VALIDATION OF HSM CRASH PREDICTION METHODS FOR SPECIFIC INTERSECTION TYPES IN OREGON

Final Report

SPR 871

Oregon Department of Transportation

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by

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16. Abstract

The Highway Safety Manual ("HSM") is the national guidance of quantitative safety analysis used in highway transportation planning, alternatives development, highway design, operations, and maintenance. However, some safety prediction models in the HSM were developed using data from other states, not Oregon. Therefore, it is necessary to validate these models for the implementation in Oregon. Recently the National Cooperative Highway Research Program ("NCHRP") project 17-68 "Intersection Crash Prediction Methods for the Highway Safety Manual" has developed safety prediction models for more intersection types. The types of intersections include all-way stop control, three-leg intersections with signal control on rural highways, intersections on high-speed urban and suburban arterials, and five-leg intersections, among others. Currently, there is no guidance for how to use these new models in Oregon. Hence, it is necessary to validate these models to facilitate implementation in Oregon. This report documents the research team's efforts to calibrate intersection models documented in NCHRP 17-68 to Oregon conditions, and to update analysis tools to facilitate implementation of the models.

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yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
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ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
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fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
MASS					**MASS**				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)					**TEMPERATURE (exact)**				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

In the United States, the American Association of State Highway Officials (AASHTO) *Highway Safety Manual* (HSM) is the national guidance document for conducting quantitative safety analysis for streets and highways (AASHTO, 2010). This document is used in highway transportation planning, alternatives development, highway design, operations, and maintenance. The safety performance functions (SPFs) and adjustment factors (AFs) or crash modification factors (CMFs) are included in the HSM to predict the traffic crashes and to understand the influence of different variables. These procedures are used to provide a guideline to identify opportunities to improve transportation safety. SPFs and their associated safety assessment procedures continue to be developed for inclusion in the HSM. As SPFs continue to be developed for intersection and segment locations, there is also a need to confirm that nationally developed SPFs reflect local safety conditions within the State of Oregon.

Recently, the National Cooperative Highway Research Program (NCHRP) Project 17-68, "Intersection Crash Prediction Methods for the Highway Safety Manual" (Torbic et al., 2021), developed a suite of crash prediction models for intersection types for inclusion into the second edition of the HSM. The results of the resulting NCHRP project, published in a Web-Only Document 267, include the list of intersections shown in Table 1-1. Appendix A includes an acronym / abbreviation table. The SPFs developed in the NCHRP study were developed using data from states other than Oregon. Several Oregon-specific characteristics indicate that the reported crash history for Oregon may differ from other states. One of these specific differences is the fact that minor Oregon crashes are self-reported. This means that when a person is involved in a crash and there are no injuries as a result of the crash, the individual drivers must prepare the crash reports (law enforcement officers do not generally respond to the crash site and, if they do, will not be responsible for completing the associated crash report for these non-injury collisions).

In addition to the self-reporting difference, Oregon also has different crash reporting thresholds than their neighboring states to the north and south (the states for which injury proportions are included in the HSM). For example, if a driver is involved in a crash which causes injury, death, or more than $2,500 damage to vehicles (including damage to any vehicle over $2500 and any vehicle is towed from the scene as a result of damage, or damages to anyone's personal property other than a vehicle involved in the crash), the driver must file an Oregon Traffic Accident and Insurance Report within 72 hours. As a result, many property-damage-only (PDO) crashes are not reported in Oregon if their value is below the $2,500 threshold. By comparison, the reporting thresholds for Washington and California are $1000 for PDO crashes (California Department of Motor Vehicles, 2011; Washington State Highway Patrol, 2006). The Oregon crash reporting threshold was $1500 until 12/31/2016.

Table 1-1: Safety Performance Functions Developed in NCHRP 17-68

Facility Type	Intersection Type	Crash Severity
All-Way Stop Control	Three-leg all-way stop-controlled intersections on rural highways (3aST)	Total crashes
All-Way Stop Control	Four-leg all-way stop-controlled intersections on rural highways (4aST)	Total crashes
All-Way Stop Control	Three-leg all-way stop-controlled intersections on urban and suburban arterials (3aST)	Fatal and injury (FI) and property damage only (PDO) crashes
All-Way Stop Control	Four-leg all-way stop-controlled intersections on urban and suburban arterials (4aST)	FI and PDO crashes
Rural Three-leg signalized with signal control	Three-leg intersections with signal control (3SG) on rural two-lane highways[1]	Total crashes
Rural Three-leg signalized with signal control	Three-leg intersections with signal control (3SG) on rural multilane highways[1]	Total and FI crashes
High-Speed Urban and Suburban Arterial	Three-leg intersections with minor road stop control on high-speed urban and suburban arterials (3ST-HS)	Multiple-vehicle [MV] total, MV FI, MV PDO, single-vehicle [SV] total, SV FI, and SV PDO crashes
High-Speed Urban and Suburban Arterial	Three-leg intersections with signal control on high-speed urban and suburban arterials (3SG-HS)	Multiple-vehicle [MV] total, MV FI, MV PDO, single-vehicle [SV] total, SV FI, and SV PDO crashes
High-Speed Urban and Suburban Arterial	Four-leg intersections with minor road stop control on high-speed urban and suburban arterials (4ST-HS) [1]	Multiple-vehicle [MV] total, MV FI, MV PDO, single-vehicle [SV] total, SV FI, and SV PDO crashes
High-Speed Urban and Suburban Arterial	Four-leg intersections with signal control on high-speed urban and suburban arterials (4SG-HS) [1]	Multiple-vehicle [MV] total, MV FI, MV PDO, single-vehicle [SV] total, SV FI, and SV PDO crashes
Atypical Configurations	Five-leg Intersections	MV total, MV FI, MV PDO, SV total, SV FI, and SV PDO crashes
Atypical Configurations	Rural two-lane three-leg turning intersections (3STT)	Total crashes
Atypical Configurations	Urban and suburban arterial three-leg turning intersections (3STT)	MV total, MV FI, MV PDO, SV total, and SV PDO crashes
Ramp Terminals	Crossroad ramp terminals at single-point diamond interchanges	FI and PDO crashes
Ramp Terminals	Crossroad ramp terminals at tight diamond interchanges	FI and PDO crashes

[1]SDFs were developed for these intersection types.

Currently, there is no definitive guideline for how to use these new crash prediction models for facilities in Oregon. It is necessary to validate these SPFs and AFs or CMFs to guide the statewide implementation. The purpose of this research project is to assess how well these SPFs predict Oregon crash conditions and develop the needed adjustments. Data Collection

1.1 SITE IDENTIFICATION PROCESS

Key issues that govern site identification are incorporated in the data collection process. These items include site selection and sample size selection.

1.1.1 Site Selection

In a previous Oregon research project, members of the research team developed a method for selecting candidate sites as an initial step in performing the Oregon calibration procedure (Dixon et al., 2012). The HSM provides a target number of sites and crashes; however, in some cases a facility may have a low crash frequency and applying the generic sample sizes recommended in the HSM may not be practical. As a result, the project team based site selection and sample size on the facility type, historic crashes for similar facilities, and random sampling procedures.

1.1.2 Sample Size

The HSM recommends a sample of 30 to 50 locations for calibrating the SPFs (AASHTO, 2010). In recent years, there has been a strong recommendation that this value be increased where possible. If the facility does not have the required sample size, all identified sites should be used for SPF development calibration The HSM also emphasizes that these sites should be randomly selected and, upon initial selection, the analyst should determine the number of crashes per year. For calibrating the SPFs, the facility should have at least 100 crashes per year, and the analysis should be based on multiple years, preferably three to five years (AASHTO, 2010). If there were not 100 crashes per year for a facility, it is recommended to include all identified available intersections in the State for each intersection type.

1.2 INTERSECTION DATABASE

The focus of this study is to evaluate safety performance primarily targeted for intersections. As a result, the research team explored ways to identify intersections and documented limitations of some facility types. An example of one such limitation is locations where the minor approach does not include traffic volume (ADT or AADT).

The site selection method for intersections on high-speed urban and suburban arterials and rural highways was based on the available data format, site conditions, and total available number of candidate intersections. For initial intersection identification at rural locations, the ODOT lane report included general intersection information that identifies the milepoint as well as the basic intersection orientation (T-intersection versus cross-intersection, signalized versus other traffic control device configuration); however, prior to incorporating an intersection into the analysis, the project team confirmed the traffic control device as well as intersection orientation using the ODOT video log and/or Google Street View. In addition, the research team assessed geometric characteristics by further exploring Google Maps. For identification of intersection locations, the research team used the geographic information system (GIS) data. The team acquired location information from the ODOT TransGIS site. This mapping resource contains a large amount of Oregon data including functional classification and aggregated crash data.

1.3 HISTORIC CRASH DATA

The research team obtained historic crash data from Oregon for years 2015 through 2022. The research team requested these data for the ODOT Statewide Crash Analysis and Reporting System (CAR). For intersections, the HSM indicates that crashes that occurred within the physical limits of the intersections as well as crashes located on the intersection approach legs (within 250 ft (15.3m)) should be included in the analysis. The research team also evaluated the crashes that were located on the intersection approach legs to determine if they qualified as intersection-related crashes.

The data for each crash included a unique crash identity number, the crash type and collision type, character of roads, intersection related as designated by reporting officers, direction from intersection, and direction of travel. The data typically also included the severity level for each crash.

1.4 ROAD CHARACTERISTIC DATA

Each SPF and associated intersection type requires specific site information for successful application to the calibration procedure. In this section, the report summarizes this required road characteristic data. In addition, this section summarizes the data collection procedures used to acquire the necessary road characteristic data.

For each intersection SPF, specific data elements are required; however, these key data elements vary for the different facility types. All road characteristic data needed for calibration for the various facility types are listed in Table 1-2. The HSM includes recommendations about ways to simplify the calibration effort by using default values for some of the less critical variables; however, to minimize the loss of precision, the research team elected to collect all possible variables for this project.

Table 1-2: Required Data Elements

Data Elements	All-Way Stop Control	Rural Three-leg signalized with signal control	High-Speed Urban and Suburban Arterials	5-leg inter-sections	Other atypical intersecti ons	Ramp Terminals
AADT of Major Road or Ramp	•	•	•	•	•	•
AADT of Minor/Cross Road	•	•	•	•	•	•
AADT of Fifth Leg				•		
Presence of Intersection Lighting	•	•	•	•	•	
Presence of Left-Turn Lanes		•	•			
Presence of Right-Turn Lanes		•	•			
Horizontal Curve Length					•	
Horizontal Curve Radius					•	
Exit Ramps with Free flow Turns						•

1.5 TRAFFIC VOLUME (AADT)

One key variable that is required for all intersections is the AADT. For most state highways, this information is available in either a measured or estimated format. The AADT information for state highways is located in the ODOT Traffic Volumes and Vehicle Classification Report. For intersections, the $AADT_{major}$ as well as the $AADT_{minor}$ values are typically needed for the SPFs. Generally, the major roads for most intersection locations are the associated state highways; however, in some instances the traffic volume for local roads may exceed that observed for state highways. For these locations, the major road can then be identified as the local road. At locations were the minor AADT is not available in the road assets database, often the local county public works departments may be able to provide this information. In some cases, this value can be estimated using statistical estimation methods.

The research team utilized two databases to extract the AADT information for each intersection. The first database was the State database that covers most of the state highways. This data was acquired from ODOT. Additionally, the research team utilized the HPMS network for the locations where the AADT data could not be obtained from the state database. Figure 1-1 shows the distribution of traffic volume data collection stations and the HPMS network. It can be observed that both databases cover the entire state; however, there are some locations where the HPMS has more coverage than the state-based AADT data collection points.

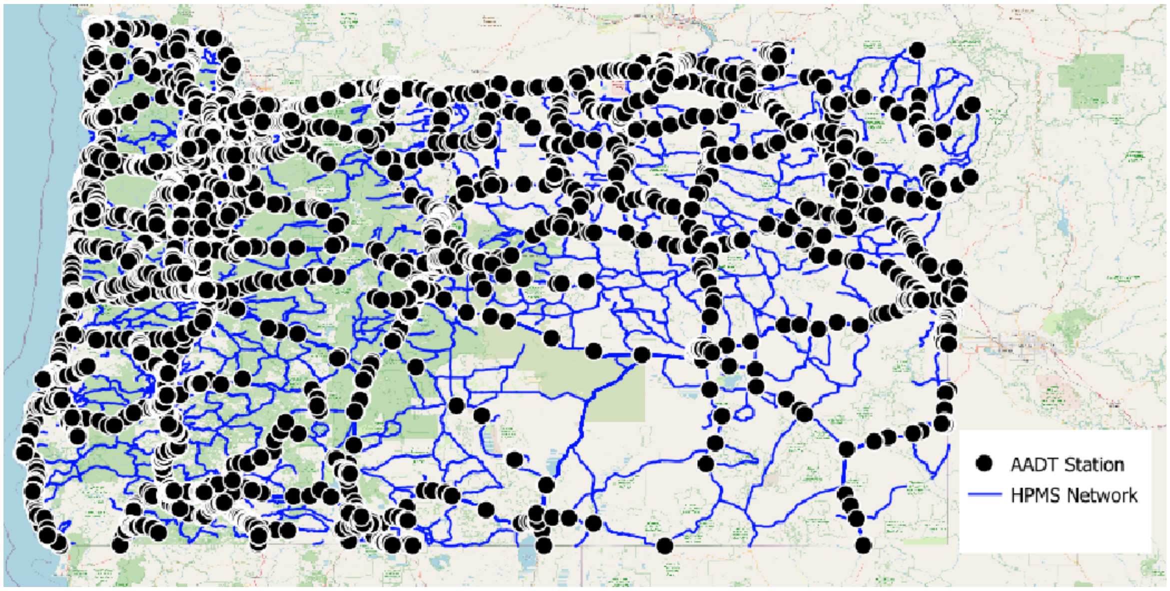


Figure 1-1: Distribution of Traffic Volume Data Collection Stations and HPMS Network

In select cases, the team could not locate AADT or ADT from any source. When this occurred, the team estimated the AADT data using statistical estimation methods. The research team utilized the technique developed in a study by Xie et al., (2011) to estimate the AADT. The Xie et al., (2011) study developed the following regression models to estimate minor approach AADTs for intersections in Oregon:

$$\boldsymbol{log_{10}AADT = 2.0281 - 0.112x(log_{10}distance - 1.175) + 0.68MIA + 0.4148MAC + 0.1391citylimit + 0.1761right + 0.2060rightcross + 0.2125landuse + 0.3028centerline + 0.1268edgeline} \quad \textbf{(1-1)}$$

Where:

Distance: the 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)

1.6 OTHER VARIABLES

The project team was not able to identify a reliable database that includes information regarding left-turn lanes, right-turn lanes, lighting, and the exit ramps with free flow turns. Therefore, the project team used the ODOT Digital Video Log and Google Street View to identify this missing data.

1.7 SUMMARY OF DATA RESOURCES

Table 1-3 provides a summary of the various data resources used to identify the elements required for calibration of the SPFs. As summarized in Table 1-3, the project team used a wide variety of resources to identify critical site elements needed for successful and comprehensive calibration of the SPFs to Oregon conditions.

Table 1-3: Data Elements and Available Resources

Data Elements	Resources
AADT of Major Road or Ramp	ODOT Traffic Volumes and Vehicle Classification Report and County Public Works Departments
AADT of Minor/Cross Road	ODOT Traffic Volumes and Vehicle Classification Report, Local County Public Works Departments, and AADT Estimate Model
AADT of Fifth Leg	ODOT Traffic Volumes and Vehicle Classification Report, Local County Public Works Departments, and AADT Estimate Model
Presence of Intersection Lighting	ODOT Digital Video Log and Aerial Photography
Presence of Left-Turn Lanes	ODOT Digital Video Log and Aerial Photography
Presence of Right-Turn Lanes	ODOT Digital Video Log and Aerial Photography
Horizontal Curve Length	ODOT State Highway Horizontal Curve Report and Field Verification
Horizontal Curve Radius	ODOT State Highway Horizontal Curve Report and Field Verification
Exit Ramps with Free flow Turns	ODOT Digital Video Log and Aerial Photography

1.8 DATA DESCRIPTION

The following section presents a description of the data collected. It covers the number and distribution of intersections and summarizes the AADT data collected for each intersection type.

1.8.1 Rural Two-Lane 3SG Intersections

In Oregon, rural two-lane 3SG intersections are rare. For this study, the research team was only able to identify two 3SG intersections on rural two-lane highways. These two intersections are located at:

- US 101 at E Bay Rd near Glasgow, and
- OR 212 at SE Richey Rd near Boring.

This sample size is much less than the recommended sample size for SPF calibration. Consequently, the research team elected not to proceed with additional data collection for this intersection type.

1.8.2 Rural Multilane 3SG Intersections

The research team identified 19 3SG intersections located on rural multilane highways. Upon closer inspection, only six of the intersections are in rural areas. The remaining intersections are near urbanized areas and can be classified as suburban intersections. Figure 1-2 and Table 1-4 show the distribution of 3SG rural multilane intersections and their associated details.

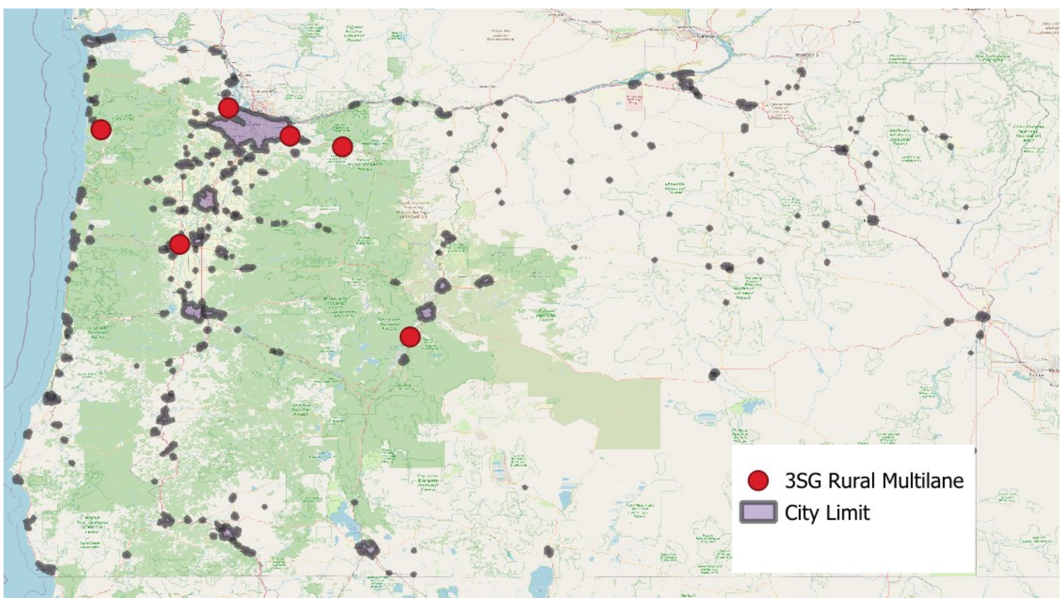


Figure 1-2: Distribution of 3SG Rural Multilane Intersections

Table 1-4: Summary of Rural Multilane 3SG Intersections

Main road	Minor road	Major AADT Leg 1 (vpd)	Major AADT Leg 2 (vpd)	Minor AADT Leg (vpd)	Source of AADT
Mt Hood Hwy	E Welches Rd	12,900	12,900	3,200	ODOT/HPMS
NE Hwy 20	Circle Blvd	6,700	12,400	11,010	ODOT/HPMS
Clackamas-Boring Hwy 174	Boring Rd	11,900	11,900	5,800	ODOT/HPMS
US 30	OR 127	22,500	22,500	13,900	ODOT/HPMS
US 101	Latimer Rd N	12,200	11,900	2,200	ODOT/HPMS
S Century Rd	Venture Ln	5,550	5,550	1,400	Estimated

As shown in Table 1-4, the team estimated the minor AADT approach AADT for only one intersection. This analysis was estimated using a statistical model shown in equation (2-1) The other AADTs were obtained from either the State-based database or the HPMS. Since the sample size is much less than the HSM recommended sample size, the research team elected not to proceed with additional data collection for this intersection type.

1.8.3 3ST-HS Intersections

The research team identified 72 intersections that met the criteria for a high-speed urban and suburban arterial 3ST-HS intersection. As shown in Figure 1-3, most of these intersections are located on the west side of the State, with a few in the central area. The east side has a relatively low number of these intersection types. Among these intersections, 49 are in urban areas, 17 in Suburban areas, and the remaining are in areas that are in more remote locations.

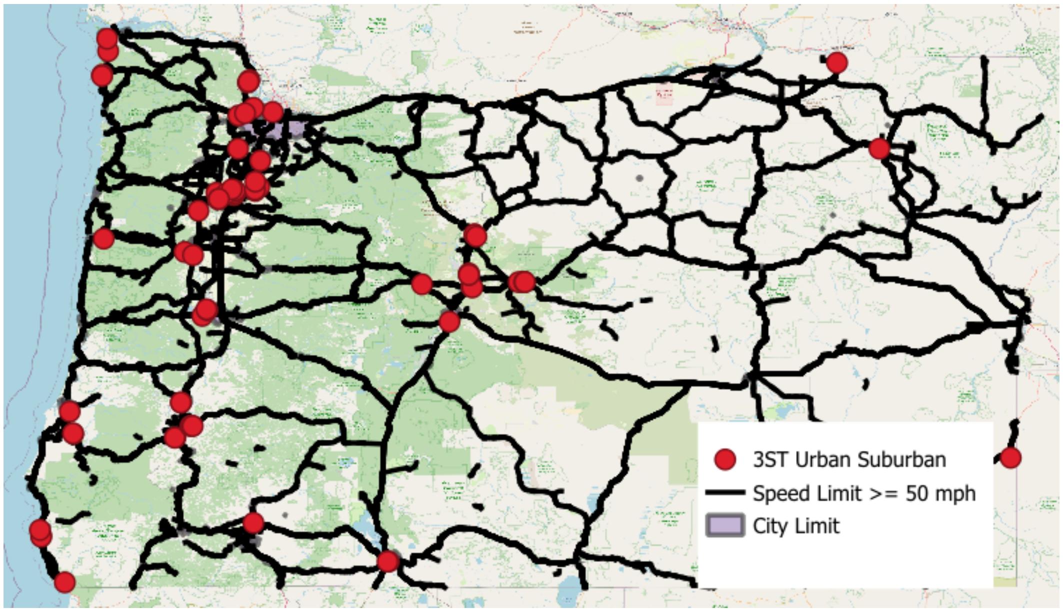


Figure 1-3: Distribution of 3ST-HS Intersections

For these 3ST-HS intersection locations, the research team collected the AADTs for major approaches from either the ODOT or HPMS databases. Additionally, the team estimated the minor approach AADTs for about 36 intersections using a statistical model. These 36 locations did not have the AADT values identified in the ODOT or HPMS databases.
Table 1-5 presents the descriptive summary statistics of the AADTs for the 3ST-HS intersections. It can be observed that the AADTs greatly vary across intersections. This can be observed from the range of the AADTs as shown by the minimum and maximum values and as by the standard deviation.

Table 1-5: AADT Summary Statistics for 3ST-HS Intersections

	Major AADT Leg 1 (vpd)	Major AADT Leg 2 (vpd)	Minor AADT Leg (vpd)
Minimum	570	570	170
Maximum	37,200	38,000	7,075
Average	11,164	11,176	1,644
Standard deviation	8,769	8,806	1,331

1.8.4 3SG-HS Intersections

The research team identified seventeen 3SG-HS intersections on high-speed urban and suburban arterials. These intersections are located on the west side of the State, including one that is near the coastal zone (see Figure 1-4). The research team collected the AADTs for major and minor approaches from the ODOT/HPMS databases (see Table 1-6). The minimum AADT for the major approach is 8,000 vpd, while that of the minor approach is 740 vpd. The maximum

AADTs identified for the for major and minor approaches were 58,100 vpd and 18,000 vpd, respectively.

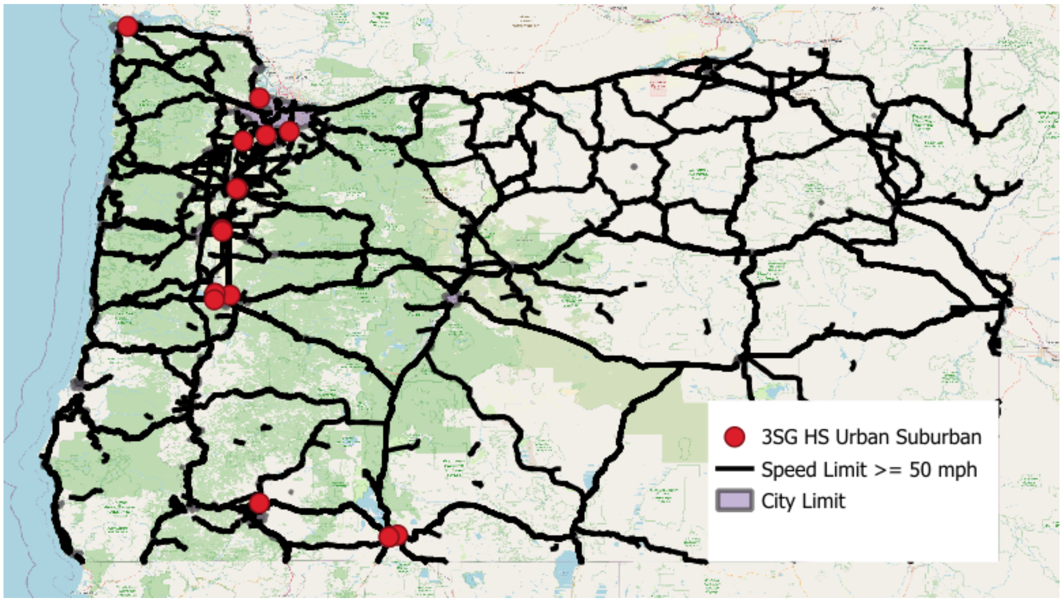


Figure 1-4: Distribution of 3SG-HS Intersections

Table 1-6: AADT Summary Statistics for 3SG-HS Intersections

	Major AADT Leg 1 (vpd)	Major AADT Leg 2 (vpd)	Minor AADT Leg (vpd)
Minimum	8,000	7,200	740
Maximum	58,100	58,100	18,000
Average	27,953	24,288	7,516
Standard deviation	17,779	15,571	5,649

1.8.5 4ST-HS Intersections

Figure 1-5 presents the distribution of 45 4ST-HS intersections. Though these intersections are primarily located on the west side of the state, there are also several of these intersections locate at the central part of the State. Of these 45 intersections, 21 are in urban areas, 22 in suburban areas, and two are in rural areas a relatively far distance from the city limit. The research team retained two intersections that are far from city limits for further assessment during the final dataset analysis.

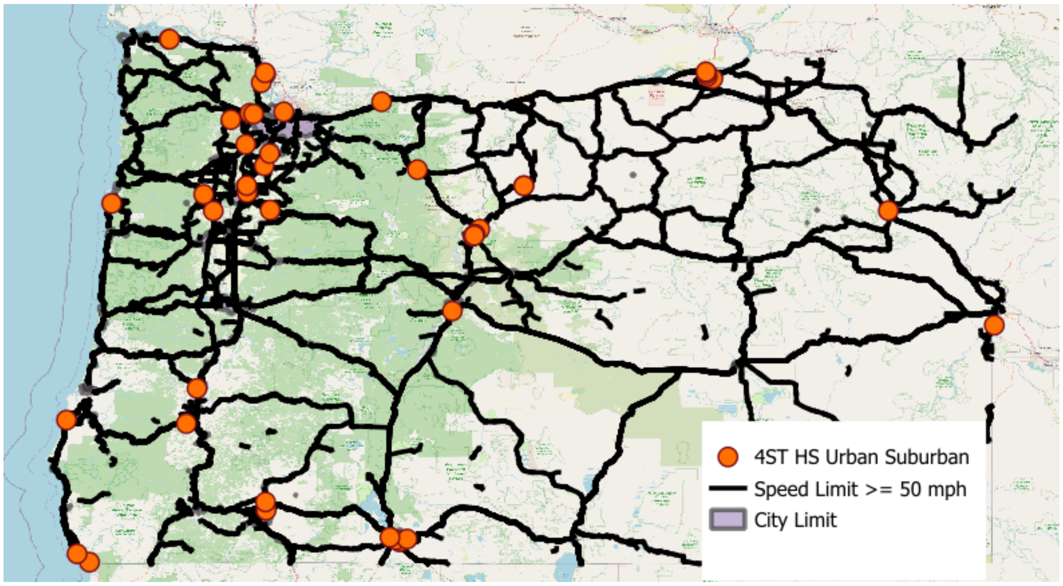


Figure 1-5: Distribution of 4ST-HS Intersections

Table 1-7 presents the AADT descriptive statistics for the 4ST-HS intersections on high-speed urban and suburban arterials. As shown in this table, the maximum AADT values for the major and minor approaches are 26,700 and 8,700 vpd, respectively. The minimum AADTs are 90 and 130 vpd, respectively.

Table 1-7: AADT Descriptive Statistics for 4ST-HS Intersections

	Major AADT Leg 1 (vpd)	Major AADT Leg 2 (vpd)	Minor AADT Leg 1 (vpd)	Minor AADT Leg 2 (vpd)
Minimum	130	130	90	150
Maximum	26,700	28,000	8,700	4,300
Average	8,390	8,307	1,751	1,740
Standard deviation	5,577	5,752	1,556	1,116

1.8.6 4SG-HS Intersections

Figure 1-6 presents the distribution of 71 4SG-HS intersections located on high-speed urban and suburban arterials. Most of these intersections are on the west side of the State but are not located along the coastal zone. A few of these 4SG-HS intersections are located on the east side of the state. Based on the type of land use, 61 of these intersections are in urban areas and the remaining are in suburban areas.

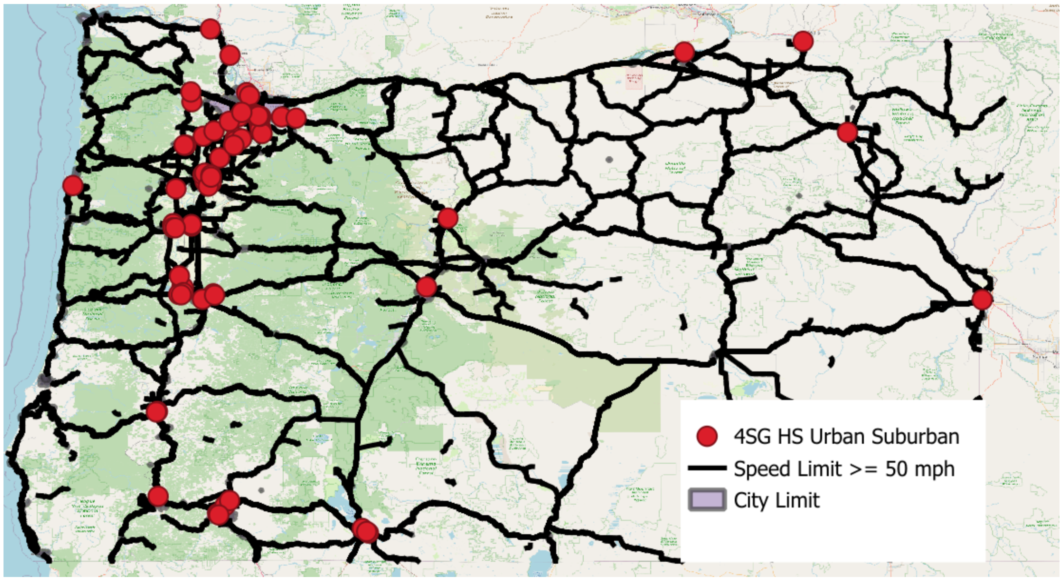


Figure 1-6: Distribution of 4SG-HS Intersections

Table 1-8 presents the descriptive summary for the 4SG-HS intersections. The maximum AADTs for the major and minor approach are 71,800 vpd and 23,900, vpd, respectively. The minimum AADTs for the major and minor approaches are 3500 and 200 vpd, respectively.

Table 1-8: 4SG-HS Intersection AADT Statistics

	Major AADT Leg 1 (vpd)	Major AADT Leg 2 (vpd)	Minor AADT Leg 1 (vpd)	Minor AADT Leg 2 (vpd)
Minimum	7,400	3,500	210	200
Maximum	71,800	58,100	22,200	23,900
Average	22,020	19,695	7,378	6,130
Standard deviation	10,816	9,787	4,989	4,715

1.9 DATA COLLECTION SUMMARY

The team focused on identifying the physical location of candidate intersections and their associated traffic exposure. Table 1-9 shows the sample size of different intersection types.

Table 1-9: Sample Size of Intersections

Intersection type	Count
3ST-HS Urban/Suburban	72
4ST-HS Urban/Suburban	45
3SG-HS Urban/Suburban	17
4SG-HS Urban/Suburban	71
3SG Rural Multilane	6
3SG Rural Two lane	2

Based on these findings, the research team proceeded with efforts to calibrate models for the following intersection types:

- 3ST-HS intersections on urban and suburban highways,
- 3SG-HS intersections on urban and suburban highways,
- 4ST-HS on urban and suburban highways, and
- 4SG-HS on urban and suburban highways.

Due to an inadequate sample size, models for 3SG intersections for rural two-lane and rural multilane intersections could not be calibrated.

2.0 DATA ANALYSIS

2.1 SAFETY PERFORMANCE FUNCTIONS

In NCHRP 17-68, the SPFs were developed consistent with the methodology in Chapter 12 of the HSM for predicting intersection crashes in urban and suburban areas as shown in Equation (2-1) and Equation (2-2):

$$\boldsymbol{N_{predicted} = \mathrm{C} \times \left(N_b + N_{ped} + N_{bike}\right)} \quad \textbf{(2-1)}$$

$$\boldsymbol{N_b = N_{spf} \times \left(CMF_{lg} \times CMF_{lt} \times CMF_{rt}\right)} \quad \textbf{(2-2)}$$

where:

$N_{predicted}$ = predicted average crash frequency for an individual intersection (crashes/year).

N_b = predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle crashes) (crashes/year).

N_{ped} = predicted average crash frequency of vehicle-pedestrian crashes of an intersection (crashes/year).

N_{bike} = predicted average crash frequency of vehicle-bicycle crashes of an intersection (crashes/year).

CMF_{lg} = CMF for presence of lighting.

CMF_{lt} = CMF for presence of left-turn lanes on approach legs.

CMF_{rt} = CMF for presence of right-turn lanes on approach legs.

The form of the SPF presented in Equation (2-3) is adopted in the NCHRP Project 17-68 separately for three- and four-leg intersections, for MV and SV crashes:

$$\boldsymbol{N_{spf} = e^{a} AADT_{maj}{}^{b} AADT_{min}{}^{c}} \quad \textbf{(2-3)}$$

where:

$AADT_{maj}$ = AADT on the major road (veh/day).

$AADT_{min}$ = AADT on the minor road (veh/day).

a, b, c = regression coefficients.

To estimate the annual vehicle-pedestrian (N_{ped}) and vehicle-bicycle (N_{bike}) crashes at stop-controlled and signalized intersections on high-speed urban and suburban arterials, the analyst needs to use Equations (2-4) and (2-5), respectively.

$$\boldsymbol{N_{ped} = N_b \times f_{ped}} \qquad \textbf{(2-4)}$$

where:

f_{ped} = pedestrian crash adjustment factor for intersection type i.

$$\boldsymbol{N_{bike} = N_b \times f_{bike}} \qquad \textbf{(2-5)}$$

where:

f_{bike} = bicycle crash adjustment factor for intersection type i.

All of the vehicle-pedestrian and vehicle-bicycle crashes predicted with Equations (2-4) and (2-5) are assumed to be FI crashes and none are PDO crashes.

2.2 CALIBRATION

Appendix B of the HSM contains guidance on developing local calibration factors for these models. The guidance calls for new calibration factors to be developed at least every 2-3 years using at least 30-50 sites. This procedure involves assembling a set of segments, obtaining the observed crash count on the segments for a given time period, computing the predicted crash count for the same time period using the HSM models, and computing the ratio of observed to predicted crashes. A separate ratio C is computed for each SPF using the following equation:

$$C = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} \hat{y}_i} \qquad \textbf{(2-6)}$$

where:

y_i = observed annual crash frequency for site i;

$\hat{y}_i$ = predicted annual crash frequency for site i; and

n = number of sites.

The predicted crashes are then adjusted to calculate the calibrated predicted crash frequency μ_i:

$$\boldsymbol{\mu_i = C\hat{y}_i} \qquad \textbf{(2-7)}$$

2.3 GOODNESS OF FIT MEASURES

To evaluate the quality of calibration factors, various goodness of fit (GOF) measures are used, as described below.

2.3.1 Cumulative Residual (CURE) Plot

A CURE plot is a graph of cumulative residuals, i.e., observed crashes minus predicted crashes, plotted against a variable of interest sorted in the ascending order (e.g., AADT or predicted crashes). The visual presentation of CURE shows the concerning areas which may require improvement of SPF models such as percent areas increasing confidence limits, long trends, and vertical changes (Lyon *et al.* 2016).

CURE plots for each segment type are constructed using the following steps.

1. The variables of interest, which in this case is predicted crashes, and AADT are sorted in ascending order,

2. For each site, the residual is calculated as the difference between observed and predicted crashes,

3. The cumulative of residuals is then calculated as the sum of residuals 1 to n (n is the total number of sites),

4. The square of residuals is calculated, followed by calculation of cumulative squared residuals, and

5. The 95 percent confidence limits are then calculated for each site as $\pm 1.96\sqrt{\sigma^2}$, where σ^2 is the variance of the random walk.

2.3.2 Error-based Methods

Two error-based methods are used to analyze the GOF (Lyon *et al.* 2016, Lord *et al.* 2021).

1. Mean Absolute Deviation (MAD) that calculates the absolute difference between the predicted number of crashes and observed number of crashes is shown below.

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|\mu_i - y_i| \qquad \textbf{(2-8)}$$

2. Mean Squared Prediction Error (MSPE) that calculates the square of difference between predicted and observed number of crashes is shown below.

$$MSPE = \frac{1}{n}\sum_{i=1}^{n}(\mu_i - y_i)^2 \qquad \textbf{(2-9)}$$

2.3.3 Modified R^2

This GOF measure is used to measure the amount of systematic variation in the predicted crashes as it subtracts the random variation that is based on the expectation that the CMFs were 100% accurate. Equation below is used to calculate the modified R^2 value:

$$R^2 = \frac{\sum_i (y_i - \bar{y})^2 - \sum_i {\varepsilon_i}^2}{\sum_i (y_i - \bar{y})^2 - \sum_i {\mu_i}^2} \qquad \textbf{(2-10)}$$

where,

$\bar{y}$ = sample average,

$\varepsilon_i = y_i - \hat{y}_i$.

2.3.4 Dispersion Parameter (k)

This measure shows the spread of observed crashes about predicted value of crashes. Since the SPFs are recalibrated, the dispersion parameter also needs to be recalibrated. The dispersion parameter is estimated for the recalibrated SPFs using the maximum likelihood method originally proposed by Fisher (1941) and later improved by Lawless (1987). The log-likelihood function of negative binomial (NB) distribution is used to model the observed crashes as a function of calibrated predicted crashes as follows.

$$Y_i \sim NB(\mu_i, k) \qquad \textbf{(2-11)}$$

The dispersion parameter of the NB model is estimated using the Generalized Reduced Gradient (GRG) nonlinear solver method in Microsoft Excel.

2.3.5 Coefficient of Variation (CV) of calibration factor

This is calculated as the standard deviation of calibration factor C divided by predicted calibration factor as shown in equation below:

$$CV = \frac{\sqrt{V(C)}}{C} \qquad \textbf{(2-12)}$$

Where,

$V(C)$ = Variance of Calibration Factor.

The variance of calibration factor is calculated as below. The square root of the variance provides the standard error (SE) of the calibration factor.

$$\boldsymbol{V(C)} = \frac{\sum_i(\boldsymbol{y_i} + \boldsymbol{k} * \boldsymbol{y_i^2})}{(\sum_i \widehat{\boldsymbol{y}}_i)^2} \quad \textbf{(2-13)}$$

where,

$\hat{y}$ = uncalibrated predicted values, and

k =recalibrated dispersion parameter.

An SPF is deemed to be acceptable when one of the below is true (Lyon *et al.* 2016):

- Five percent or less of CURE plot ordinates for calibrated predicted values exceed the 2σ limits, or
- The *CV* of the calibration factor is less than 0.15.

2.4 CALIBRATION RESULTS

Table 2-1 presents the summary statistics for intersections by intersection type used for developing local calibration factors. The research team considered two sets of crash data: 2015 to 2019 and 2015 to 2022, since COVID-19 had an impact on safety in 2020 and 2021.

Table 2-1. Summary Statistics of the Data Used for Calibrating Intersection SPFs

Int. Type	No. of int.	Maj. ADT, veh/day	Min. ADT, veh/day	Years	MV FI Crash Count	MV PDO Crash Count	SV FI Crash Count	SV PDO Crash Count
3ST-HS	72	570 – 36700	170 – 14150	2015-19	0 - 9	0 - 7	0 - 2	0 - 2
3ST-HS	72	570 – 36700	170 – 14150	2015-22	0 - 12	0 - 7	0 - 2	0 - 2
4ST-HS	45	195 – 40050	100 – 3770	2015-19	0 - 5	0 - 4	0 - 1	0 - 1
4ST-HS	45	195 – 40050	100 – 3770	2015-22	0 - 10	0 - 4	0 - 2	0 - 1
3SG-HS	17	8000 – 58100	740 – 18000	2015-19	0 - 15	0 - 12	0 - 2	0 - 3
3SG-HS	17	8000 – 58100	740 – 18000	2015-22	0 - 15	0 - 12	0 - 2	0 - 3
4SG-HS	71	5450 – 64950	554 – 15367	2015-19	0 - 22	0 - 24	0 - 2	0 - 3
4SG-HS	71	5450 – 64950	554 – 15367	2015-22	0 - 22	0 - 24	0 - 2	0 - 3

Table 2-2 summarizes the calibration factors for 3ST-HS intersections. The results show that the calibration factors vary from 0.61 to 2.81 for FI crashes, whereas it is 0.12 to 0.83 for PDO crashes. Lower values of calibration factors for PDO crashes may be attributed to the Oregon self-reporting crash rules or may also be due to the various reporting thresholds. In almost all crashes, the calibration factor is higher with 2015 to 2022 crashes than with 2015 to 2019 crashes. This means that more crashes per year were observed in the 2020 to 2022 period than in the 2015 to 2019 period, on average.

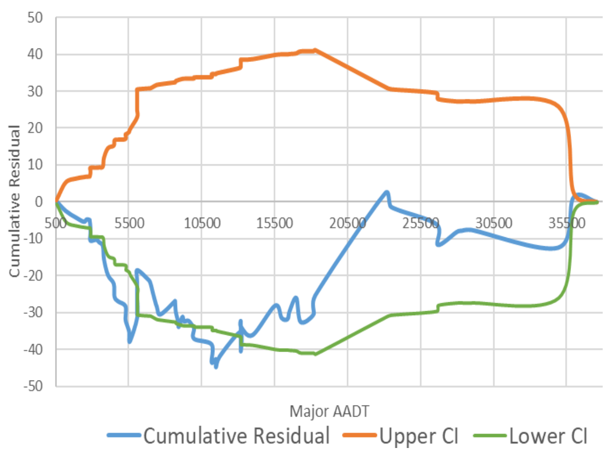
Table 2-2. Calibration Factors for 3ST-HS Intersections

Years	Crash Type	Observed Crash Count	Predicted Crash Count	Local Calibration Factor *C*
2015-19	MV FI	246	212.45	1.16
2015-19	MV PDO	135	422.28	0.32
2015-19	SV FI	38	20.49	1.85
2015-19	SV PDO	51	87.19	0.58
2015-22	MV FI	393	297.42	1.32
2015-22	MV PDO	200	591.13	0.34
2015-22	SV FI	69	32.78	2.10
2015-22	SV PDO	72	139.51	0.52

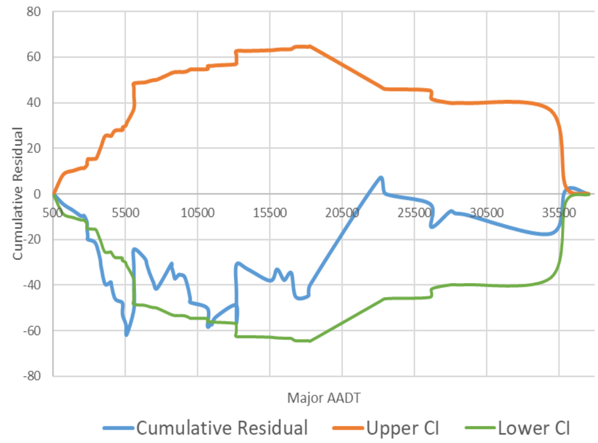
Table 2-3 shows the results for the different GOF measures for 3ST-HS intersections. Figure 2-1 and Figure 2-2 show the CURE plots for SV and MV crashes at 3ST-HS intersections, respectively. The GOF measures show that, for MV crashes, CURE plot ordinates for calibrated predicted values exceeded the 2σ limits more than 5%. This result is also evident from the CURE plots. This shows that the new SPFs for MV crashes may need to be developed for this intersection type. For SV crashes, CURE plot ordinates for calibrated predicted values exceeded the 2σ limits less than 5% with 2015 to 2022 crash data. This result is also evident from the CURE plots. This shows that the calibration factors for SV crashes are accurate and the calibrated SPFs can be used for this intersection type. The calibration factors with 2015 to 2022 crashes provided better fit than with 2015 to 2019 crashes, so those are recommended for use in Oregon.

Table 2-3. GOF Measures for Re-Calibrated 3ST-HS Intersection Models

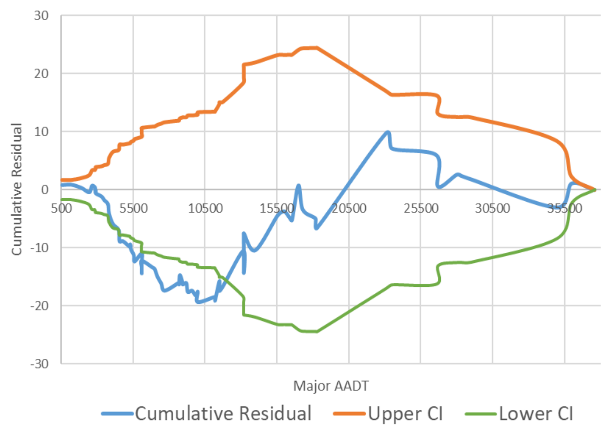
Years		*C*	SE of *C*	MAD	MSPE	Modified R^2	Disp. Parm.	CV	Exceeding 95% CI
2015-19	MV FI	1.16	27.49	3.23	24.60	0.26	1.20	0.24	39
2015-19	MV PDO	0.32	10.36	1.76	8.47	0.39	1.13	0.26	47
2015-19	SV FI	1.85	0.76	0.68	0.80	0.86	1.05	0.28	7
2015-19	SV PDO	0.58	1.17	0.77	1.08	0.19	0.75	0.23	7
2015-22	MV FI	1.32	68.82	4.90	62.33	0.28	1.26	0.24	31
2015-22	MV PDO	0.34	23.84	2.51	19.21	0.38	1.29	0.28	46
2015-22	SV FI	2.10	1.62	0.98	1.68	0.63	0.69	0.20	1
2015-22	SV PDO	0.52	2.59	1.05	2.24	0.31	1.22	0.27	1



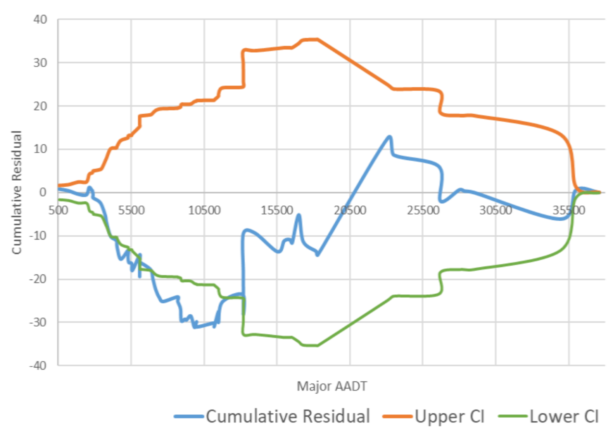
A. MV FI Crashes, 2015-19



B. MV FI Crashes, 2015-22

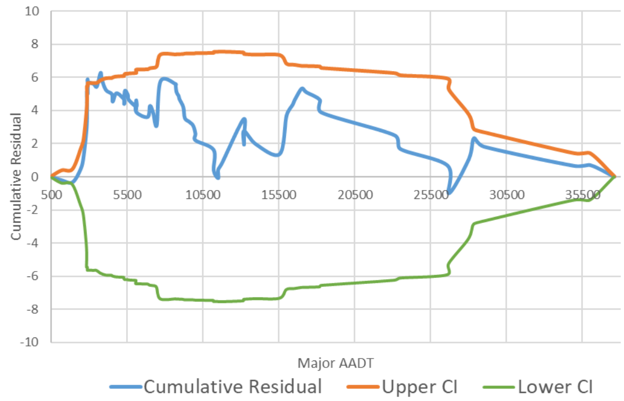


C. MV PDO Crashes, 2015-19

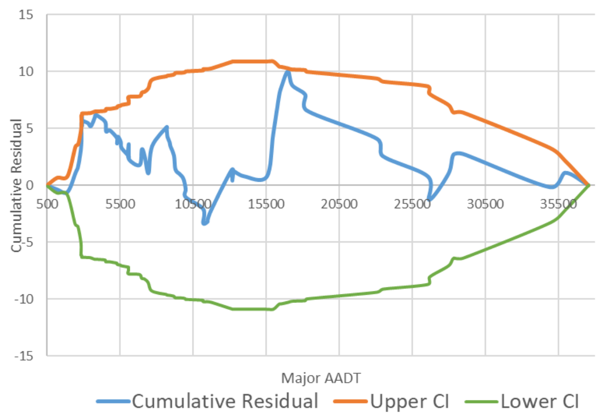


D. MV PDO Crashes, 2015-22

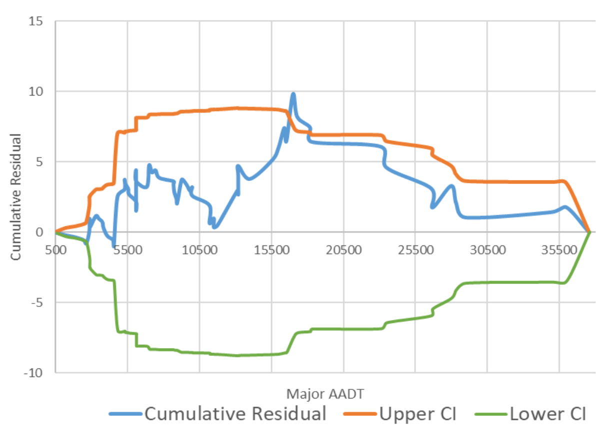
Figure 2-1. CURE Plots for MV Crashes at 3ST-HS Intersections



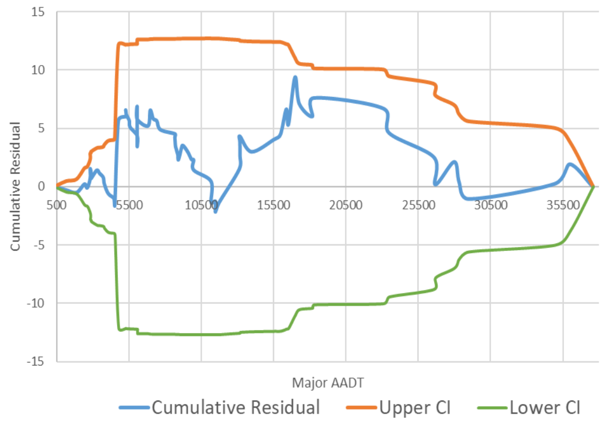
A. SV FI Crashes, 2015-19



B. SV FI Crashes, 2015-22



C. SV PDO Crashes, 2015-19



D. SV PDO Crashes, 2015-22

Figure 2-2. CURE Plots for SV Crashes at 3ST-HS Intersections

Table 2-4 summarizes the calibration factors for 4ST-HS intersections. The results show that the calibration factors vary from 0.54 to 1.01 for FI crashes, where it is 0.20 to 0.35 for PDO crashes. In almost all crashes, the calibration factor is higher with 2015 to 2022 crashes than with 2015 to 2019 crashes. This means that more crashes per year were observed in the 2020 to 2022 period than the 2015 to 2019 period, on average.

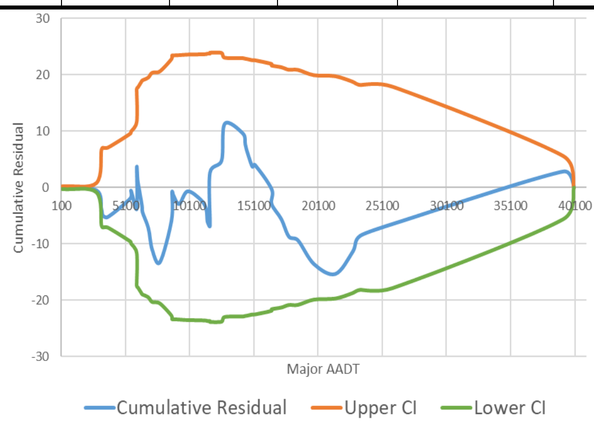
Table 2-4. Calibration Factors for 4ST-HS Intersections

Years	Crash Type	Observed Crash Count	Predicted Crash Count	Local Calibration Factor *C*
2015-19	MV FI	154	286.01	0.54
2015-19	MV PDO	86	385.12	0.22
2015-19	SV FI	18	21.09	0.85
2015-19	SV PDO	21	69.18	0.30
2015-22	MV FI	258	457.61	0.56
2015-22	MV PDO	125	616.19	0.20
2015-22	SV FI	34	33.75	1.01
2015-22	SV PDO	39	110.69	0.35

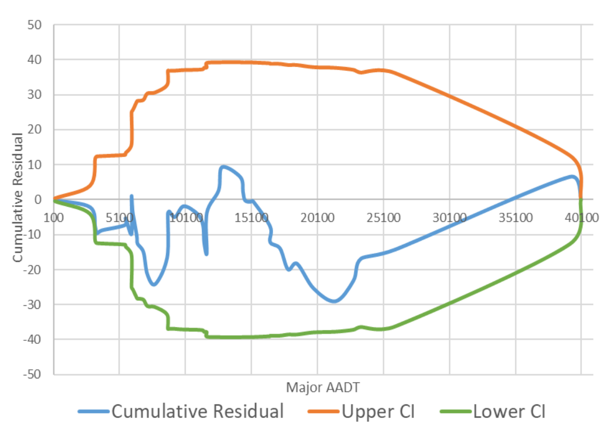
Table 2-5 shows the results for the different GOF measures for 4ST-HS intersections. Figure 2-3 and Figure 2-4 show the CURE plots for SV and MV crashes at 4ST-HS intersections, respectively. The GOF measures show that, except for one case, CURE plot ordinates for calibrated predicted values exceeded the 2σ limits less than 5%. This result is also evident from the CURE plots. This shows that the calibration factors are accurate and the calibrated SPFs can be used for this intersection type. The calibration factors with 2015 to 2019 crashes provided better fit than with 2015 to 2022 crashes, so those are recommended for use in Oregon.

Table 2-5. GOF Measures for Re-Calibrated 4ST-HS Intersection Models

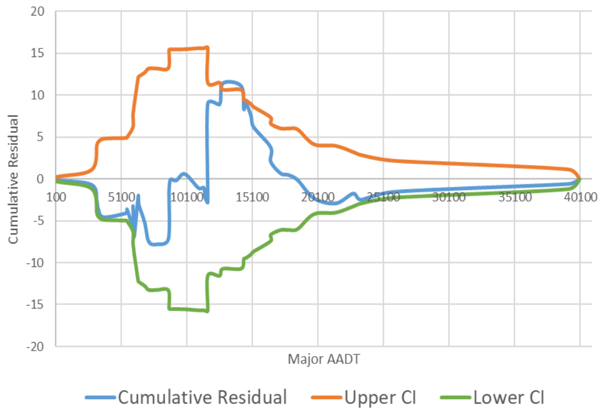
Years		*C*	SE of *C*	MAD	MSPE	Modified R^2	Disp. Parm.	CV	Exceeding 95% CI
2015-19	MV FI	0.54	16.75	2.82	12.88	0.56	0.96	0.24	2
2015-19	MV PDO	0.22	6.95	1.56	6.01	0.47	0.81	0.25	7
2015-19	SV FI	0.85	0.47	0.52	0.42	0.92	0.13	0.26	2
2015-19	SV PDO	0.30	0.39	0.54	0.37	-0.71	0.00	0.22	2
2015-22	MV FI	0.56	45.47	4.47	34.43	0.56	0.92	0.23	2
2015-19	MV PDO	0.20	10.40	2.11	8.76	0.57	0.71	0.21	2
2015-19	SV FI	1.01	1.01	0.71	0.87	0.61	0.21	0.21	2
2015-19	SV PDO	0.35	0.66	0.65	0.63	6.03	0.00	0.16	2



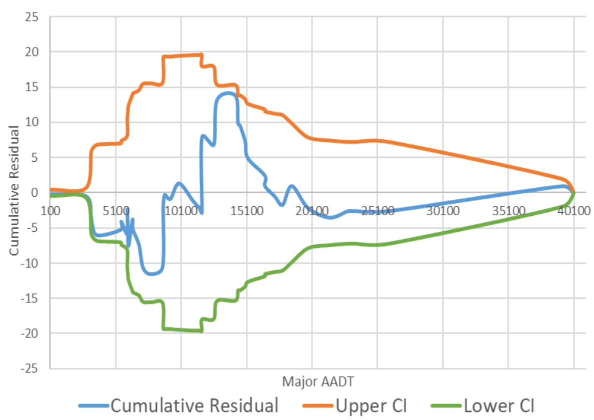
A. MV FI Crashes, 2015-19



B. MV FI Crashes, 2015-22

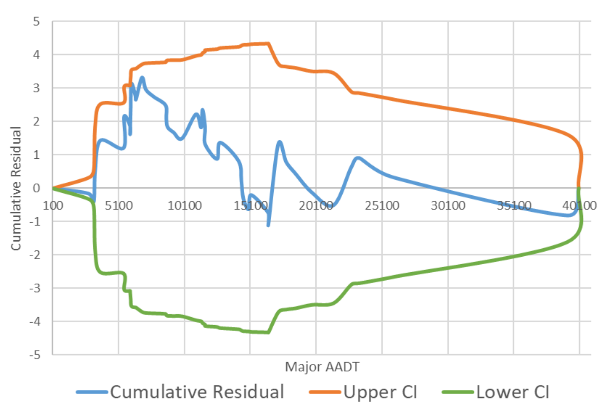


C. MV PDO Crashes, 2015-19

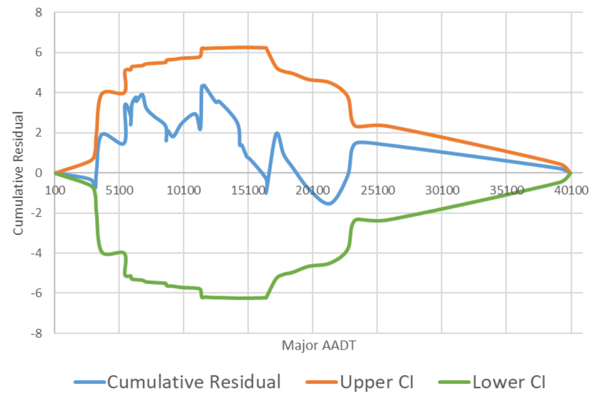


D. MV PDO Crashes, 2015-22

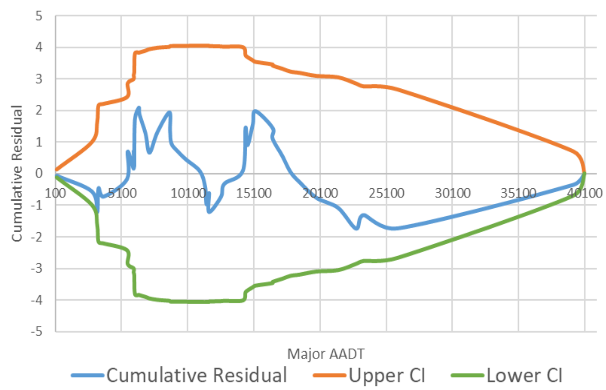
Figure 2-3. CURE Plots for MV Crashes at 4ST-HS Intersections



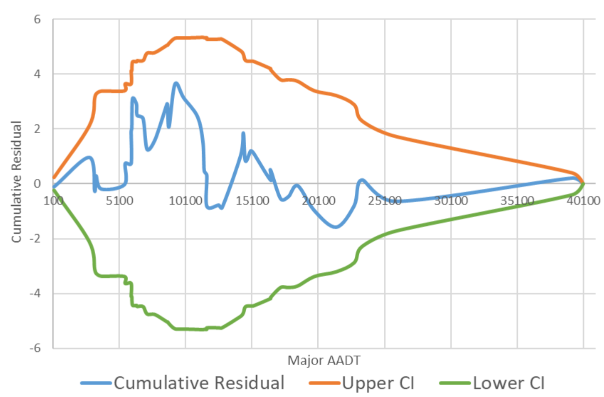
A. SV FI Crashes, 2015-19



B. SV FI Crashes, 2015-22



C. SV PDO Crashes, 2015-19



D. SV PDO Crashes, 2015-22

Figure 2-4. CURE Plots for SV Crashes at 4ST-HS Intersections

Table 2-6 summarizes the calibration factors for 3SG-HS intersections. The results show that the calibration factors vary from 1.23 to 2.04 for FI crashes, where it is 0.40 to 0.92 for PDO crashes. In almost all crashes, the calibration factor is higher with 2015 to 2019 crashes than with 2015 to 2022 crashes. This means that fewer crashes per year were observed in the 2020 to 2022 period than the 2015 to 2019 period, on average.

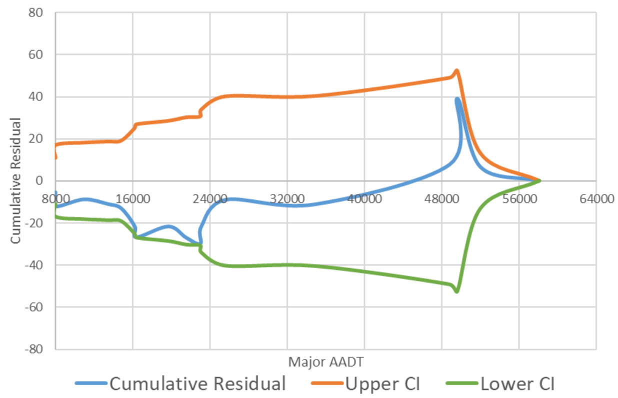
Table 2-6. Calibration Factors for 3SG-HS Intersections

Years	Crash Type	Observed Crash Count	Predicted Crash Count	Local Calibration Factor *C*
2015-19	MV FI	264	129.26	2.04
2015-19	MV PDO	177	193.29	0.92
2015-19	SV FI	13	10.59	1.23
2015-19	SV PDO	15	33.22	0.45
2015-22	MV FI	364	206.82	1.76
2015-22	MV PDO	255	309.26	0.82
2015-22	SV FI	23	16.95	1.36
2015-22	SV PDO	21	53.15	0.40

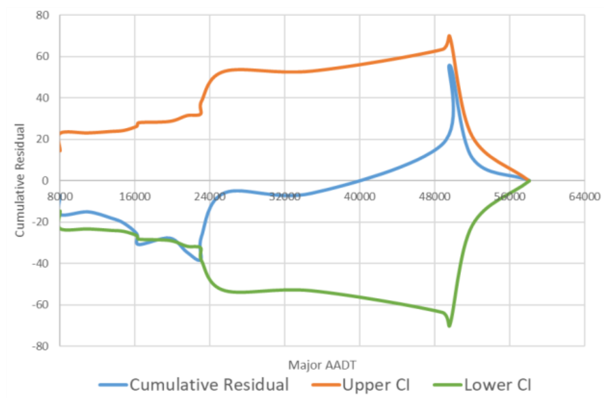
Table 2-7 shows the results for the different GOF measures for 3SG-HS intersections. Figure 2-5 and Figure 2-6 show the CURE plots for SV and MV crashes at 3SG-HS intersections, respectively. The GOF measures with 2015-19 crash data show that, except for one case, CURE plot ordinates for calibrated predicted values exceeded the 2σ limits less than 6%. This result is also evident from the CURE plots. This shows that the calibration factors with 2015 to 2019 crash data are accurate and the calibrated SPFs can be used for this intersection type. The calibration factors with 2015 to 2022 crashes have questionable accuracy as evident by the GOF measures.

Table 2-7. GOF Measures for Re-Calibrated 3SG-HS Intersection Models

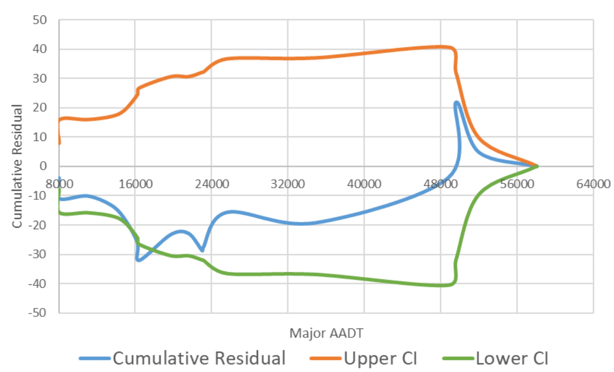
Years	Collision Type	*C*	SE of *C*	MAD	MSPE	Mod. R^2	Disp. Parm.	CV	Exceeding 95% CI
2015-19	MV FI	2.04	261.1	9.35	172.0	0.62	0.68	0.29	6
2015-19	MV PDO	0.92	134.5	7.58	99.4	0.57	0.87	0.34	18
2015-19	SV FI	1.23	0.9	0.75	0.8	0.79	0.20	0.33	0
2015-19	SV PDO	0.45	0.9	0.71	0.8	2.19	0.00	0.26	6
2015-22	MV FI	1.76	441.3	11.60	293.4	0.65	0.67	0.28	18
2015-22	MV PDO	0.82	211.5	9.32	155.4	0.64	0.75	0.29	12
2015-22	SV FI	1.36	2.7	0.97	3.0	-0.37	0.70	0.38	12
2015-22	SV PDO	0.40	1.7	0.97	1.4	0.81	0.17	0.26	6



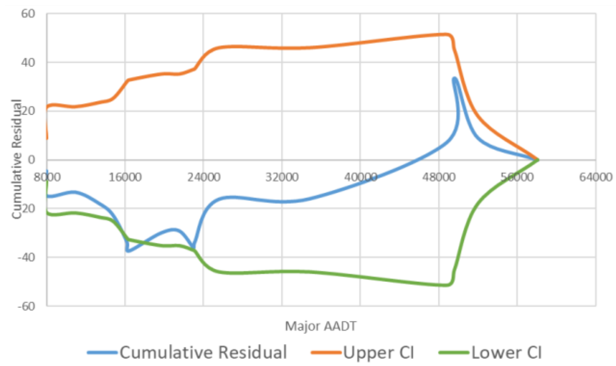
A. MV FI Crashes, 2015-19



B. MV FI Crashes, 2015-22

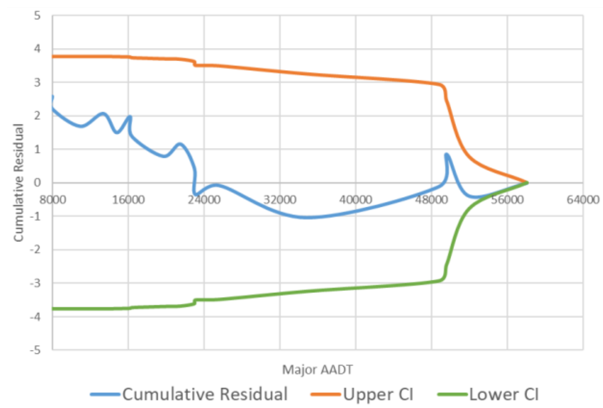


C. MV PDO Crashes, 2015-19

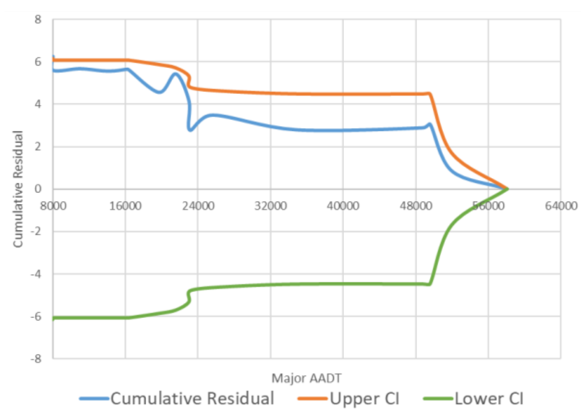


D. MV PDO Crashes, 2015-22

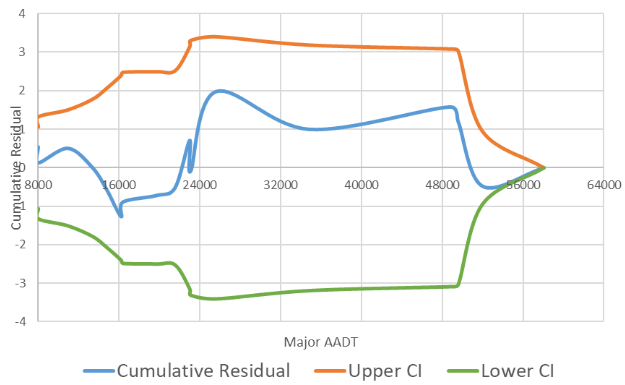
Figure 2-5. CURE Plots for MV Crashes at 3SG-HS Intersections



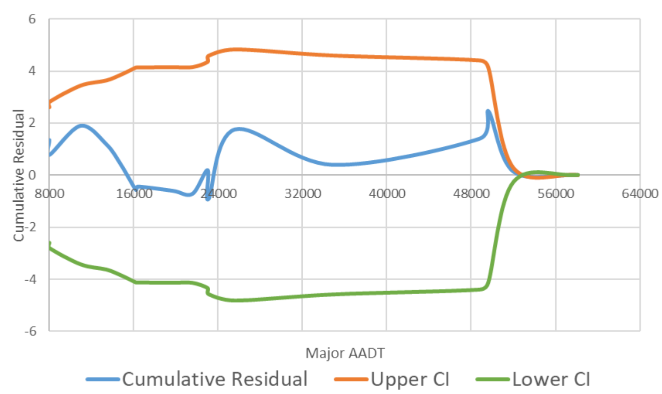
A. SV FI Crashes, 2015-19



B. SV FI Crashes, 2015-22



C. SV PDO Crashes, 2015-19



D. SV PDO Crashes, 2015-22

Figure 2-6. CURE Plots for SV Crashes at 3SG-HS Intersections

Table 2-8 summarizes the calibration factors for 4SG-HS intersections. The results show that the calibration factors vary from 1.05 to 1.48 for FI crashes, where it is 0.43 to 0.52 for PDO crashes. The calibration factors are higher with 2015 to 2019 data for MV crashes than with 2015 to 2022 crashes, where it is the opposite for the SV crashes. This means that fewer MV crashes and more SV crashes per year were observed in the 2020 to 2022 period than the 2015 to 2019 period, on average.

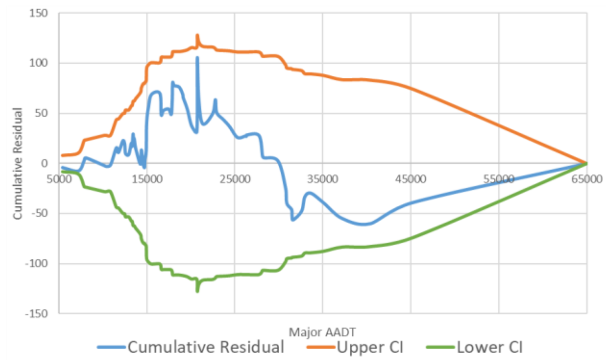
Table 2-8. Calibration Factors for 4SG-HS Intersections

Years	Crash Type	Observed Crash Count	Predicted Crash Count	Local Calibration Factor *C*
2015-19	MV FI	1411	952.94	1.48
2015-19	MV PDO	1015	1957.03	0.52
2015-19	SV FI	68	64.78	1.05
2015-19	SV PDO	62	143.02	0.43
2015-22	MV FI	2055	1524.70	1.35
2015-22	MV PDO	1457	3131.25	0.47
2015-22	SV FI	111	103.65	1.07
2015-22	SV PDO	103	228.84	0.45

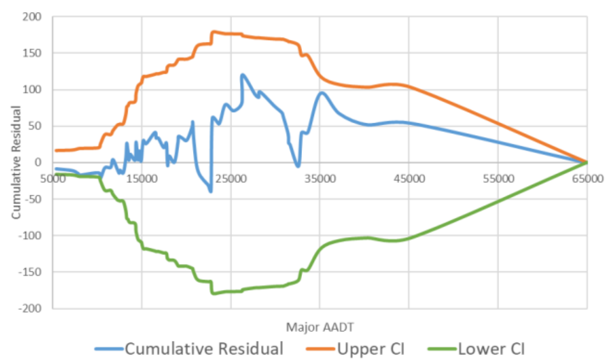
Table 2-9 shows the results for the different GOF measures for 4SG-HS intersections. Figure 2-7 and Figure 2-8 show the CURE plots for SV and MV crashes at 4SG-HS intersections, respectively. The GOF measures show that, except for one case, CURE plot ordinates for calibrated predicted values exceeded the 2σ limits less than 5%. This result is also evident from the CURE plots. This shows that the calibration factors are accurate and the calibrated SPFs can be used for this intersection type. The calibration factors with 2015 to 2019 crashes provided better fit than with 2015 to 2022 crashes, so those are recommended for use in Oregon.

Table 2-9. GOF Measures for Re-Calibrated 4SG-HS Intersection Models

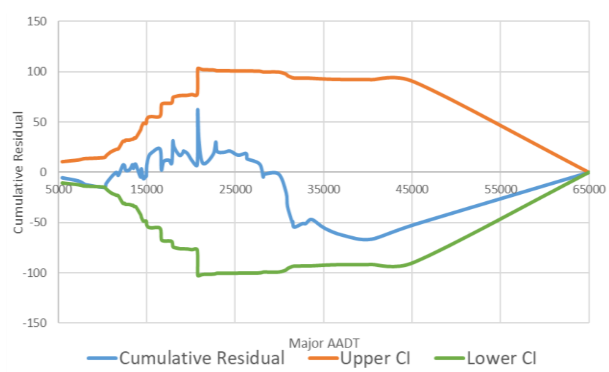
Years		*C*	SE of *C*	MAD	MSPE	Modified R^2	Disp. Parm.	CV	Exceeding 95% CI
2015-19	MV FI	1.48	273.6	10.63	238.1	0.63	0.44	0.11	0
2015-19	MV PDO	0.52	184.0	7.48	150.4	0.62	0.44	0.11	3
2015-19	SV FI	1.05	1.7	0.93	1.7	-0.04	0.67	0.20	3
2015-19	SV PDO	0.43	1.4	0.84	1.4	0.34	0.57	0.20	1
2015-22	MV FI	1.35	546.7	14.76	461.6	0.66	0.44	0.10	1
2015-19	MV PDO	0.47	340.7	10.88	289.5	0.63	0.48	0.11	1
2015-19	SV FI	1.07	3.4	1.30	3.3	0.11	0.59	0.17	11
2015-19	SV PDO	0.45	2.2	1.06	2.1	0.64	0.24	0.13	0



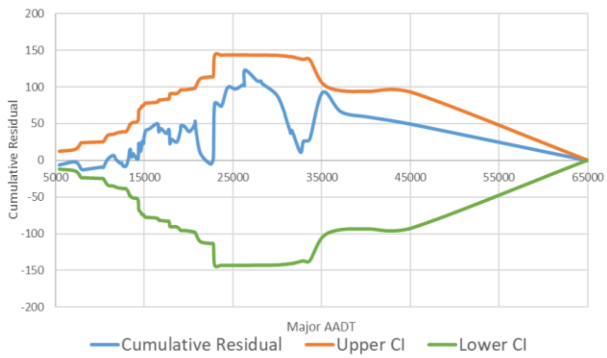
A. MV FI Crashes, 2015-19



B. MV FI Crashes, 2015-22

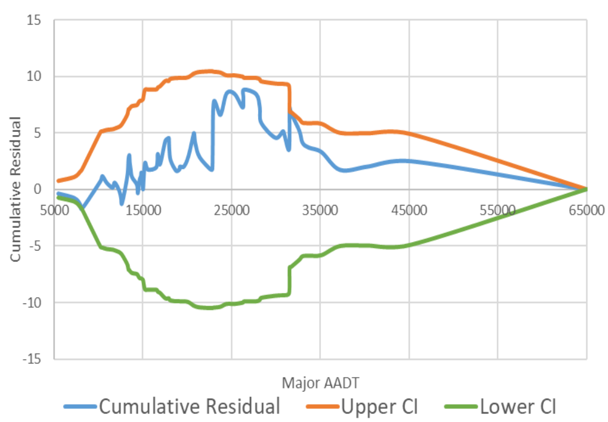


C. MV PDO Crashes, 2015-19

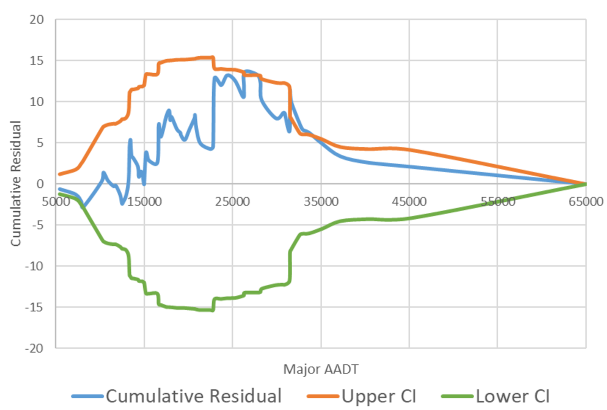


D. MV PDO Crashes, 2015-22

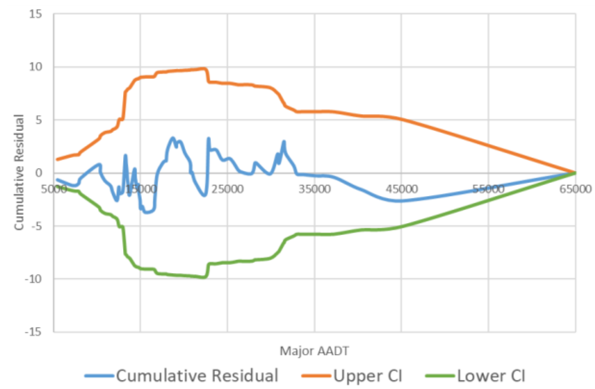
Figure 2-7. CURE Plots for MV Crashes at 4SG-HS Intersections



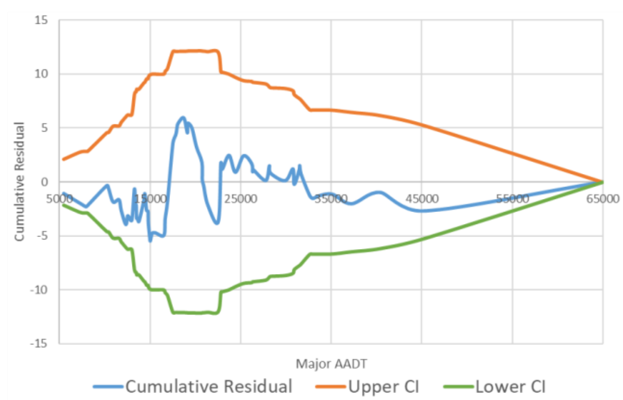
A. SV FI Crashes, 2015-19



B. SV FI Crashes, 2015-22



C. SV PDO Crashes, 2015-19



D. SV PDO Crashes, 2015-22

Figure 2-8. CURE Plots for SV Crashes at 4SG-HS Intersections

2.5 RECOMMENDED SPFS

The research team developed new SPFs for the MV crashes at 3ST-HS intersections since the calibration results showed that the accuracy of calibration factors is questionable. The research team adopted the same SPF functional form as documented in the NCHRP Project 17-68. Table 2-10 contains the SPF calibrated coefficients, standard error, *t*-statistic, and *p*-value for MV crashes at 3ST-HS intersections.

Table 2-10. Calibrated Coefficients for MV Crashes at 3ST-HS Intersections.

Crash Severity	Variable	Value	Std. Dev	*t*-statistic	*p*-value
FI	Intercept (a)	-12.35	1.99	-6.22	<0.0001
FI	$AADT_{maj}$ (b)	0.90	0.20	4.56	<0.0001
FI	$AADT_{min}$ (c)	0.51	0.16	3.27	0.0017
FI	Dispersion parameter	0.99	0.24	4.11	<0.0001
PDO	Intercept (a)	-16.63	2.45	-6.77	<0.0001
PDO	$AADT_{maj}$ (b)	0.96	0.22	4.35	<0.0001
PDO	$AADT_{min}$ (c)	0.89	0.19	4.51	<0.0001
PDO	Dispersion parameter	0.79	0.29	2.75	0.0076

The results for 4ST-HS, 3SG-HS, and 4SG-HS intersections showed that the calibration factors developed with 2015 to 2019 crash data are accurate and calibrated SPFs can be used for predicting crashes at Oregon intersections. For 3ST-HS intersections, results with 2015 to 2022 crash data suggested that calibrated SPFs can be used for SV crashes. Table 2-11 shows the model coefficients and overdispersion parameter for each crash type and severity level for all intersection types.

Table 2-12 and Table 2-13 provide the proportions developed using Oregon data for crash severity for MV and SV crashes, respectively. These tables can be used to separate the FI crash frequencies by crash severity level.

Table 2-14 (MV crashes) and Table 2-15 (SV crashes) provide percentages of FI and PDO crash severities by collision types, separately for each intersection type. These percentages were calculated based on all multiple- and SV crash counts at all intersections for those specific intersection types in Oregon.

Table 2-16 provides the distribution of pedestrian crashes by total crashes for intersections on high-speed urban and suburban arterials, based on Oregon data. The proportion of pedestrian crashes is used to estimate the number of pedestrian crashes at intersections on high-speed urban and suburban arterials.

Table 2-11. Calibrated Coefficients for Intersections on High-Speed Urban and Suburban Arterials

Intersection Type	Crash Type	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	Overdispersion parameter
3ST-HS	MV FI	-12.35	0.90	0.51	0.99
3ST-HS	MV PDO	-16.63	0.96	0.89	0.79
3ST-HS	SV FI	-13.26	0.79	0.53	2.10
3ST-HS	SV PDO	-12.72	0.92	0.31	0.75
4ST-HS	MV FI	-8.55	0.55	0.45	0.89
4ST-HS	MV PDO	-6.97	0.42	0.32	0.94
4ST-HS	SV FI	-14.12	0.91	0.45	1.64
4ST-HS	SV PDO	-7.35	0.24	0.41	1.40
3SG-HS	MV FI	-6.57	0.64	0.17	0.09
3SG-HS	MV PDO	-3.16	0.25	0.19	0.34
3SG-HS	SV FI	-7.20	0.63	-0.09	1.04
3SG-HS	SV PDO	-8.38	0.61	0.08	0.74
4SG-HS	MV FI	-9.22	0.86	0.29	0.31
4SG-HS	MV PDO	-11.35	1.04	0.29	0.38
4SG-HS	SV FI	-9.84	0.83	0.04	0.98
4SG-HS	SV PDO	-5.94	0.37	0.11	0.84

Table 2-12. MV Crash Severity Proportion for Intersections on High-Speed Urban and Suburban Arterials.

Crash Severity Level	3ST-HS Intersections	4ST-HS Intersections	3SG-HS Intersections	4SG-HS Intersections
Fatal	0.3	3.5	0.3	0.6
Incapacitating Injury	10.9	12.0	5.5	4.4
Nonincapacitating Injury	38.7	42.9	26.6	24.1
Possible Injury	50.1	41.7	67.7	70.8
Total	100	100	100	100

Table 2-13. SV Crash Severity Proportion for Intersections on High-Speed Urban and Suburban Arterials.

Crash Severity Level	3ST-HS	4ST-HS	3SG-HS	4SG-HS
Fatal	0.1	0.1	0.1	2.1
Incapacitating Injury	13.8	6.9	5.9	14.6
Nonincapacitating Injury	43.1	51.7	41.2	50.0
Possible Injury	43.1	41.4	52.9	33.3
Total	100	100	100	100

Table 2-14. Proportion of MV Crashes by Manner of Collision for Intersections on High-Speed Urban and Suburban Arterials

Manner of Collision	3ST-HS FI	3ST-HS PDO	4ST-HS FI	4ST-HS PDO	3SG-HS FI	3SG-HS PDO	4SG-HS FI	4SG-HS PDO
Angle	32.9	24.7	82.2	72.0	56.2	51.0	31.5	25.6
Head-on	0.3	0.0	0.8	0.8	2.8	0.5	0.6	0.2
Other MV collisions	0.3	0.4	0.8	0.0	0.0	1.5	0.4	1.6
Rear-end	61.9	63.1	13.9	25.6	38.2	37.0	63.7	62.3
Sideswipe	4.7	11.8	2.3	1.6	2.8	10.0	3.8	10.3
Total MV crashes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2-15. Proportion of SV Crashes by Manner of Collision for Intersections on High-Speed Urban and Suburban Arterials

Manner of Collision	3ST-HS FI	3ST-HS PDO	4ST-HS FI	4ST-HS PDO	3SG-HS FI	3SG-HS PDO	4SG-HS FI	4SG-HS PDO
Fixed Object or Other Object	83.1	75.0	82.8	89.7	76.5	90.5	78.1	80.4
Non-collision	6.2	4.2	10.3	2.6	11.8	4.8	16.7	5.6
Animal	10.8	19.4	6.9	7.7	11.8	0.0	2.1	8.4
Other SV collisions	0.0	1.4	0.0	0.0	0.0	4.8	3.1	5.6
Total SV crashes	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2-16. Distribution of Pedestrian Crash Counts and Percentages for Intersections on High-Speed Urban and Suburban Arterials

Intersection Type	Number of Pedestrian Crashes	Total Crashes	Proportion of Pedestrian Crashes
3ST-HS	4	734	0.54
4ST-HS	4	456	0.88
3SG-HS	5	663	0.75
4SG-HS	22	3860	0.57

No vehicle-bicycle crashes were reported at intersections on high-speed urban and suburban arterials for the period considered in this study. It is recommended to consider the proportion of bicycle crashes reported in the NCHRP 17-68 study. Table 2-17 provides the proportion of bicycle crashes that can be used to estimate the number of bicycle crashes at intersections on high-speed urban and suburban arterials.

Table 2-17. Distribution of Bicycle Crash Percentages for Intersections on High-Speed Urban and Suburban Arterials

Intersection Type	Proportion of Bicycle Crashes
3ST-HS	0.00
4ST-HS	0.00
3SG-HS	0.11
4SG-HS	0.07

2.5.1 Crash Modification Factors

The CMFs in the NCHRP 17-68 for intersections on high-speed urban and suburban arterials were adopted from Chapter 12 of first edition of the HSM. The same CMFs are recommended for use in the state of Oregon.

2.5.1.1 Lighting CMF

The CMF for intersection lighting presented in the HSM was based on the work by Elvik and Vaa (2004). The base condition for lighting is the absence of intersection lighting. The lighting CMF is described using Equation (2-14).

$$CMF_{lg} = 1 - 0.38 \times p_{ni} \quad \textbf{(2-14)}$$

where,

CMF_{lg} = crash modification factor for the effect of lighting on total crashes; and

p_{ni} = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes). Table 2-18 presents for the nighttime crash proportion, p_{ni}, by intersection type, estimated using Oregon data.

Table 2-18. Nighttime Crash Counts and Proportions for Unlighted Intersections on High-Speed Urban and Suburban Arterials

Intersection Type	Number of Sites	Number of Nighttime Crashes	Total Crashes	Proportion of Nighttime Crashes
3ST-HS	29	203	734	0.277
4ST-HS	23	133	456	0.292
3SG-HS	4	176	663	0.265
4SG-HS	36	1032	3860	0.267

2.5.1.2 Intersection Approaches with Left-Turn Lanes CMF

The CMFs for providing a left-turn lane on one or more intersection approaches at an urban or suburban intersection reported in the HSM was based on the work by Harwood et al. (2002). The base condition is the absence of left-turn lanes on intersection approaches. The CMFs for providing a left-turn lane on one or more intersection approaches are presented in Table 2-19. These CMFs apply to all severity levels.

Table 2-19. CMF for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	1 Approach with Left-Turn Lanes	2 Approaches with Left-Turn Lanes	3 Approaches with Left-Turn Lanes	4 Approaches w Left-Turn Lanes
3ST-HS	0.67	0.45	-	-
4ST-HS	0.73	0.53	-	-
3SG-HS	0.93	0.86	0.80	-
4SG-HS	0.90	0.81	0.73	0.66

Note: Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes.

2.5.1.3 Intersection Approaches with Right-Turn Lanes CMF

The CMFs for providing a right-turn lane on one or more intersection approaches at an urban or suburban intersection reported in the HSM was based on the work by Harwood et al. (2002). The base condition is the absence of right-turn lanes on intersection approaches. The CMFs for providing a right-turn lane on one or more intersection approaches are presented in Table 2-20. These CMFs apply to all severity levels.

Table 2-20. CMF for Installation of Right-Turn Lanes on Intersection Approaches

Intersection Type	1 Approach with Right-Turn Lanes	2 Approaches with Right-Turn Lanes	3 Approaches with Right-Turn Lanes	4 Approaches with Right-Turn Lanes
3ST-HS	0.86	0.74	-	-
4ST-HS	0.86	0.74	-	-
3SG-HS	0.96	0.92	-	-
4SG-HS	0.96	0.92	0.88	0.85

Note: Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.

3.0 FINDINGS AND RECOMMENDATIONS

The research team developed local calibration factors and calibrated new SPFs for intersections on high-speed urban and suburban arterials. Although data were collected for 3SG intersections on rural two-lane and multi-lane highways, calibration factors could not be developed due to inadequate sample size. This chapter summarizes the recommended factors and SPFs, provides suggested revisions to ODOT's *Analysis Procedures Manual* (APM), and describes updates to HSM analysis spreadsheets.

3.1 RECOMMENDED CALIBRATION FACTORS AND SPFS

The research team recommends the use of the HSM calibration factors developed with local proportions and the use of local proportions in all calculations, except for MV crashes at 3ST-HS intersections where the calibration factors had questionable accuracy. These recommended calibration factors for intersections on high-speed urban and suburban arterials are summarized in Table 7.1. It is advised that the road characteristic data created for calibration purposes be maintained and that calibration factors be updated for future years (with updated AADT values and future recorded crashes) with minimal additional work. Nevertheless, it's probable that some of the calibration intersections have undergone changes or enhancements over time, necessitating the collection of new data.

Table 3-1. Recommended Oregon Calibration Factors

Intersection Type	Crash Type	Local Calibration Factor ***C***
3ST-HS	SV FI	2.10
3ST-HS	SV PDO	0.52
4ST-HS	MV FI	0.54
4ST-HS	MV PDO	0.22
4ST-HS	SV FI	0.85
4ST-HS	SV PDO	0.30
3SG-HS	MV FI	2.04
3SG-HS	MV PDO	0.92
3SG-HS	SV FI	1.23
3SG-HS	SV PDO	0.45
4SG-HS	MV FI	1.48
4SG-HS	MV PDO	0.52
4SG-HS	SV FI	1.05
4SG-HS	SV PDO	0.43

For MV FI crashes at 3ST-HS intersections, the following equation can be used:

$$N_{spf} = e^{-12.35} AADT_{maj}^{0.90} AADT_{min}^{0.51} \quad \textbf{(3-1)}$$

For MV PDO crashes at 3ST-HS intersections, the following equation can be used:

$$N_{spf} = e^{-16.63} AADT_{maj}^{0.96} AADT_{min}^{0.89} \quad \textbf{(3-2)}$$

3.2 ANALYSIS PROCEDURES MANUAL REVISIONS

Text revisions based on the results of this project are highlighted green. Other suggested revisions are highlighted yellow.

4.4.4 Local Calibration Coefficients (REVISED)

Calibration coefficients are developed locally by comparing predictive results to locally observed results. These adjust the prediction to account for differences in geography, crash reporting, enforcement policy, and driver behavior between the general models provided in the HSM and the location of application. Oregon calibration coefficients are not yet available for all predictive models. In cases where a state- or region-specific SPF has been produced, calibration coefficients are not applied.

In Oregon, crash reporting is a driver responsibility with some enhancement for enforcement. This means that it is more likely to have a police report if there was a serious injury than for a crash involving property damage only. Oregon's required reporting threshold is typically higher than many other states (at $1,500) so many minor crashes are not reported and do not show up in the crash data. Because of these reporting requirements, Oregon conditions data should not be directly related to national averages or adjacent states (i.e., Washington), which have different reporting thresholds.

ODOT has created Oregon calibration factors for some of the HSM Part C models in the following reports:

- *Calibrating The Future Highway Safety Manual Predictive Methods For Oregon State Highways* (2012). This report covers the Rural Two-Lane models, Rural Multilane models, and Urban/Suburban Arterial models for both segments and intersections.

- <Insert title, publication year, and link for this project's final report here.> This report covers the following intersection types: High-Speed Urban and Suburban Arterial 3-leg stop-controlled, 3-leg signalized, 4-leg stop-controlled, and 4-leg signalized.

The ODOT Driveway Safety models do not require calibration, because they were developed using local Oregon data. PLANSAFE does not require calibration by the analyst, because the program self-calibrates using provided data. An attempt was made to calibrate the freeway and interchange Part C models but was unsuccessful. Results from the Enhanced Interchange Safety Analysis Tool (ISATe) must be reported uncalibrated, as described below.

The locally-derived calibration factors listed in Exhibit 4-11 adjust total predicted crash frequencies to a value that is representative of Oregon conditions. Predicted crashes are multiplied by the calibration factor to determine the calibrated predicted crashes. For example, if an uncalibrated model estimated 10 predicted crashes per year and had a local calibration factor of 0.50, the locally-calibrated result would be five predicted crashes per year.

Exhibit 4-11: Locally-Derived Oregon HSM Calibration Factors

Segment Facility Type	SPF Source (1)	Calibration Factor (1)
R2 Rural 2-lane undivided	HSM 1st Edition	0.74
MRU Multilane Rural Undivided	HSM 1st Edition	0.37
MRD Multilane Rural Divided	HSM 1st Edition	0.77
U2U Urban and Suburban 2-lane Undivided Arterials	HSM 1st Edition	0.62
U3T Urban and Suburban 3-lane with TWLTL Arterials	HSM 1st Edition	0.81
U4D Urban and Suburban 4-lane Divided Arterials	HSM 1st Edition	1.41 / 0.64 (2)
U4U Urban and Suburban 4-lane Undivided Arterials	HSM 1st Edition	0.63
U5T Urban and Suburban 5-lane with TWLTL Arterials	HSM 1st Edition	0.64
R3ST Rural Two-Lane 3-leg, minor stop	HSM 1st Edition	0.31
R4ST Rural Two-Lane 4-leg, minor stop	HSM 1st Edition	0.31
R4SG Rural Two-Lane 4-leg, signalized	HSM 1st Edition	0.15
MR3ST Rural Multilane 3-leg, minor stop	HSM 1st Edition	0.15
MR4ST Rural Multilane 4-leg, minor stop	HSM 1st Edition	0.39
MR4SG Rural Multilane 4-leg, signalized	HSM 1st Edition	0.15
U3ST Urban and Suburban 3-leg, minor stop Arterials	HSM 1st Edition	0.35

Segment Facility Type	SPF Source [(1)]	Calibration Factor [(1)]
U4ST Urban and Suburban 4-leg, minor stop Arterials	HSM 1st Edition	0.45
U3SG Urban and Suburban 3-leg, signalized Arterials	HSM 1st Edition	0.73
U4SG Urban and Suburban 4-leg, signalized Arterials	HSM 1st Edition	1.05
U3ST-HS High-Speed Urban and Suburban 3-leg, minor stop Arterials	ODOT SPR 871 (MV), NCHRP 17-68 (SV)	1.00 (MV FI), 1.00 (MV PDO), 2.10 (SV FI), 0.52 (SV PDO)
U4ST-HS High-Speed Urban and Suburban 4-leg, minor stop Arterials	NCHRP 17-68	0.54 (MV FI), 0.22 (MV PDO), 0.85 (SV FI), 0.30 (SV PDO)
U3SG-HS High-Speed Urban and Suburban 3-leg, signalized Arterials	NCHRP 17-68	2.04 (MV FI), 0.92 (MV PDO), 1.23 (SV FI), 0.45 (SV PDO)
U4SG-HS High-Speed Urban and Suburban 4-leg, signalized Arterials	NCHRP 17-68	1.48 (MV FI), 0.52 (MV PDO), 1.05 (SV FI), 0.43 (SV PDO)

Table Notes:
(1) MV = multiple-vehicle, SV = single-vehicle, FI = fatal and injury, PDO = property damage only
(2) Value of 1.41 based on small sample size and geometric designs no longer used. Value of 0.64 should be used for all future new designs.

Additional locally derived severity and crash type distributions are included in the reports listed above. The best way to ensure that all appropriate Oregon calibration factors are accounted for is to use or refer to the HSM Spreadsheets that are pre-filled with Oregon calibration factors. These spreadsheets include tables with all recommended locally derived calibration factors and distributions, and are described in APM Section 4.4.13 below.

Where an Oregon calibration factor does not exist, the results of the predictive analysis should only be used for relative comparisons such as net difference in predicted crashes or percent change in predicted crashes. Uncalibrated predicted crashes should be identified as such and reported separately from calibrated predicted crashes or expected crashes.

Other Revisions

- Revise version number in file name (currently APMv2.pdf, should become APMv3.pdf).
- Revise version number, update date, copyright date, and staff names in the front matter.
- Check pagination in the front matter – currently skips from *iii* to *v* with no *iv*.

- Check footers on all pages (may need to do in multiple places if the source file is a Word document with multiple section breaks):

- Document title is *Analysis Procedures Manual* (plural Procedures), but all the footers say "Analysis Procedure Manual Version 2" (singular Procedure).

- Update version number (2 to 3).

- Update all "last updated" dates as needed (currently inconsistent on different pages, not sure if they should all match the date on the cover page or if they reflect revision dates for specific sections or chapters).

3.3 SPREADSHEET UPDATES

As stated in the APM, ODOT maintains three HSM analysis spreadsheets that have been calibrated using Oregon crash data. These spreadsheets help the analyst implement the safety prediction models in Chapters 10, 11, and 12 of the HSM. The original versions of these spreadsheets were developed in NCHRP project 17-38, and the current versions of these spreadsheets are posted on AASHTO's HSM web page (https://www.highwaysafetymanual.org/Pages/Tools.aspx). The research team downloaded the spreadsheets from the HSM page and updated them for ODOT application by entering the local calibration factors into the various reference tables in the spreadsheets. Most of these factors were derived in previous ODOT-sponsored research as described in the APM, and the research team derived the local calibration factors for high-speed urban and suburban arterial intersections.

To update the Chapter 12 spreadsheet, the research team modified the structures of the worksheets for intersections ("Intersection_1" and "Reference Tables (Intersection)") to accommodate the analysis of high-speed intersections. Figure 3-1 shows a screenshot of the updated urban and suburban arterial intersections worksheet, which uses the codes of 3ST-HS, 4ST-HS, 3SG-HS, and 4SG-HS to specify the different types of high-speed intersections.

	A–D	E–G	H–I	J–N	O
1					
2	**Worksheet 2A -- General Information and Input Data for Urban and Suburban Arterial Intersections**				
3	**General Information**		**Location Information**		
4	Analyst	(enter name)	Roadway	(enter roadway name)	
5	Agency or Company	(enter agency)	Intersection	(enter intersection name)	
6	Date Performed	(enter date)	Jurisdiction	(enter jurisdiction)	
7			Analysis Year	2019	
8	**Input Data**		**Base Conditions**	**Site Conditions**	
9	Intersection type (3ST, 3SG, 4ST, 4SG, 3ST-HS, 4ST-HS, 3SG-HS, 4SG-HS)		--	4ST-HS	Unsignalized four-leg high-
10	AADT $_{major}$ (veh/day)	$AADT_{MAX}$ = 67,700 (veh/day)	--	3ST	AADT OK
11	AADT $_{minor}$ (veh/day)	$AADT_{MAX}$ = 33,400 (veh/day)	--	3SG	AADT OK
12	Intersection lighting (present/not present)		Not Present	4ST	
13	Calibration factor, C_i		1.00	4SG 3ST-HS	Oregon Calibration Factor- Auto filled based
14	Data for unsignalized intersections only:		--	4ST-HS	
15	Number of major-road approaches with left-turn lanes (0,1,2)		0	3SG-HS	
16	Number of major-road approaches with right-turn lanes (0,1,2)		0	4SG-HS	
17	Data for signalized intersections only:		--	--	
18	Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]		0	0	
19	Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]		0	0	
20	Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]		--	0	Not applicable for high-speed intersections
21	Type of left-turn signal phasing for Leg #1		Permissive	Not Applicable	Not applicable for high-speed intersections
22	Type of left-turn signal phasing for Leg #2		--	Not Applicable	Not applicable for high-speed intersections
23	Type of left-turn signal phasing for Leg #3		--	Not Applicable	Not applicable for high-speed intersections
24	Type of left-turn signal phasing for Leg #4 (if applicable)		--	Not Applicable	Not applicable for high-speed intersections
25	Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]		0	0	Not applicable for high-speed intersections
26	Intersection red light cameras (present/not present)		Not Present	Not Present	Not applicable for high-speed intersections
27	Sum of all pedestrian crossing volumes (PedVol) -- Signalized intersections only			1	
28	Maximum number of lanes crossed by a pedestrian (n_{lanesx})		--	1	

Figure 3-1. Screenshot of Updated Urban and Suburban Intersections Worksheet

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APPENDIX A: ACRONYM AND ABBREVIATION LIST

Table A-1: Acronyms and Abbreviations Used in Report

Abbreviation	Definition
3aST	Three-leg all-way stop-controlled intersection
4aST	Four-leg all-way stop-controlled intersection
3ST	Three-leg intersection with stop control on minor street only
4ST	Four-leg intersection with stop control on minor street only
3SG	Three-leg intersection with signal control
4SG	Four-leg intersection with signal control
3ST-HS	High-speed urban and suburban arterial three-leg intersection with stop control on minor street only
4ST-HS	High-speed urban and suburban arterial four-leg intersection with stop control on minor street only
3SG-HS	High-speed urban and suburban arterial three-leg intersection with signal control
4SG-HS	High-speed urban and suburban arterial four-leg intersection with signal control
3STT	Three-leg turning intersection
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AF	Adjustment Factor
APM	Analysis Procedures Manual
CAR	Crash Analysis and Reporting System
CMF	Crash Modification Factor
FI	Fatal and Injury (crash)
ft	feet
GIS	Geographic Information System
HPMS	Highway Plan Management System
HSM	Highway Safety Manual
m	meter
MV	Multiple Vehicle (crash)
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
OSM	Open Street Map
PDO	Property Damage Only (crash)
SDF	Severity Distribution Function
SPF	Safety Performance Function
SV	Single Vehicle (crash)
UGB	Urban Growth Boundary