALIBRATIONS

PURPOSE AND SCOPE

The purpose of this document is to explain how to apply the calibration factors (C) derived from the TRC 15-03 research project to certain safety performance functions (SPF) contained in the *Highway Safety Manual* (HSM), published by the American Association of State Highway and Transportation Officials in 2010. Calibration factors were developed for the roadway types enumerated in Exhibit B-1. The calibration factors are applicable to rural roadways and intersections on the Arkansas state-numbered system, having speeds limits or horizontal curve speeds of 50 miles-per-hour or more. Exhibit B-2 lists the volume ranges in which the 2010 HSM SPFs were developed.

EXHIBIT B-1 Types which were calibrated

	2-lane undivided	4-lane divided
Rural Segments	✓	✓
Rural 3-leg intersections, STOP controlled minor	✓	✓
Rural 4-leg intersections, STOP controlled minor	✓	✓

EXHIBIT B-2 Types which were calibrated

	2-lane undivided volume range in vpd	4-lane divided volume range in vpd
Segments	0-17,800 (HSM p 10-15)	0-89,300 (HSM p 11-18)
Intersections 3-leg, STOP	Major rd: 0-19,500 (HSM p 10-18) Minor rd: 0-4,300	Major rd: 0-78,300 (HSM p 11-21) Minor rd: 0-23,000
Intersections 4-leg, STOP	Major rd: 0-14,700 (HSM p 10-19) Minor rd: 0-3,500	Major rd: 0-78,300 (HSM p 11-21) Minor rd: 0-7,400

ABBREVIATIONS AND SYMBOLS

Exhibit B-3 lists some of the abbreviations and symbols used in this appendix.

COMPUTING SAFETY PERFORMANCE FUNCTIONS

Safety performance functions are equations that, for specific roadway types, predict a number of crashes that would occur in a given time frame. The predictions are derived from historical counts of crashes on actual roadways of a similar type, and with the presence of stated “base” conditions. For instance, for a rural intersection on a two-lane

EXHIBIT B-3 List of abbreviations and symbols

Abbreviation or symbol	Meaning
AADT	annual average daily traffic
ADT	average daily traffic
C	calibration factor
CMF	crash modification factor
ft	feet or foot
HSM	*Highway Safety Manual*
L	length of a specific roadway segment
N	number of crashes
SPF	safety performance function
vpd	vehicles per day

roadway with stop control on the minor legs, assumed base conditions consist of 0^{0} skew angle, no turn lanes on the through-road approaches, and no artificial illumination at the intersection. For complete lists of base conditions, refer to the HSM description for the particular roadway type.

Exhibit B-4 displays the SPFs from the 2010 HSM for which the 15-03 research project calculated calibration factors. These equations are further modified by the inclusion of additional terms called crash modification factors (CMF), which in effect adjust the outcome of the initial equation by accounting for differences from assumed base conditions, e.g., shoulder width other than 6 ft on a rural two-lane segment, or presence of a turn lane at a rural intersection.

To undertake the process, follow the HSM procedure to divide a roadway facility into what the HSM terms "sites", which can be intersections or single homogeneous roadway segments (HSM Vol 2, p C-8). After the publication of the 2010 HSM, the user community has moved toward limiting the length of a segment to two miles. Crashes are classified as intersection crashes if:

(a) within the physical limits of the intersection;

(b) within 250 ft of the intersection, if crash was also coded as "intersection related";

(c) within 250 ft of the intersection and other crash attributes suggest it was related to intersection, such as rear end (queue of vehicles backed up), or same direction sideswipe (changing lanes prior to turn) orientations.

Intersection crashes are not also included in segment crashes:

sum of segment crashes + intersection crashes = total number of crashes;

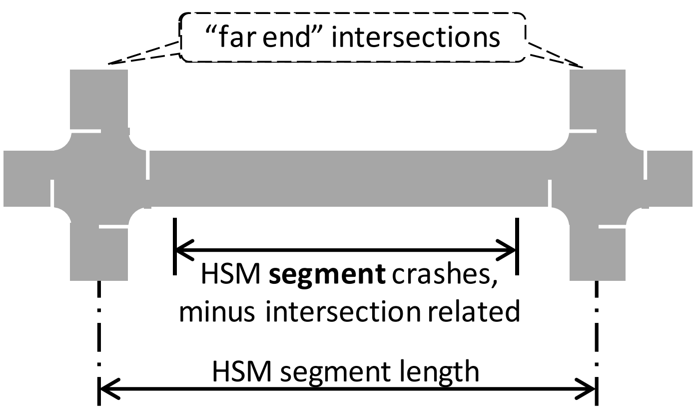
i.e., there is no double counting of crashes – see Exhibit B-5.

EXHIBIT B-4 Safety performance functions

Type	HSM reference	$N_{predicted}$ =
Rural segment: 2-lane, 2-way	Chapter 10	$L \times AADT \times 365 \times 10^{-6} \times e^{-0.312}$
Rural segment: 4-lane divided	Chapter 11	$e^{[-9.025 + 1.049 \ln(AADT) + \ln(L)]}$
Rural intersection, STOP control: 2-lane, 3-leg	Chapter 10	$e^{[-9.86 + 0.79 \ln(AADT_{major}) + 0.49 \ln(AADT_{minor})]}$
Rural intersection, STOP control: 2-lane, 4-leg	Chapter 10	$e^{[-8.56 + 0.60 \ln(AADT_{major}) + 0.61 \ln(AADT_{minor})]}$
Rural intersection, STOP control: 4-lane, 3-leg	Chapter 11	$e^{[-12.526 + 1.204 \ln(AADT\ major) + 0.236 \ln(AADT\ minor)]}$
Rural intersection, STOP control: 4-lane, 4-leg	Chapter 11	$e^{[-10.008 + 0.848 \ln(AADT_{major}) + 0.448 \ln(AADT_{minor})]}$

NOTE: AADT = volume L = segment length N = number of crashes

EXHIBIT B-5 Separating intersection crashes from segment crashes



Next, proceed to collect the inputs necessary for the SPF and the calibration computations. For instance, for a rural intersection on a two-lane roadway, with stop control on the minor approaches, inputs include volumes on all approach legs, intersection skew angles, number and type of turn lanes on the through-road approaches, and absence or presence of artificial illumination at the intersection. The lists of requisite inputs vary according to the facility type.

Then, execute the SPF calculation for the site, and also apply the calibration factors. For an example, Exhibit B-6 presents the inputs for a hypothetical rural 3-leg intersection on a two-lane road, with stop control on the minor approach.

EXHIBIT B-6 Inputs for example problem

Volume major approach 1	Volume major approach 2	Volume minor approach	Skew angle = 90^0 – actual angle	Presence of left turn lane on major road	Presence of right turn lane on major road	Presence of artificial illumination
4000 vpd	3600 vpd	400 vpd	10^0	yes	yes	no
			$e^{(0.004\,x\,skew)}$	0.56	0.86	1

Given these inputs, the safety performance function and the crash modification factors are applied as follows. Note that the larger of the two major road volumes is used (HSM p 10-6).

$$e^{[-9.86 + 0.79 \ln(AADT_{major}) + 0.49 \ln(AADT_{minor})]} \times CMF_i$$

$$e^{[-9.86 + 0.79 \ln(4000) + 0.49 \ln(400)]} \times 1.04 \times 0.56 \times 0.86 \times 1 = 0.35\ crash/yr$$

Thus, before calibration, the process is predicting 0.35 crashes per year at this intersection.

APPLY CALIBRATION FACTORS

The following two tables (Exhibits B-7 and B-8) list the calibration factors to apply to the unadjusted predicted numbers of crashes for both segments and intersections, along with the standard errors of the means.

EXHIBIT B-7 SPF calibration factors for rural segments

	Flatter Terrain	Hilly Terrain
Rural 2-Lane segments	Calibration factor C = 0.54 Standard error = 0.17	Calibration factor C = 0.73 Standard error = 0.32
Rural 4-Lane Divided segments	Calibration factor C = 0.66 Standard error = 0.17	Calibration factor C = 0.75 Standard error = 0.23

EXHIBIT B-8 SPF calibration factors for rural intersections

	3 Leg	4 Leg
Rural 2-Lane intersections STOP control	Calibration factor C = 0.65 Standard error = 0.19	Calibration factor C = 0.46 Standard error = 0.12
Rural 4-Lane Divided intersections STOP control	Calibration factor C = 0.70 Standard error = 0.29	Calibration factor C = 0.74 Standard error = 0.22

Before applying calibration factors for rural segments, one must first determine in which of the two topographic regions the site falls. The state was divided into two topographic regions, designated as "flatter" and "hilly". The Ozark and Ouachita areas were considered hilly, with the south and east parts of the state, as well as the River Valley, considered flat. The dashed dividing line Exhibit B-9 demarks the two areas.

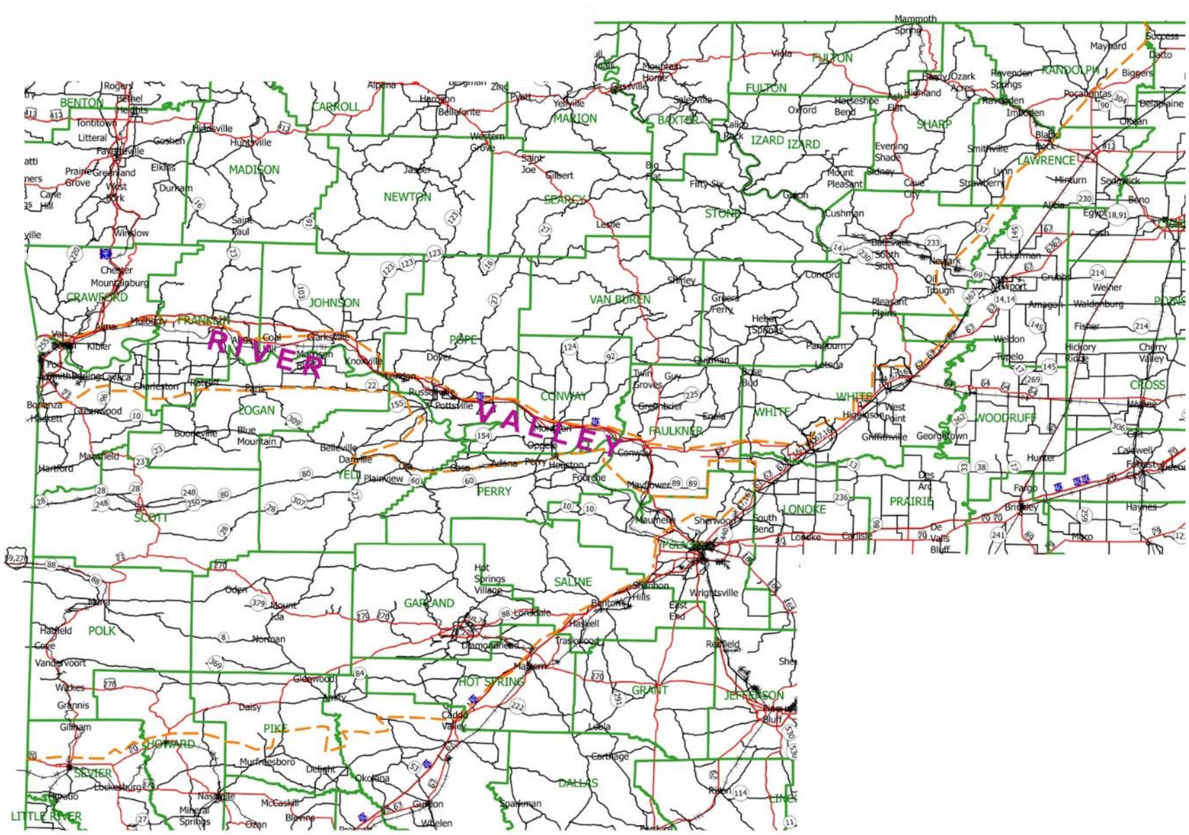


EXHIBIT B-9 Dashed line dividing the hilly from the flatter regions

Continuing the previously developed hypothetical example of a rural three-leg intersection, the uncalibrated predicted number of crashes is 0.35 crashes per year at this intersection. Application of the calibration factor for rural three-leg intersections on two-lane roadways produces the following prediction.

$$0.35\frac{crashes}{year} \times 0.65 = 0.23\frac{crashes}{year}$$

When applying the factors calibrated to actual historical Arkansas crash data, remember the following.

- Available evidence suggests that some municipal and county law enforcement agencies do not forward all crash reports to the statewide database as required. Thus, there is probably some crash underreporting of an unknown magnitude.

- The years on which these calibration factors were based may have been years with a lower than normal crash frequency. There is some indication that numbers of crashes are slightly rebounding from this low.

Either of these could cause the calculated calibration factors to be slightly less than they should, resulting in a calibrated prediction slightly below what it should be.