The Calibrator:

An SPF Calibration and Assessment Tool

Updated User Guide

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16. Abstract This user guide provides background information on safety performance functions (SPFs) and the need for calibration. It also serves as a companion "how-to" manual for The Calibrator software tool. This is an updated user guide based on enhancements to The Calibrator, including the ability to calibrate SPFs based on calibration functions and dispersion functions. INSTALLATION NOTE: The Calibrator was developed for Microsoft Excel versions 2007 and later, running on Windows Operating Systems with the SOLVER add-in installed. Since the file includes macros, there may be warnings about enabling macros or Trusting the document before using it. Other issues that users may encounter include Trust Center settings. Users can access the Trust Center by navigating to (File, Options, and Trust Center). In the Trust Center options, click on Macro Settings and adjust according to your organizations policy. Microsoft also releases updates that can occasionally break ActiveX/Macros. Refer to your IT department about resolutions/hotfixes for ActiveX controls.			
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LIST OF ACRONYMS

AADT	Annual average daily traffic
AADTMAJ	Average annual daily traffic on major road
AADTMIN	Average annual daily traffic on minor road
AASHTO	American Association of State Highway and Transportation Officials
AIC	Akaike's Information Criterion
BIC	Bayesian Information Criterion
CMF	Crash Modification Factor
CURE	Cumulative residuals
CV	Coefficient of variation
DCMF	Development of Crash Modification Factors
FHWA	Federal Highway Administration
GOF	Goodness-of-fit
HSM	Highway Safety Manual
k	Dispersion
KABCO	Refers to a scale that is used to represent injury severity in crash reporting: K is fatal injury, A is serious injury, B is minor injury, C is possible injury, and O is property damage only.
MAD	Mean absolute deviation
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PDO	Property damage only
SPF	Safety Performance Function
V	Variance
V(C)	Variance of the calibration factor

1. INTRODUCTION

Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) are integral parts of the Highway Safety Manual (HSM) methods for estimating the expected number of crashes for a given site. SPFs and CMFs are available from a number of sources, including the HSM, CMF Clearinghouse, AASHTOWare Safety Analyst™, and State-specific reports. While SPFs and CMFs are widely available, they are produced using data from specific locations and times. For various theoretical and practical reasons, SPFs and CMFs may not be directly transferable across jurisdictions or over time within the same jurisdiction. As such, SPFs and CMFs may not be nationally applicable in their raw form. For example, SPFs and CMFs are intended for application under certain conditions, including factors related to how the crash data are coded. If data for a given time and place do not meet the same standard or if the conditions differ from those used to develop the SPF or CMF, then it is necessary to calibrate the SPFs and/or CMFs.

The Calibrator is a spreadsheet-based tool to help users assess SPF and CMF compatibility and applicability, and to calibrate SPFs and CMFs for application in a different time or place. The tool is applicable to all SPFs or predictions from the combination of SPFs and CMFs as is consistent with the HSM Part C Predictive Method. The tool provides the option of calculating a single calibration factor or calculating a unique factor for each site based on a calibration function for each SPF or SPF and CMF combination. The tool also provides various goodness-of-fit measures and an assessment of how the predictions are performing over the range of all variables in the SPF and CMFs applied.

The audience for the tool and this user guide are road safety practitioners responsible for developing new SPFs or calibrating existing SPFs to data from their jurisdiction. The tool is intended to automate the calibration process and provide information to users that will allow them to assess the suitability of one or more SPFs or to compare between alternate SPFs. Specifically, the tool can help users to complete the following:

- Assess the performance of the HSM Predictive Method as a whole on local data.
- Assess the performance of the uncalibrated HSM Part C SPFs on local data.
- Assess the performance of SPFs and CMFs from other sources on local data.
- Calibrate existing SPFs to local data using the HSM calibration procedure.
- Calibrate the dispersion parameter of an existing SPF to local data.
- Compare the performance of multiple SPFs.
- Identify the most appropriate SPFs and CMFs to apply from a list of alternatives.

Note: The tool is NOT for developing original SPFs, creating the required datasets for calibration, or calibrating standalone CMFs.

This user guide provides directions for using the tool and illustration of its application through screenshots and examples using real data. It is intended to accompany the application of the tool. To facilitate that application, the user guide provides a brief background on the theory of SPF calibration, goodness-of-fit measures, and SPF selection. The guide draws on content from the following six key resources, and users of the tool are encouraged to read the first three prior to using the tool.

1. **The Highway Safety Manual, First Edition, Volume 2, Appendix A**.(1) This appendix addresses the calibration of the Part C predictive SPFs.
2. **User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors**.(2) This project provides guidance for assessing the quality of a calibration factor. Relevant content includes guidance on preparing for calibration and on collecting data, a discussion of minimum sample sizes for reliable calibration factors, and guidance on when to split up the calibration dataset and estimate separate factors, for example, for different regions or terrain types.
3. **Safety Performance Function Decision Guide: SPF Calibration vs. SPF Development**.(3) This guidebook discusses the factors that need to be considered while making the decision of whether to calibrate an existing SPF or develop a new SPF.
4. **Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs**.(4) This guidebook provides the state of the knowledge on what data, expertise, tools, and other resources are required to develop jurisdiction-specific SPFs.
5. **The Art of Regression Modeling in Road Safety**.(5) This book provides instruction on how to fit and assess a multivariable statistical SPF to cross-sectional safety data using a simple spreadsheet.
6. **Estimation of Calibration Functions for Predicting Crashes on Rural Two-Lane Roads in Arizona**.(6) This paper discusses the development of a calibration function.

2. BACKGROUND ON SPF CALIBRATION

WHY CALIBRATE?

As stated in the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors*, the use of SPFs in any jurisdiction calls for a calibration of such SPFs, and for the replacement of any default crash distributions applied to local and current conditions.(2)

Calibration is required because SPFs are developed using data associated with a single or select group of jurisdictions and for a specific time period. If applied to another jurisdiction, or to another time period, the predictions may be biased. The purpose of calibration is to ensure that this bias is tolerably small. The bias may arise from differences in several factors, including the following:

- Crash reporting practices (e.g., minimum reporting thresholds).
- Socio-demographic characteristics of the driving population.
- Weather.
- Roadway maintenance practices.
- Other factors affecting crash risk, which are not represented in the SPF and which may differ by location or over time.

For the same reason, it is appropriate to replace any default crash distributions and adjustment factors, such as those found in the HSM, using jurisdiction-specific data for the same years as the jurisdiction-specific SPF calibration factors.(1)

Since the publication of the HSM, several State transportation departments have engaged in projects to develop calibration factors for HSM SPFs using their own data, such as Oregon, Illinois, Virginia, Washington, Louisiana, and Missouri.(2) The results of a study by the Oregon Department of Transportation (ODOT) highlighted the critical need to calibrate SPFs. The use of uncalibrated SPFs from Part C of the HSM would have over-estimated total crashes for most facilities in Oregon. The estimates would have been biased by 25 percent in the case of rural two-lane roadway segments and more than 80 percent for four-legged signalized intersections on rural multilane highways. Biases in uncalibrated SPFs may lead to suboptimal decisions when selecting sites for investigation, identifying safety strategies, or evaluating design alternatives.

METHODOLOGY FOR CALIBRATION

The calibration of an SPF includes two components: the estimation of a calibration factor or function and the estimation of the dispersion parameter or function. A calibration factor serves as a multiplier to adjust the original SPF estimate. For example, a calibration factor of 1.25 would increase the original SPF estimate by 25 percent, indicating that the uncalibrated SPF is under-predicting crashes. A calibration function is an equation that provides a unique calibration factor for each site, the values of which are dependent on the site-specific variables included in the equation. The calibrated dispersion parameter is applicable if the SPF was developed using a negative binomial error distribution assumption. The dispersion parameter is required for use of the Empirical Bayes procedure presented in the HSM. A dispersion function is an equation that provides a unique dispersion parameter for each site, the values of which are dependent on the site-specific variables included in the equation.

Figure 1 shows the five-step procedure for calibrating an SPF.

Step 1: Identify facility types for which the applicable SPF is to be calibrated.

Step 2: Select sites for calibration of the SPF for each facility.

Step 3: Obtain data for each site applicable to a specific calibration period.

Step 4: Apply the SPF to predict crash frequency for each site during the calibration period.

Step 5: Compute the calibration factor or function and calibrated dispersion parameter or function.

Figure 1. Chart. Calibration process.

To compute a calibration factor, first apply the existing SPF to estimate the predicted crashes for each site in the calibration dataset. Then, sum both the observed and predicted crashes over all sites. Figure 2 shows the equation for computing the calibration factor. Finally, apply the calibration factor as a multiplier to the existing SPF for application (i.e., $SPF_{calibrated} = C * SPF_{existing}$).

$$C = \frac{\sum_{all\ sites} observed\ crashes}{\sum_{all\ sites} predicted\ crashes}$$

Figure 2. Equation. Calibration factor.

Where:

C = estimate of calibration factor for SPF of a given facility type.

To compute a calibration function, fit a negative binomial regression model to the calibration data with the observed crashes as the dependent variable and the uncalibrated SPF estimates for each site as the predictor variable. In so doing, estimate the two parameters, a and b, as shown in Figure 3.

$$Observed\ Crashes = a\left(SPF_{existing}\right)^{b}$$

Figure 3. Equation. Calibration function.

It is also logical to calibrate the dispersion parameter as this not only indicates how well the calibrated SPF fits the data, but also facilitates the use of the Empirical Bayes methodology. The dispersion parameter may be a constant value or a function of site characteristics. In the HSM first edition, all dispersion parameters are either constant or a function of segment length. The form (i.e., constant or function) and value of the dispersion parameter are typically provided with the existing SPF. The discussion to follow will refer to the dispersion parameter as f(*k*), indicating that it is a function which may or may not be a constant.

Calibrating the dispersion parameter occurs through a maximum likelihood procedure, which determines the most likely dispersion parameter value that maximizes the negative binomial likelihood function (5). The spreadsheet tool can calibrate a constant dispersion parameter, k, or one that varies by length (for road segments). Figure 4 shows the equation for a variable dispersion parameter that is a linear function of length. Figure 5 shows the equation for a variable dispersion parameter that is a nonlinear function of length.

$$dispersion = \frac{k}{length}$$

Figure 4. Equation. Variable dispersion as linear function of length.

$$dispersion = \mathrm{c}(length)^{d}$$

Figure 5. Equation. Variable dispersion as nonlinear function of length.

Where:

k, c, and d = estimated parameter.

length = length of road segment.

While analysts can select any of the optional dispersion parameter forms within The Calibrator when estimating a calibration factor or calibration function, it is suggested to use the same dispersion parameter form as the existing SPF. If the SPF of interest uses a dispersion parameter form other than one of those provided, then it is suggested to use a constant dispersion parameter form. At the time of this publication, The Calibrator software includes dispersion parameter forms to accommodate all SPFs included in the HSM first edition and AASHTOWare Safety Analyst™.

GUIDANCE ON PREPARING DATA FOR CALIBRATION

The development of calibration factors requires data for observed crashes, exposure (traffic volume), and any roadway characteristics included in the SPF or that define the facility types to which the SPF pertains (e.g., four-legged, rural, signalized intersections). To use the spreadsheet-based calibration tool, the data are required to be in a specified format prior to importing into the tool. The section titled, *Using the Tool*, provides further details on the required data format.

There are three key aspects of data preparation: 1) selecting sites for calibration, 2) dealing with outliers, and 3) comparing the range of calibration data. The following sections provide an overview of these three aspects of data preparation. The tool itself does not directly accomplish these aspects and thus the content provided here is merely to illuminate the issues involved.

Selecting Sites for Calibration

The *SPF Decision Guide: SPF Calibration vs. SPF Development* discusses the development of a calibration dataset.(3) Step 2 of that process is the selection of sites for calibration. The guide indicates that sites should represent the intended application of the SPF(s). Two applications include network screening and before-after studies.

- **Network Screening**: If the intended application of the calibrated SPF is for network screening, then the calibration dataset should represent the network considered for screening. Further, analysts may desire multiple calibration factors to account for regional or jurisdictional differences in data. This decision depends on the variation in terrain, climate, crash reporting practices, driver population, animal population, and other factors among the regions or jurisdictions.
- **Before-After Study**: If the analyst intends to use the calibrated SPF in a before-after study or an analysis that only applies to a select group of sites defined by specific characteristics of interest, then the calibration dataset should only comprise those sites. For example, if the calibrated SPF is to be used in an empirical Bayes before-after study of installing centerline rumble strips on curves on two-lane rural roads, then the original SPF and reference group used for SPF calibration should include curves without centerline rumble strips on two-lane rural roads. The reference sites used for calibration should match the treated sites on other characteristics such as traffic volume, lane width, and roadside conditions.

Randomization is another consideration in selecting appropriate sites for the calibration dataset. In general, it is preferred to use all sites within the population to calibrate network-level SPFs such as those in AASHTOWare Safety Analyst™. Network-level SPFs require limited data (i.e., observed crashes, traffic volume, and segment length), which are typically available for all sites across the network. To calibrate SPFs from Part C of the HSM, and others that require detailed data, it is often necessary to use a sample because the detailed data are not available on a network-wide basis. The aspect of selecting sites randomly is important because calibration factors will likely differ for various subsets of the facility type. For example, the calibration factors will likely differ for subsets from different regions or subsets with different traffic volume ranges. Since the dependence of the calibration factor to these elements is unknown, the only way to ensure a sample is representative is to select units by some random process.

Dealing with Outliers

Outliers can influence the calibration estimates and result in misleading or incorrect findings. As such, users should perform basic data quality checks before calibration. Quality checks include plotting the data (e.g., X-Y plots, boxplots, and distribution plots) and calculating distributional statistics for each variable (dependent and independent). Values of predictor variables that are far outside the range of typical values for that variable could be considered leverage points and should be investigated. Looking at crash rates (e.g., crashes per million vehicle miles traveled) across specific groups of segments will highlight unusual crash rates and crash counts. Analysts should exclude extreme observations from the data unless they can verify and correct obvious errors. Hauer proposes a method to identify outliers that involves looking for a vertical "jump" in the cumulative residuals (CURE) plot.(7) Users are also encouraged to read the *SPF Development Guide: Developing Jurisdiction-Specific SPFs* prior to calibrating an existing SPF. While it focuses on developing original SPFs, it discusses the elimination of outliers and other data quality control issues that would bias the estimates if not accounted for.(4)

Comparing the AADT Range of Calibration Data

Another important consideration during data assembly is the range of traffic volumes and other variables used in the initial development of the SPFs. Applying SPFs to sites with variables significantly outside the range of those in the existing SPF may not provide reliable results. As such, analysts should assemble sufficient data in the desired range. If traffic volumes for local sites are significantly outside the range volumes applicable to the existing SPFs, then an agency may consider developing their own SPFs. As an approximation, and an alternative to developing jurisdiction-specific SPFs, an agency may consider developing separate calibration factors, one for the data within the range of the original SPF and another for the data outside of this range. For example, if the existing SPF represents sites with traffic volumes between 10,000 and 20,000 vehicles per day, but some of the sites in question represent traffic volumes less than 10,000, then the analyst may develop two separate calibration factors; one for sites with volumes less than 10,000 and a second for sites with volumes greater than 10,000 vehicles per day. Appendix D of the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors* provides guidance on when to estimate separate calibration factors for subsets of data including subsets grouped by AADT.(2)

MINIMUM SAMPLE SIZES

Sample size refers to the number of sites and number of crashes in the data used for calibration. If either few sites or few crashes are used, then the calibration may not be reliable. The HSM(1) provides guidance on the required sample size, but this is based on experience rather than science. Several research reports show that larger sample sizes are usually required for common facility types.(8-11) The *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors Appendix B* provides additional guidance on estimating required minimum sample sizes for a calibration dataset.(2) The guidance details how to estimate the standard error and coefficient of variation of the calibration factor and provides guidance on acceptable ranges for the coefficient of variation.

NCHRP Project 17-62, *Improved Prediction Models for Crash Types and Crash Severities*, provides an updated HSM calibration procedure. The procedure estimates the sample size iteratively, starting with an available sample that is at least as large as that recommended in the HSM. The next step is to estimate and assess a constant calibration factor, which analysts can achieve by using The Calibrator tool. If the assessment indicates that the sample is insufficient, then there is a need to assemble data for additional sites and re-estimate the calibration factor. This continues until the analyst achieves a successful calibration. As a further step, there is an opportunity to estimate and assess a calibration function with the final sample.

In addition, if the analyst is calibrating a dispersion parameter as a function of site characteristics (i.e., a variable dispersion parameter), then a larger sample may be required than for calibrating a constant dispersion parameter. If it is not practically feasible to assemble the suggested minimum sample, then it may still be acceptable, with appropriate cautions, to attempt a calibration exercise. This was successfully done for calibrations in Oregon, Louisiana, and Italy.(12-14) For fatal and injury collisions, smaller samples may suffice, given that fatal and injury collision data are more reliable than those that include property damage only crashes.(14)

MULTIPLE CALIBRATION FACTORS

It may be appropriate to develop separate calibration factors for large regions with stark differences in terrain, climate, driver population, and other factors that can influence crashes. This is similar to the issue related to the range of traffic volumes described above in the section titled, *Comparing the AADT Range of Calibration Data*. Appendix D of the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors* provides guidance on when to estimate separate calibration factors for subsets of data.(2) Users of The Calibrator are encouraged to read both Appendices B and D of that Guide for further guidance on developing calibration factors.(2) The following paragraph is merely a summary of the issues raised in that Guide. The tool itself does not address these issues; however, it can estimate separate calibration factors for subsets of data grouped by levels of a categorical variable or imported as separate datasets.

As the Guide notes, the HSM suggests, "For large jurisdictions, such as entire states, with a variety of topographical and climate conditions, it may be desirable (to) develop separate calibration factors for each specific terrain type or geographical region."(1) The underlying rationale, according to the Guide, is that calibration factors may differ from terrain to terrain, region to region or, more generally, from condition to condition. For example, if there is a large difference between the calibration factors for statewide and mountainous conditions, then applying the statewide factor to a site located in the mountainous terrain will introduce bias in the estimate of the number of crashes expected at that site.

While the calibration factor can vary across a jurisdiction, there is a practical limit to the number of separate calibration factors. As noted in the Guide, how many separate calibration factors to estimate depends on two considerations:

1. How close is close enough? Should the difference between the calibration factors be within ±10 percent of the calibration factor for the conditions of the site or is ±50 percent acceptable?
2. How different are the calibration factors in different conditions? For example, is the ratio of the mountainous to statewide calibration factors 1.5 or only 1.05?

INTERPRETATION OF THE CONSTANT CALIBRATION FACTOR

If the sum of the SPF crash predictions in the calibration sample match exactly to the sum of the observed crashes, then the process produces a constant calibration factor of 1.0. If the SPF under-predicts crashes in the calibration sample, then the calibration factor is greater than 1.0. If the SPF over-predicts crashes in the calibration sample, then the calibration factor is less than 1.0. If the calibration factor is substantially different from 1.0 (i.e., much less or much greater), then the agency's crash experience is much different from the data that were used to estimate the original SPF. If the differences are only in the magnitude of crash frequencies, and not the form of the distribution, then a calibrated SPF can still perform quite well. The SPF Decision Guide: SPF Calibration vs. SPF Development discusses the need to assess the quality of the calibration process in addition to the magnitude of the calibration factor.(3)

Where the calibration factor is a single multiplier, users need to assess how well the calibrated SPF performs in terms of explaining the variability of crash frequency among sites. Various goodness-of-fit (GOF) measures are available for this assessment in deciding if the SPF calibration is acceptable or in comparing multiple SPFs to determine which is most acceptable for calibration. As noted earlier, there is an opportunity to estimate a calibration function once the analyst deems an SPF acceptable based on a constant calibration factor. This will theoretically improve the SPF performance in terms of explaining the variability of crash frequency among sites.

The following section elaborates on GOF measures and their use in assessing the quality of the calibration process. Further guidance on assessing the quality of the calibration factor is available in the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors* and the *SPF Development Guide: Developing Jurisdiction-Specific SPFs*.(2,4) For more advanced information, consult *The Art of Regression Modeling in Road Safety*.(5)

3. GOODNESS-OF-FIT MEASURES

This section provides a summary of the GOF measures available in the spreadsheet-based calibration tool, including the mean absolute deviation, modified R^2, dispersion parameter, coefficient of variation (CV) of the calibration factor, and cumulative residual (CURE) plots. It is relatively straightforward to use these GOF measures to compare the relative performance of competing SPFs considered for application. More challenging is the use in assessing whether a single SPF is adequate as there are no guidelines on acceptable thresholds except for the CV of the calibration factor and the CURE plot. Thus, some subjective judgment is required to supplement the assessment based on the CV with a consideration of the other GOF measures.

MEAN ABSOLUTE DEVIATION

Figure 6 provides the equation for the mean absolute deviation (MAD), which provides a measure of the average magnitude of variability of prediction. Smaller values are preferred to larger values in comparing two or more competing SPFs. The MAD is the sum of the absolute value of predicted minus observed crashes, divided by the number of sites. The values of predicted and observed crashes are from the calibration data.

$$MAD = \frac{\sum_i |\hat{y}_i - y_i|}{n}$$

Figure 6. Equation. Mean absolute deviation.

Where:

y_i = observed counts.

$\hat{y}_i$ = predicted values from the SPF.

n = validation data sample size.

MODIFIED R^2

Figure 7 shows the equation for the modified R^2 value.(15) This GOF measure subtracts the normal amount of random variation expected if the SPF were 100 percent accurate. Even with a perfect SPF, some variation in observed crash counts would be observed due to the random nature of crashes.(15) As a result, the amount of systematic variation explained by the SPF is measured. Larger values indicate a better fit to the data in comparing two or more competing SPFs. Values greater than 1.0 indicate the SPF is over-fit (i.e., the SPF is incorrectly explaining some of the expected random variation as systematic variation).

$$R^2 = \frac{\sum_i (y_i - \bar{y})^2 - \sum_i \widehat{\mu_i}^2}{\sum_i (y_i - \bar{y})^2 - \sum_i \hat{y}_i}$$

Figure 7. Equation. Modified R^2 value.

Where:

y_i = observed counts.

$\widehat{y_i}$ = predicted values from the SPF.

$\bar{y}$= sample average.

$\widehat{\mu_i}$ = y_i-$\widehat{y_i}$.

DISPERSION PARAMETER

The dispersion parameter, f(*k*), in the negative binomial distribution is reported from the variance equation. Figure 8 provides the variance equation, rearranged in Figure 9 to provide the equation for the dispersion parameter.

$$Var\{m\} = E\{m\} + f(k)E\{m\}^2$$

Figure 8. Equation. Variance of negative binomial distribution.

$$f(k) = \frac{Var\{m\} - E\{m\}}{E\{m\}^2}$$

Figure 9. Equation. Dispersion parameter.

Where:

f(*k)* = estimated dispersion parameter.

Var{m} = estimated variance of mean crash rate.

E{m} = estimated mean crash rate.

The estimated variance increases as dispersion increases, and consequently the standard errors of estimates are inflated. As a result, all else being equal, an SPF with less dispersion (i.e., smaller values of f(*k*)) is preferred to an SPF with more dispersion. Note that f(*k*) can be specified as a constant or as a function of site characteristics. The tool facilitates the estimation of the dispersion parameter, either as a constant or from a function, as one GOF measure.

COEFFICIENT OF VARIATION OF THE CALIBRATION FACTOR

For a constant calibration factor, analysts can use the CV of the calibration factor to assess the GOF. Figure 10 provides the equation for the CV of a constant calibration factor, which is the standard deviation of the calibration factor divided by the estimate of the calibration factor.

$$CV = \frac{\sqrt{V(C)}}{C}$$

Figure 10. Equation. Coefficient of variation of a constant calibration factor.

Where:

CV = coefficient of variation of the calibration factor.

V(C) = variance of the calibration factor.

C = estimate of the calibration factor.

Figure 11 shows the equation for the variance of the calibration factor [V(C)]. The standard deviation of the calibration factor is the square root of the variance.

$$V(C) = \frac{\sum_{all\ sites}(y_i + k * y_i^2)}{(\sum_{all\ sites} \hat{y})^2}$$

Figure 11. Equation. Variance of calibration factor.

Where:

y_i = observed counts.

$\hat{y}_i$ = uncalibrated predicted values from the SPF.

k = dispersion parameter (recalibrated).

Appendix B of the *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors* provides guidance on estimating the accuracy of a calibration factor using the CV.(2) This guidance is intended for application in assessing the *sample size* of the calibration dataset; however, it seems reasonable to also apply it to assess the accuracy of a calibration factor regardless of the sample size.(2)

The Guide suggests that a reasonable upper threshold for the CV is 0.10 to 0.15. Users of the calibration tool can apply this threshold to assess whether or not the SPF, and the estimated calibration factor based on the calibration dataset, are acceptable. If the CV exceeds this threshold, then analysts should review the cumulative residual plots, described in the following subsection, to determine if the SPF is acceptable. In any case, analysts can use the CV for comparative evaluation of two or more SPFs where smaller values are preferred to larger values.

CUMULATIVE RESIDUAL PLOTS

Another tool to assess GOF is the CURE plot. A CURE plot is a graph of the cumulative residuals (observed minus predicted crashes) against a variable of interest sorted in ascending order (e.g., major road traffic volume). CURE plots provide a visual representation of GOF over the range of a given variable, and help to identify potential concerns such as the following:

- **Long trends**: long trends in the CURE plot (increasing or decreasing) indicate regions of bias that analysts should rectify through improvement to the SPF either by the addition of new variables or by a change of functional form.
- **Percent exceeding the confidence limits**: cumulative residuals outside the confidence limits indicate a poor fit over that range in the variable of interest. Cumulative residuals frequently outside the confidence limits indicate notable bias in the SPF. The upper threshold for the percent of cumulative residuals exceeding the 95 percent confidence limits is five percent.
- **Vertical changes**: Large vertical changes in the CURE plot are potential indicators of outliers, which require further examination. For further discussion of outliers, see the prior section titled, *Dealing with Outliers*. More advanced users can consult Chapter 7 of Hauer's book, *The Art of Regression Modeling in Road Safety*, in this regard.(5)

The tool constructs CURE plots through the following nine steps:

1. Sort sites in ascending order of the variable of interest, such that N is the number of sites, n is an integer between 1 and N, and S(n) is the cumulative sum of residuals from 1 to n.
2. For each site, calculate the residuals, *res*, as the observed minus predicted crashes.
3. For each site, calculate the cumulative residuals, *S(n)*, as the sum of residuals from 1 to n.
4. For each site, calculate the squared residuals, res^2.
5. For each site, calculate the cumulative squared residuals, $\sigma^2(n)$, as the sum of squared residuals from 1 to n.
6. Sum the cumulative squared residuals over all sites to compute the sum of cumulative squared residuals, $\sigma^2(N)$.
7. For each site, estimate the variance of the random walk, σ^2, using the equation in Figure 12.

$$\sigma^2 = \sigma^2(n)\left[1 - \frac{\sigma^2(n)}{\sigma^2(N)}\right]$$

Figure 12. Equation. Variance of random walk.

8. For each site, calculate the 95 percent confidence limits using the equations in Figure 13 and Figure 14.

$$Lower\ Limit = -1.96\sqrt{\sigma^2}$$

Figure 13. Equation. Lower 95 percent confidence limit.

$$Upper\ Limit = +1.96\sqrt{\sigma^2}$$

Figure 14. Equation. Upper 95 percent confidence limit.

9. Plot the cumulative residuals, *S(n)*, and the 95 percent confidence limits on the y-axis against the explanatory variable of interest on the x-axis.

Figure 15 shows an example CURE plot for the variable indicating major road traffic volume at an intersection. In this example, the SPF performs relatively well based on the general pattern and the 95 percent confidence interval. The pattern shows the cumulative residuals oscillating above and below zero. Note that a sustained increasing or decreasing trend would indicate a range of under- or over-prediction, respectively. In this example, the cumulative residuals also remain within the 95 percent confidence limits over most of the range, only exceeding the confidence limits for a short range of lower AADT. The areas outside the confidence limits indicate a poor fit as indicated in the figure. Cumulative residuals frequently outside the confidence limits would indicate notable bias in the SPF. Another notable observation is the sharp increase in the value of cumulative residuals at an AADT of approximately 175,000 vehicles per day. This may indicate the presence of an outlier in the data.

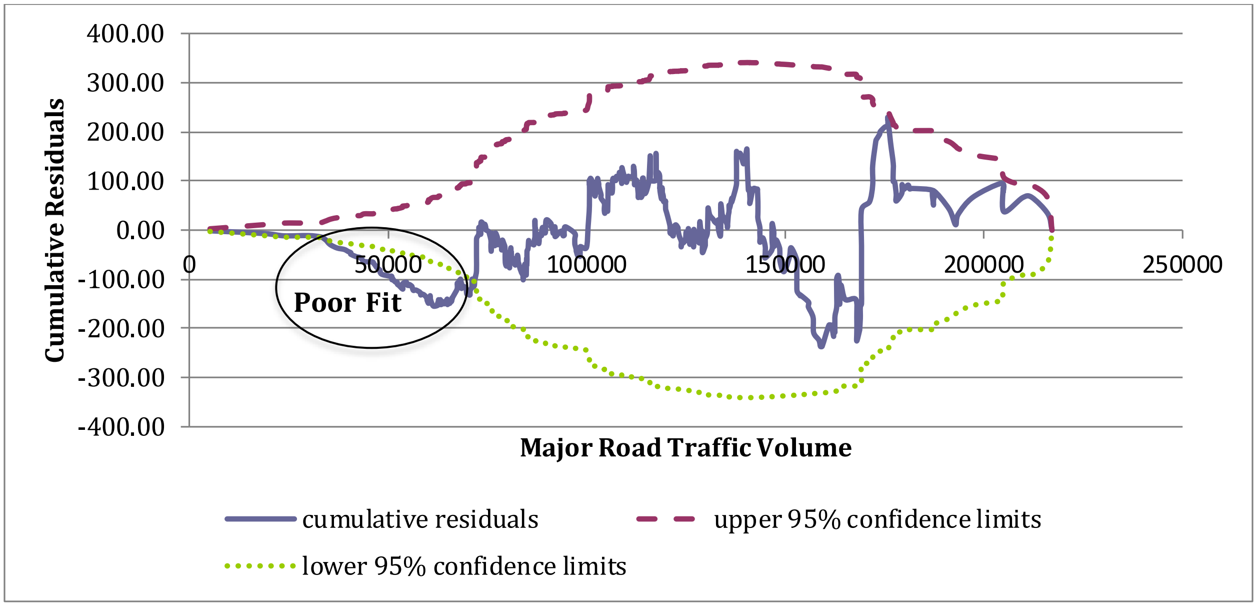


Figure 15. Chart. Example CURE plot.

The calibration tool automatically provides a CURE plot similar to Figure 15 for fitted values (after applying the calibration factor(s)), and allows a user to choose any other available continuous variable for the x-axis. The tool calculates the maximum deviation as well as the percent of observations outside the 95 percent confidence limits. With this information, users can follow the procedure in Hauer's book to determine whether an SPF is acceptable and in comparing multiple SPFs.(5)

While the guidance provided by Hauer for making these decisions is useful for users of the tool, it is largely subjective. The most objective consideration is a review of the CURE plot and 95 percent (2σ) confidence limits. As Hauer notes, "inasmuch as the CURE plot is a sum of many independent random variables, it is approximately normally distributed. For a normal distribution, about 95% of the probability mass is within two standard deviations from the mean. Thus, the CURE plot for an 'everywhere unbiased' SPF should only rarely go beyond the 2σ limits." Hauer's book (p. 150) also mentions, "the overall fit of the SPF is best judged by the CURE plot for fitted values".(5) Thus, for users of the calibration tool, the following are general rules for assessing the percent of the CURE plot exceeding the 95 percent (2σ) confidence limit:

1) An upper threshold of five percent of CURE plot ordinates for *fitted* values (after applying the calibration factor(s)) exceeding 2σ limits is indicative of an SPF that calibrates well to the entire range of a jurisdiction's data.
2) If the CURE plot exceeds the 95 percent confidence limits by more than five percent, then the analyst should consider the CV of the constant calibration factor. If the CV is within acceptable limits, then the SPF may be acceptable for application, with due recognition for ranges of variables where significant bias is indicated.

Analysts can also use the percent of CURE plot ordinates for *fitted* values (after applying the calibration factor) exceeding the 2σ limits to compare two or more competing SPFs where lower values of 'percent exceeding' are preferred.

AKAIKE'S INFORMATION CRITERION (AIC)

Figure 16 shows the equation for the AIC. The AIC penalizes for the addition of parameters, and thus helps to select an SPF that fits well, but has a minimum number of parameters. AIC is not typically used as a GOF measure, but analysts can use the AIC to compare the relative fit of alternate SPFs. Smaller values are preferred to larger values in comparing two or more competing SPFs.

$$AIC = -2(\mathrm{loglikelihood}) + 2K$$

Figure 16. Equation. Akaike's Information Criterion (AIC).

Where:

K = number of estimated parameters included in the SPF (i.e., number of variables plus the intercept).

Loglikelihood = statistical output reflecting the overall SPF fit (larger values indicate a better fit).

SCHWARZ BAYESIAN INFORMATION CRITERION (BIC)

Figure 17 shows the equation for the BIC. The BIC is complementary to AIC in that it also penalizes for the addition of parameters, and thus selects an SPF that fits well, but has a minimum number of parameters. BIC is not typically used as a goodness of fit measure, but analysts can use the BIC to compare the relative fit of alternate SPFs. Smaller values are preferred to larger values in comparing two or more competing SPFs.

$$BIC = -2(\mathrm{loglikelihood}) + K * \log(number\ of\ observations)$$

Figure 17. Equation. Schwarz Bayesian Information Criterion (BIC).

Where:

K = number of estimated parameters included in the SPF (i.e., number of variables plus the intercept).

Loglikelihood = statistical output reflecting the overall SPF fit (larger values indicate a better fit).

ASSESSMENT TABLES

While the CURE plot method works well for continuous variables, it is not applicable to variables with few categories (e.g., a database with speed limits of 45, 55, and 65 mph). For such variables, it is useful to develop a table of "calibration bias factors" that include factors for each category of the variable as in the example below. Calibration bias factors are the sum of the observed crashes for the category divided by the sum of the predictions obtained when the calibration factor is applied. If this bias factor is less than 1.0, then the calibrated SPF is over-predicting for the category. If this bias factor is greater than 1.0, then the calibrated SPF is under-predicting. Analysts can use these bias factors for the comparative assessment of two or more SPFs in conjunction with CURE plots for other measures.

In the example in Table 1, there are three categories of speed limit with corresponding observed crashes and calibration factors. As shown by the calibration factors, the SPF is over-predicting crashes at lower speed limits and under-predicting crashes at higher speed limits.

Table 1. Example of categorical variable assessment.

Variable	45 mph	55 mph	65 mph
Observed crashes	200	320	275
Number of sites	30	35	40
Calibration bias factor	0.85	1.05	1.15

Analysts can use an assessment table to identify categories or levels of a given variable for which there is concern about the quality of the calibration process. Calibration bias factors less than 0.8 or greater than 1.2 indicate potential areas of concern, providing these factors are based on at least 100 crashes.

SUMMARY OF SPF ASSESSMENT

This section provides a quick reference summary of the key considerations in SPF assessment. Given a single SPF, analysts can use the CURE plot and the CV of a constant calibration factor to determine whether the calibrated SPF is acceptable. Given the choice from multiple SPFs, analysts can use several GOF measures to determine the most suitable SPF for the local dataset, and subsequently consider the CURE plot and CV of the constant calibration factor to determine if the preferred SPF is acceptable. The Calibrator generates these GOF measures, but it does not indicate the preferred SPF or acceptability given the need for further research in this area.

Assessing the Acceptability of an SPF

An analyst may deem an SPF with a constant calibration factor as acceptable if either of the following conditions is met:

1) Five percent or less of CURE plot ordinates for *fitted* values (after applying the calibration factor) exceed the 2σ limits, or
2) The CV of a constant calibration factor is less than 0.15.

The analyst should then estimate a calibration function that provides a unique calibration factor for each site. The analyst may deem the function preferable if either of the above conditions is met (i.e., the calibrated SPF is acceptable based on a constant calibration factor) and the percent of CURE plot ordinates for *fitted* values (after applying the unique calibration factors) exceeding the 2□limits is lower than that for the constant calibration factor. It is likely that the function will then be preferable by other assessment measures (MAD, AIC, BIC).

As a caution, if the analyst does not deem the constant calibration factor as acceptable, but a calibration function shows less than five percent of CURE plot ordinates for fitted values exceeding the 2□limits, this may be due to a small number of sites or crashes in the calibration dataset. Consider the sample size before adopting the calibration function. If there is a large sample, then the calibration function may be acceptable.

If both conditions above are not met, consider increasing the calibration sample. If, with the largest feasible calibration sample, both conditions above are still not met for the constant calibration factor, and the first condition is not met with the calibration function, then the analyst should consider calibrating another existing SPF or developing a jurisdiction-specific SPF.

Comparing Multiple SPFs

Table 2 presents seven measures for comparing the performance of multiple SPFs. For this comparison, the analyst must first estimate a constant calibration factor for each SPF. For each measure, the analyst can rank the SPFs numerically from 1 to n, where 1 represents the best SPF with respect to the given measure and n represents the number of alternative SPFs. To determine the aggregate ranking based on all seven measures, an analyst may sum the numeric rankings over the seven measures. The SPF with the lowest sum of ranks is the preferred SPF for calibration to a jurisdiction’s data. The analyst may then refine the preferred SPF based on a constant calibration factor by estimating a calibration function and assessing the SPF performance with this refinement. Note that there is still a need to determine if the preferred SPF is acceptable as outlined above based on the CURE plot and CV for the calibration factor or the CURE plot for the calibration function.

Table 2. Summary of GOF measures for ranking SPFs.

GOF Measure	Preferred Values	Ranking Method
Mean Absolute Deviation (MAD)	Smaller values	Smallest value is ranked number 1
Modified R^2	Larger values	Largest value is ranked number 1
Constant Dispersion Parameter*	Smaller values	Smallest value is ranked number 1
Coefficient of variation of the constant calibration factor (CV)	Smaller values	Smallest value is ranked number 1
Percent of CURE plot ordinates for *fitted* values (after calibration) exceeding 2σ limits	Smaller values	Smallest value is ranked number 1
Akaike's Information Criterion (AIC)	Smaller values	Smallest value is ranked number 1
Bayesian Information Criterion (BIC)	Smaller values	Smallest value is ranked number 1

* Criterion is only considered where all original candidate SPFs have a constant dispersion parameter.

4. ISSUES IN SPF SELECTION

This section discusses general issues in the selection of an appropriate SPF that will be subject to the calibration process. These include the following:

1. Use of HSM or non-HSM SPFs and CMFs.
2. Meeting the data requirements.
3. SPFs required for specific subsets of an entity type.
4. Desired precision of predictions.

Previous sections partially-address some of these issues.

USE OF HSM OR NON-HSM SPFS AND CMFS

The SPFs presented in Part C of the HSM are mainly for design-level applications. Design-level applications involve estimating the predicted number of crashes for alternative designs and comparing the change in crashes with changes in specific design features. The CMFs applied to the SPFs facilitate this assessment. If an analyst desires to use SPFs for design applications, then they should calibrate design-level SPFs such as those in Part C of the HSM.

SPFs also apply to planning-level safety analyses covered in Part B of the HSM. Planning-level analyses include the following:

- Network screening to identify sites with promise of safety improvement. For this, two types of SPFs are available to predict crashes for average sites of a specific type. One type of SPF has traffic volume and possibly segment length as the only predictor variables. The other type of SPF includes additional variables such as lane width, shoulder width, or horizontal curvature. Related to this application is the selection of sites for systemic safety mitigations by implicitly ranking sites by predicted benefit-cost ratio, on the assumption that benefits are proportional to expected crashes (based on SPFs) and fixed costs per site or per mile.
- Estimating the benefit of a proposed treatment to improve the safety of a site. The SPF applied should be applicable to sites with the same characteristics as the subject site.
- Evaluating the safety effect of an implemented treatment in the empirical Bayes before-after study methodology. Again, the SPF applied should be applicable to sites with the same characteristics as the subject site.

The HSM documents these applications; however, it does not provide specific SPFs to support them. For various reasons, the HSM Part C and other design-level SPFs may not be appropriate for these applications. Using these SPFs in network screening would necessitate the collection of all required data for the HSM Part C Predictive Method for all roads in a jurisdiction, which could be cost-prohibitive. For estimating the safety benefits of proposed treatments or evaluating the safety effects of implemented treatments, the SPF should reflect the safety performance of sites in need of treatment. As such, design-level SPFs such as those in Part C of the HSM are not appropriate because they reflect the safety performance of "average" sites.

For planning-level analyses (Part B of the HSM), the preferred option is to develop SPFs using the jurisdiction's data. Such SPFs will still require calibration when they are applied to a different time period or subset of entities (e.g., those in a specific region or those with a different range in traffic volumes) than were used to develop the original SPFs. If SPFs do not meet desirable criteria, then The Calibrator can help assess the suitability of SPFs from other sources. One alternative source of existing SPFs for planning-level analyses is the original research reports used in developing the HSM (See, e.g., Lord at al. and Vogt and Bared).(16,17) Such SPFs are also being developed in NCHRP Project 17-62 (*Improved Prediction Models for Crash Types and Crash Severities*) for various crash types and severities for all facility types for consideration in the second edition of the HSM. Other sources include AASHTOWare Safety Analyst™ documentation and the reports for evaluations conducted under FHWA's Development of Crash Modification Factors (DCMF) project (See, e.g., Srinivasan et al.).(18) SPFs developed for FHWA's DCMF project evaluations would be especially applicable for estimating safety effects of contemplated or implemented treatments, while SPFs from the other sources would be more applicable for network screening. The 'Resources' section of the CMF Clearinghouse provides a list of States that have developed State-specific SPFs.

MEETING THE DATA REQUIREMENTS

If a design-related analysis is to be undertaken, then the data needs for applying the HSM Part C Predictive Method (i.e., data pertaining to the CMF-related variables) should not be a major factor in selecting and calibrating SPFs from the HSM. Detailed data are only required for a limited number of sites for calibration, and subsequently only for the corridor that is under design during application of SPFs. Agencies should not interpret these data needs as a need to collect the required data for all sites in the jurisdiction. [Note: This is a common misconception.]

If the application is not design-related, then the selection of an SPF should consider what variables are required for the application and calibration. Ideally, the variables in a contemplated SPF should be readily available or easily collected in the jurisdiction of interest. Thus, consideration of the data requirements and availability is a vital step in the selection of SPFs for calibration.

SPFS FOR SPECIFIC CONDITIONS

Analysts need to consider if the SPF is required for a specific condition (e.g., curves) or a general facility type (e.g., rural, two-lane roads). As noted earlier, specific SPFs are particularly relevant when estimating the safety effects of proposed or implemented treatments. Analysts should prioritize SPFs for specific conditions (e.g., an SPF developed for curves on rural, two-lane roads) since that should provide more accurate estimates than an SPF developed using both curve and tangent segments. Other examples include SPFs for nighttime or motorcycle crashes. Evaluation reports for FHWA's DCMF project are a source for such SPFs.

DESIRED PRECISION OF PREDICTIONS

In selecting an SPF that will be subject to the calibration process, users should consider the desired precision of the predictions from the calibrated SPF. The highest level of precision is required for design applications for new facilities; therefore, analysts should select high quality SPFs based on quality data and developed using state-of-the-art methods for calibration. For estimating the safety benefits of contemplated treatments and evaluating the safety effect of implemented treatments of a facility redesign, the precision need not be as high. This is because the empirical Bayes procedure adjusts for the precision of the SPF utilizing the crash history of a site. Analysts should also perform this adjustment in network screening applications, but since the aim is merely to prioritize sites for further investigation, the consequences of using a less precise SPF are not as severe as for other applications.

5. USING THE CALIBRATOR

The Calibrator can help users to calibrate and assess SPF performance. The Calibrator applies to all SPFs or predictions from the combination of SPFs and CMFs as is consistent with the HSM Part C Predictive Method. The tool provides a single calibration factor or calibration function for each SPF or SPF and CMF combination, along with various goodness-of-fit measures and an assessment of how the predictions are performing over the range of all variables. The tool does not address the calibration of standalone CMFs.

INSTALLATION NOTE: The Calibrator was developed for Microsoft Excel versions 2007 and later, running on Windows Operating Systems with the SOLVER add-in installed. Since the file includes macros, users may need to enable macros or Trust the document. Users may also encounter issues related to Trust Center settings. Access the Trust Center by navigating to (File, Options, and Trust Center). In the Trust Center options, click on Macro Settings and adjust according to your organization's policy. Microsoft also releases updates that can break ActiveX/Macros. Refer to your IT department about resolutions for ActiveX controls.

The tool automates the calibration process and provides information to users for assessing the suitability of, or comparing between, alternate SPFs. Specifically, the tool can help users to:

- Assess the performance of the HSM Predictive Method as a whole on local data.
- Assess the performance of the uncalibrated HSM Part C SPFs on local data.
- Assess the performance of SPFs and CMFs from other sources on local data.
- Calibrate existing SPFs to local data using the HSM 1st Edition calibration procedure.
- Calibrate the dispersion parameter of an existing SPF to local data.
- Compare the performance of multiple SPFs.
- Identify the most appropriate SPFs and CMFs to apply from a list of alternatives.

The previous sections provide a brief background on the theory of SPF calibration, goodness-of-fit measures, and SPF selection. The remainder of this guide provides directions for using the tool. The following is an overview of the process, followed by detailed instructions for each step. **Illustrative screenshots accompany these instructions, representing a variety of example applications using real data.** Screenshots also accompany the three illustrative examples presented later, representing the specific example presented.

1. Importing Data: The first step is to import the calibration dataset for the desired site type into the spreadsheet.
2. Defining SPFs and CMFs: The second step is to define the SPFs and CMFs (if applicable) for the desired site types or select predefined HSM or AASHTOWare Safety Analyst™ SPFs from a list available in the tool. Note that the Appendix of this guide presents the predefined SPFs included in the spreadsheet tool. Section A.1 presents the base condition SPFs from the HSM for two-lane rural roads, multilane rural roads, urban and suburban arterials, and freeways. Section A.2 presents the SPFs from AASHTOWare Safety Analyst™.
3. Calibrating SPFs: The tool calibrates the desired SPFs to the data, producing the calibration factor or function and dispersion parameter or function for each calibrated SPF.

4. Assessing SPFs: The user can request multiple goodness-of-fit statistics. All output is contained in the spreadsheet.

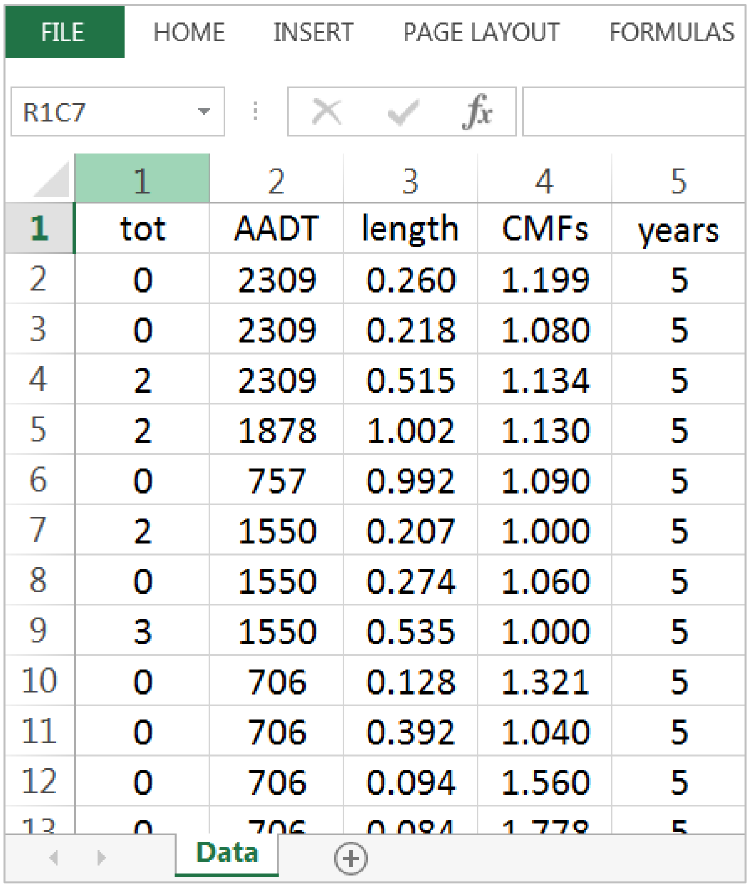
IMPORTING DATA

The first step is to import the data for calibration from an Excel spreadsheet. Analysts can only import one dataset at a time. Thus, separate spreadsheets are required for different datasets.

The requirements for importing data are as follows:

1. The user must create an Excel spreadsheet with calibration data on a tab labeled "Data."
2. The data for each site must be in a single row with crash counts and all variables required for the selected SPF and CMFs in columns. The variables will depend on the SPF selected. Note that Appendix sections A.1 and A.2 present the SPFs and required variables for SPFs from the HSM and AASHTOWare Safety Analyst™, respectively. For example, if the analyst selects the SPF from AASHTOWare Safety Analyst™ for rural, two-lane segments, then the variables required to apply the SPF are AADT and segment length. For HSM SPFs, the variables would be as specified in the HSM for the site type.
3. If multiple years of data are included, then the crash counts in each row of the data file must represent the sum of crashes across all years and the file should contain a column indicating the number of years included. The tool only computes a single calibration factor, so if the user desires multiple calibration factors (e.g., one for each year), then the user will need to prepare a separate file for each year and run the process separately.
4. The imported file should only include sites applicable to the calibrated SPFs.
5. If the user selects predefined SPFs, then the column headings must match the variable names (case sensitive) for the predefined SPFs. The Appendix documents the predefined SPFs and appropriate variable names.
6. No sites should have missing values for the variables required to apply the SPF or CMFs.

Figure 18 provides an example of the data structure required for calibration in an Excel file.



	1	2	3	4	5
1	tot	AADT	length	CMFs	years
2	0	2309	0.260	1.199	5
3	0	2309	0.218	1.080	5
4	2	2309	0.515	1.134	5
5	2	1878	1.002	1.130	5
6	0	757	0.992	1.090	5
7	2	1550	0.207	1.000	5
8	0	1550	0.274	1.060	5
9	3	1550	0.535	1.000	5
10	0	706	0.128	1.321	5
11	0	706	0.392	1.040	5
12	0	706	0.094	1.560	5

Figure 18. Image. Example road segment database required for calibration.

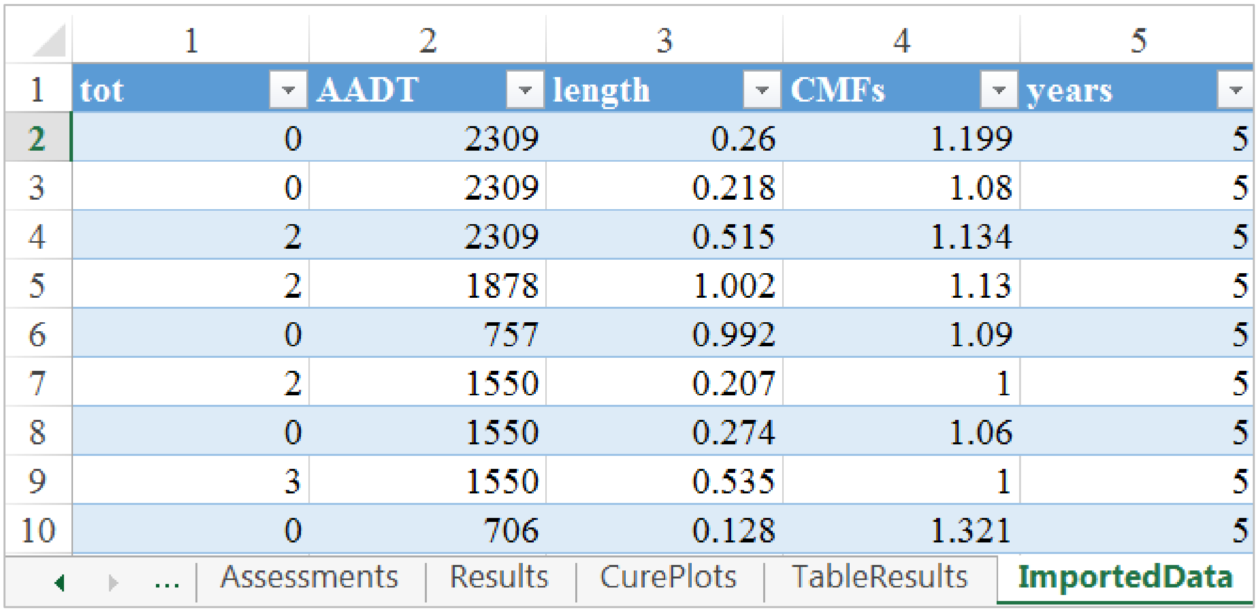
Steps for Importing Data

1. On the 'Define Variables' tab click the 'Import Data' button.
2. Browse to the desired file, select, and click OK.

This will import the data from the selected file into the 'ImportedData' tab. On the 'Define Variables' tab, all variables will be listed in the 'Variable List' box.

Figure 19 is an example screenshot of data imported to the 'ImportedData' tab. There are a number of variables, including the following:

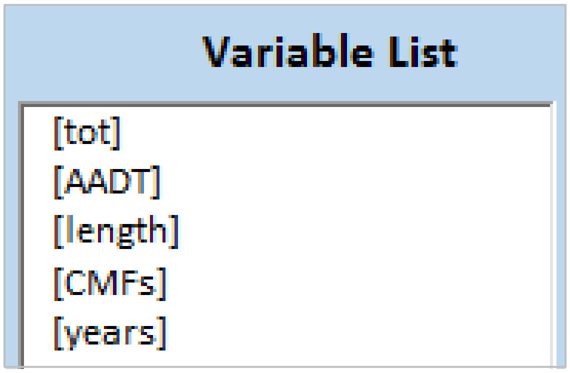
- tot = total observed crashes in 5-year study period.
- AADT = annual average daily traffic.
- length = segment length in miles.
- CMFs = product of applicable CMFs for given site conditions.
- years = number of years of crash data.



	1	2	3	4	5
1	tot	AADT	length	CMFs	years
2	0	2309	0.26	1.199	5
3	0	2309	0.218	1.08	5
4	2	2309	0.515	1.134	5
5	2	1878	1.002	1.13	5
6	0	757	0.992	1.09	5
7	2	1550	0.207	1	5
8	0	1550	0.274	1.06	5
9	3	1550	0.535	1	5
10	0	706	0.128	1.321	5

Figure 19. Image. Example of imported data.

Figure 20 is an example screenshot showing the imported variables in the ‘Variable List’ box.



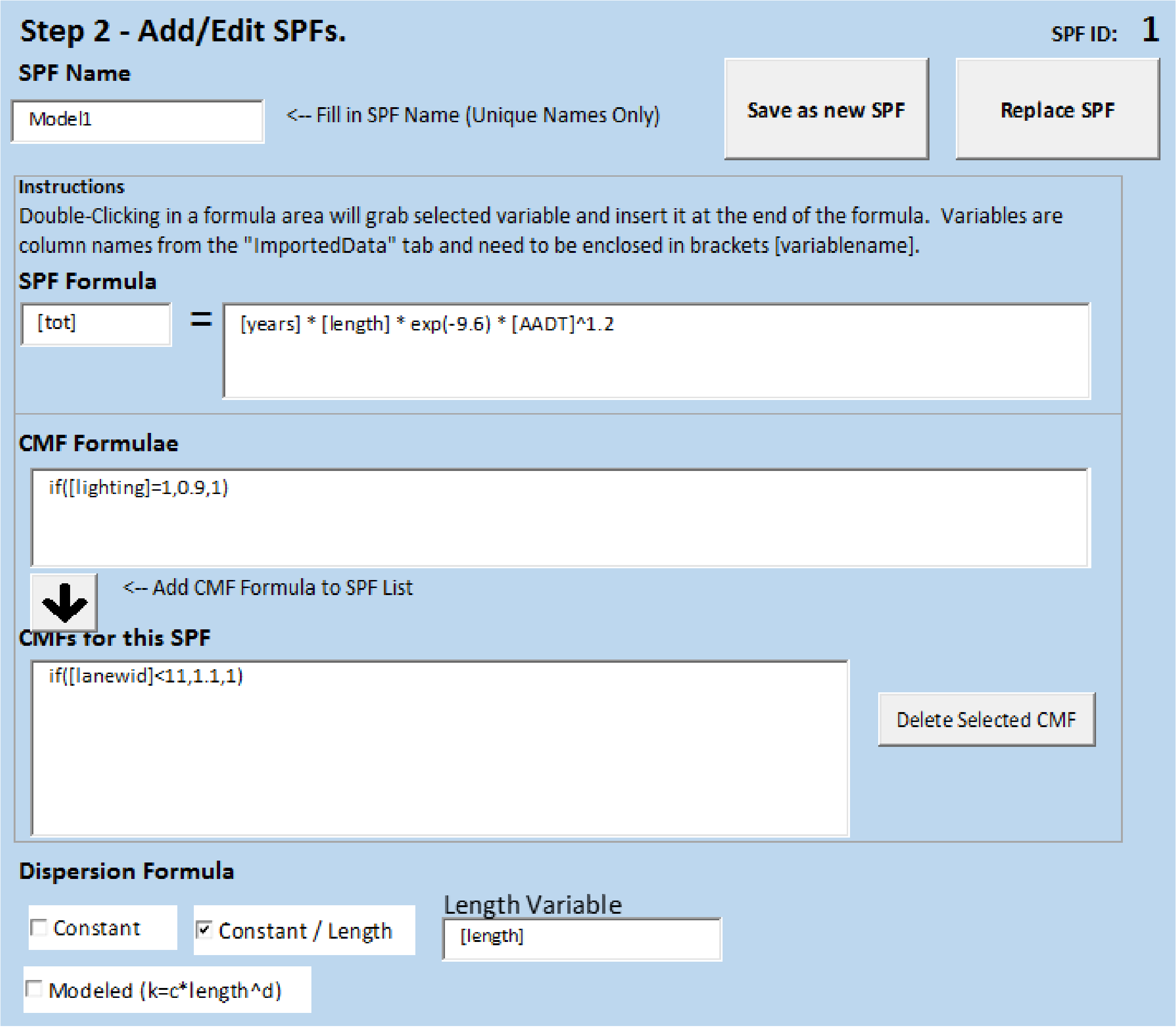
Variable List

[tot]
[AADT]
[length]
[CMFs]
[years]

Figure 20. Image. Example of variable list for imported data.

DEFINING SPFS AND CMFS

The second step is to define the SPFs and CMFs (where the CMFs are not already part of the SPF and with values embedded in the imported data). Users may enter SPFs manually (user-defined), or select from available HSM and AASHTOWare Safety Analyst™ SPFs hard coded in the tool (predefined). Figure 21 is a screenshot showing a user-defined SPF. The SPF name is ‘Model1’ and the SPF predicts total crashes as a function of years, length, and AADT. The example shows one CMF already defined for lane width in the area titled ‘CMFs for this SPF.’ It shows another CMF for lighting in the ‘CMF Formulae’ area, which is in development. The example specifies the dispersion parameter as an inversely-proportional function of length. The steps required for producing the inputs for this screenshot follow the figure.



SPF Name: Model1 <-- Fill in SPF Name (Unique Names Only)

Instructions

Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula: [tot] = [years] * [length] * exp(-9.6) * [AADT]^1.2

CMF Formulae: if([lighting]=1,0.9,1)

<-- Add CMF Formula to SPF List

CMFs for this SPF: if([lanewid]<11,1.1,1)

Dispersion Formula

☐ Constant

☑ Constant / Length

Length Variable: [length]

☐ Modeled (k=c*length^d)

Figure 21. Image. Example of user-defined SPF and CMFs.

Steps for Defining SPFs

1. Enter a name for the SPF in the ‘SPF Name’ box. In the Figure 21 example, this is “Model1”.
2. Enter the dependent variable (i.e., the crash type the SPF is predicting) from the ‘Variable List’. In the original dataset file (Figure 19) and the associated variable list (Figure 20), the label for the dependent variable is ‘tot’, representing the total observed crashes in the five-year study period. Users can enter the variable name manually or by selecting the variable from the ‘Variable List’ (as shown in Figure 20) and then double-clicking in the left box under the ‘SPF Formula’ section (as shown in Figure 21).

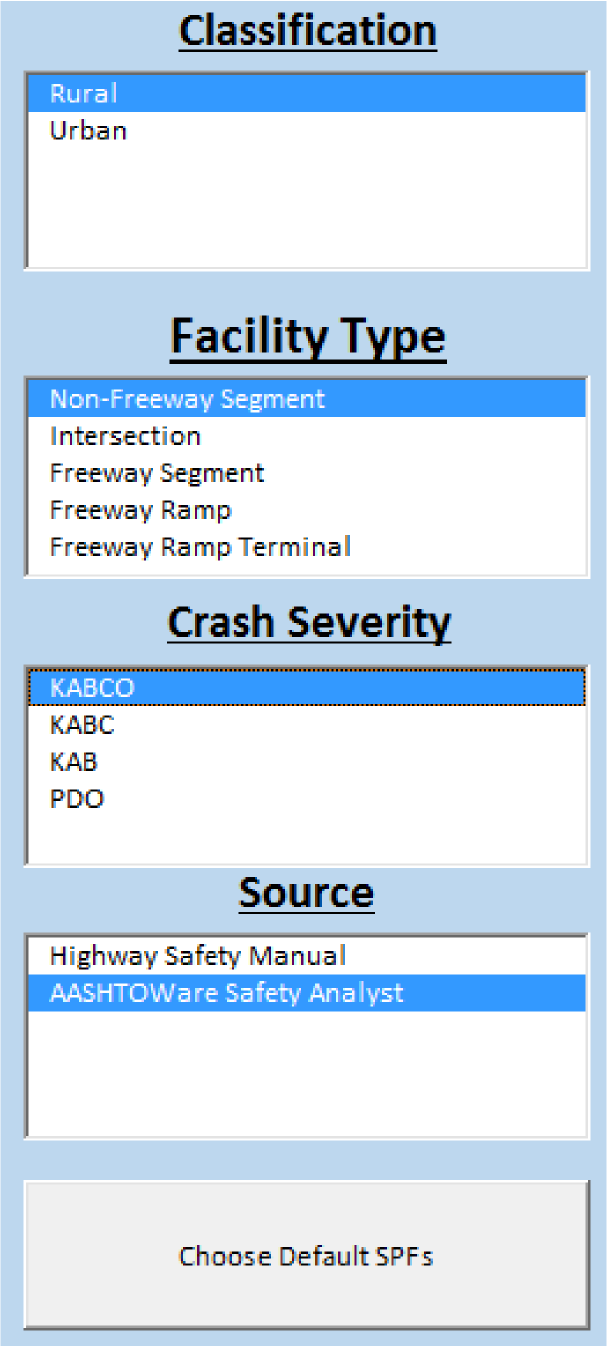
Important: If entering variables manually, then remember to enclose the variable name in square brackets (e.g., [tot]).

3. Enter the independent variables (i.e., the variables used in the SPF to predict crashes) from the ‘Variable List’. Click in the right box under the ‘SPF Formula’ section and enter the SPF formula as one would in a cell of an Excel spreadsheet. Users can enter the variable name manually or by selecting the variable from the ‘Variable List’ (as shown in Figure 20) and then double-clicking in the right box under the ‘SPF Formula’ section (as shown in Figure 21). SPFs may require the use of CMFs, which users can define as individual formulas within the tool or pre-calculate with associated values embedded in the imported data. The following section describes the steps for defining CMFs.

Important: If entering variables manually, then remember to enclose the variable name in square brackets (e.g., [AADT]).

Steps for Selecting a Predefined SPF

To add a predefined SPF into the 'Available SPFs' list, select the Classification, Facility Type, Crash Severity and/or Source of interest and click 'Choose Default SPFs'. All eligible SPFs will be added to the 'Available SPFs' list as illustrated in the Figure 22 screenshot.



Classification

- Rural
- Urban

Facility Type

- Non-Freeway Segment
- Intersection
- Freeway Segment
- Freeway Ramp
- Freeway Ramp Terminal

Crash Severity

- KABCO
- KABC
- KAB
- PDO

Source

- Highway Safety Manual
- AASHTOWare Safety Analyst

Figure 22. Image. Example of selection of predefined SPFs.

Steps for Defining CMFs

If CMFs are part of the crash prediction and not already embedded in the data, then the user must define these CMFs in the 'CMF Formulae' box using standard Excel syntax. This is the case when using SPFs from Part C of the HSM. The Figure 21 screenshot shows example CMFs. The following describes how to enter the CMF for lighting in the 'CMF Formulae' box.

1. In the 'CMF Formulae' box, enter the CMF as one would in Excel using an IF statement. [Note: Excel defines an IF statement as follows: IF(logical test, value if true, value if false) where 'logical test' is the condition to test, 'value if true' is the value returned if the logical test is true, and 'value if false' is the value returned if the logical test is false.] Users can enter variable names manually or by selecting the variable from the 'Variable List' and then double-clicking in the 'CMF Formulae' box. Figure 21 provides an example screenshot that illustrates this step with a CMF for lighting presence.

Important: If entering variables manually, then remember to enclose the variable name in square brackets (e.g., [lighting]).

2. Click the down arrow to add the CMF to the list of CMFs associated with the given SPF. The Figure 21 example shows a CMF already added for lane width.

Important: Note the user needs to define all potential values of a CMF. For example, if a CMF for lighting presence is 0.90, then user should also define the alternative condition (i.e., not present):

- If lighting = 'not present' then CMF=1.00.
- If lighting = 'present' then CMF=0.90.

Important: If NOT all conditions are defined, then the SPF will assume a value of zero for the undefined conditions, resulting in zero predicted crashes for sites with those conditions.

It may be simplest to use numerical values for categorical variables. For example, if the presence of lighting is defined as lighting=1, and absence of lighting is defined as lighting=0, then the CMF formula could be written as follows using the Excel syntax for 'if-then' statements:

IF([lighting]=1,0.9,1)

The IF statement assigns a CMF value of 0.9 if the lighting variable is equal to 1.0. The IF statement assigns a value of 1.0 if the lighting variable is not equal to 1.0. As noted, this is the example shown in the Figure 21 screenshot.

Users can delete CMFs by selecting the CMF and then clicking 'Delete Selected CMF'.

Steps for Defining Dispersion Parameter

The tool calibrates the dispersion parameter of the SPF for one of three assumptions: 1) constant dispersion, 2) variable dispersion (constant/length), or 3) variable dispersion as a power function of length.

1. Click the applicable box to select the desired dispersion option.
2. If the user selects a variable dispersion parameter, then the user must also specify the name of the length variable in the imported data. Users can enter the variable name manually or by selecting the variable from the 'Variable List' (as shown in Figure 20) and then double-clicking in the 'Length Variable' box (as shown in Figure 21).

Important: If entering variables manually, then remember to enclose the variable name in square brackets (e.g., [length]).

Saving and Editing SPFs and CMFs

Save the SPF and associated CMFs, along with the dispersion parameter specification, before applying the tool. To do this, click the 'Save as new SPF' box shown in Figure 21.

Select an existing SPF for application or editing by double clicking the SPF name in the 'Available SPFs' box. Delete SPFs by selecting the SPF name in the 'Available SPFs' box and then clicking the 'Delete Selected SPF' button.

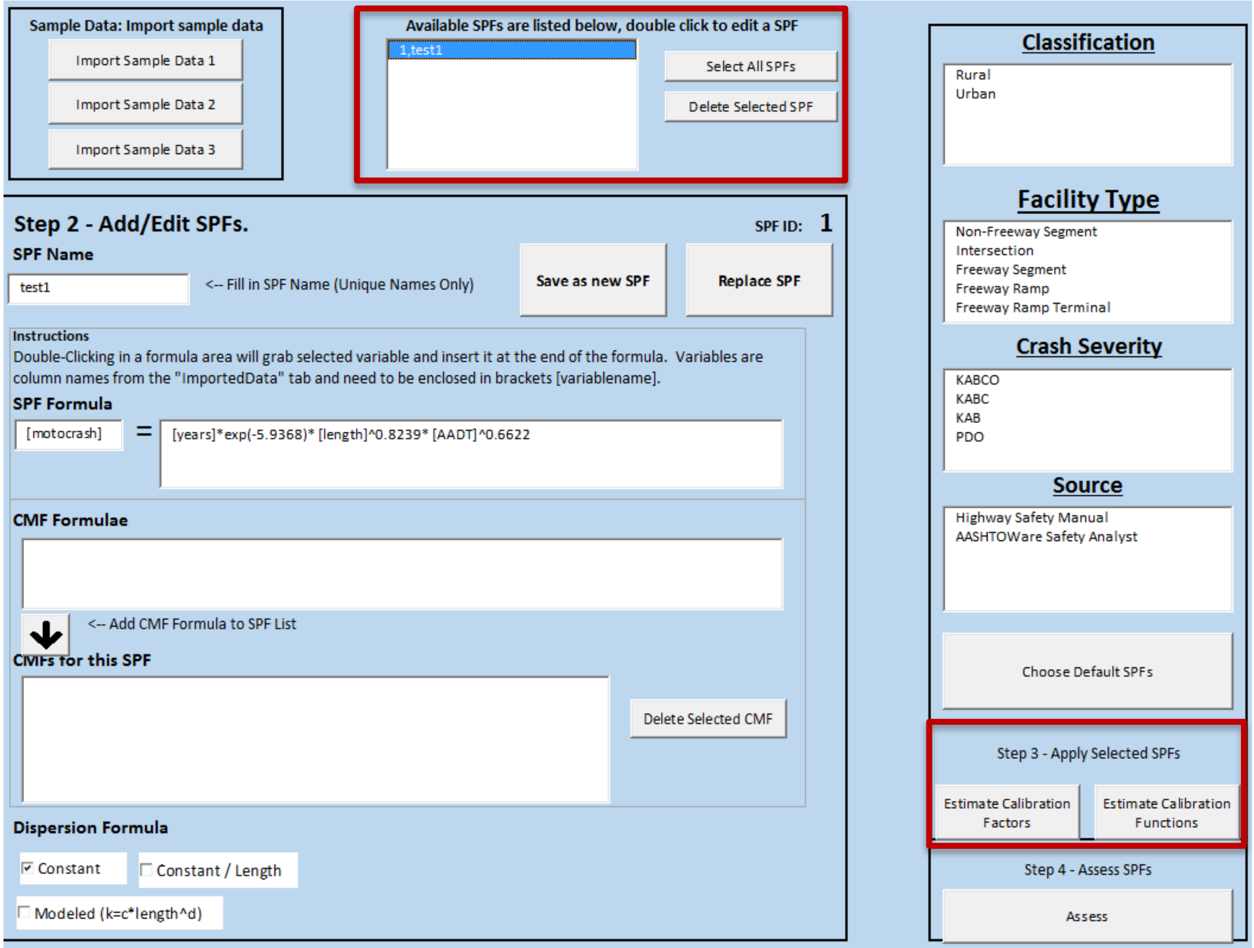
When editing an existing SPF, replace the existing SPF by clicking the 'Replace SPF' button or save as a new SPF by clicking the 'Save as new SPF' button.

CALIBRATION AND GOODNESS-OF-FIT MEASURES

The third step is to calibrate the selected SPFs. The tool automatically computes the GOF measures in this step.

Steps for Calibrating SPFs and Dispersion Parameters

1. Select the SPF(s) for calibration from the 'Available SPFs' list as shown in Figure 23. If the SPF is selected by double-clicking, the 'SPF Formula,' 'SPF Name,' and 'Dispersion Formula' boxes are populated as shown in Figure 23. If the user specifies CMFs for the SPF, then the tool will populate 'CMFs for this SPF' as well.
2. If a calibration factor is desired, click the 'Estimate Calibration Factors' button. If a calibration function is desired, click the 'Estimate Calibration Functions' button. These are shown in the lower right of Figure 23.
3. As illustrated in Figure 24, the Excel Solver box will appear once the tool finds a solution for calibrating the SPF and dispersion parameter. Click on 'Keep Solver Solution' and then click 'OK'.



Step 2 - Add/Edit SPFs.

SPF ID: 1

SPF Name: test1 <-- Fill in SPF Name (Unique Names Only)

Instructions

Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula: [motocrash] = [years]*exp(-5.9368)* [length]^0.8239* [AADT]^0.6622

CMF Formulae

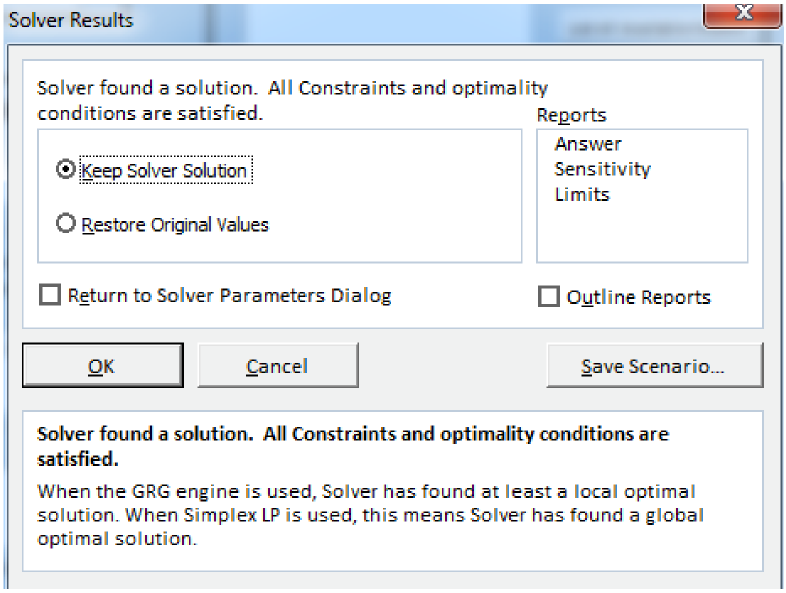
Dispersion Formula

☑ Constant

☐ Constant / Length

☐ Modeled (k=c*length^d)

Figure 23. Image. Example of selecting an SPF to calibrate from predefined SPFs.



Solver found a solution. All Constraints and optimality conditions are satisfied.

● Keep Solver Solution

○ Restore Original Values

☐ Return to Solver Parameters Dialog

☐ Outline Reports

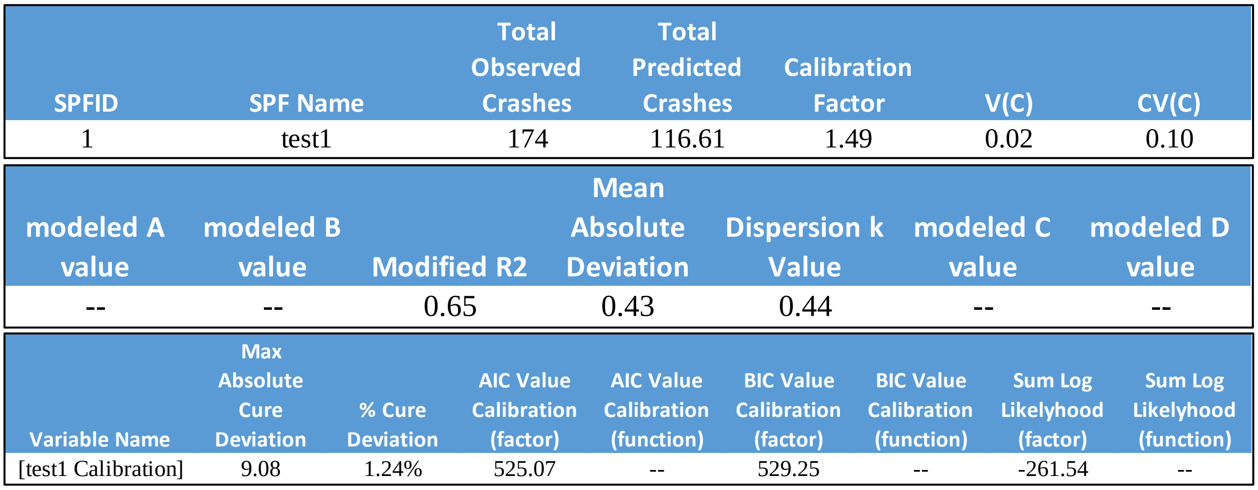
Solver found a solution. All Constraints and optimality conditions are satisfied.

When the GRG engine is used, Solver has found at least a local optimal solution. When Simplex LP is used, this means Solver has found a global optimal solution.

Figure 24. Image. Example of the solver results screen.

The 'Results' tab then appears. As illustrated in Figure 25, this contains the SPF name, total observed crashes, total predicted crashes using the uncalibrated SPF. When applicable, it also shows the calibration factor(s), variance of the calibration factor(s), covariance of the calibration factor(s), parameter estimates of the calibration function(s), calibrated dispersion parameter(s), and parameter estimates of the dispersion parameter function(s) for each SPF selected for calibration.

The GOF measures, MAD, and modified R^2 are determined during the SPF calibration and displayed on the 'Results' tab. Also displayed are the AIC, BIC, and sum of loglikelihood values. A CURE plot for the SPF against the calibrated predictions is also prepared and shown on the Cure Plots tab. The Results tab shows the maximum absolute deviation from zero and percent of observations exceeding the two standard error limits.



SPFID	SPF Name	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	V(C)	CV(C)
1	test1	174	116.61	1.49	0.02	0.10

modeled A value	modeled B value	Modified R2	Mean Absolute Deviation	Dispersion k Value	modeled C value	modeled D value
--	--	0.65	0.43	0.44	--	--

Variable Name	Max Absolute Cure Deviation	% Cure Deviation	AIC Value Calibration (factor)	AIC Value Calibration (function)	BIC Value Calibration (factor)	BIC Value Calibration (function)	Sum Log Likelyhood (factor)	Sum Log Likelyhood (function)
[test1 Calibration]	9.08	1.24%	525.07	--	529.25	--	-261.54	--

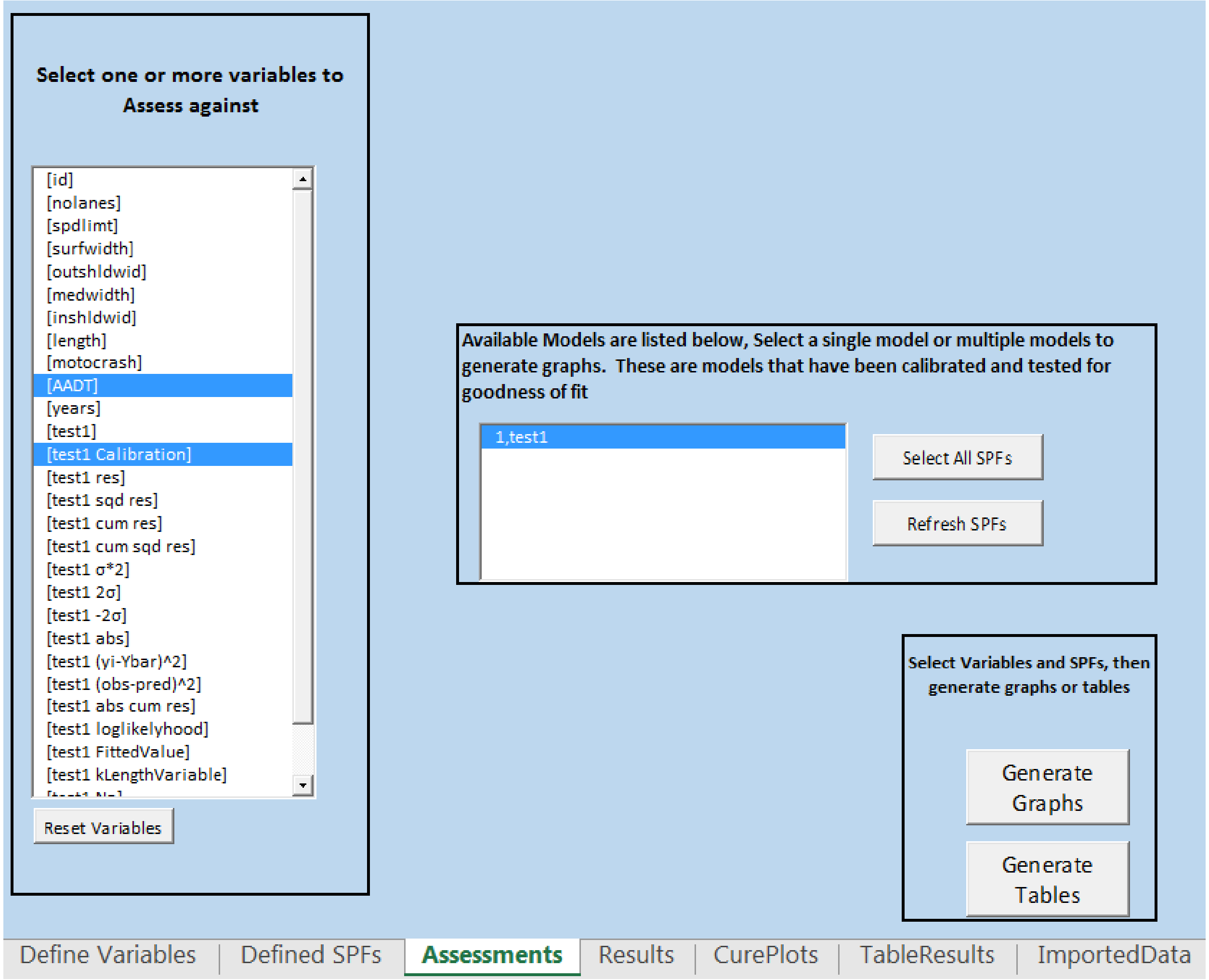
Figure 25. Image. Example results from 'Results' tab.

CURE PLOTS AND ASSESSMENT TABLES

Users can create CURE plots and assessment tables for any variable from the 'Assessments' tab as illustrated in Figure 26.

Steps for Creating CURE Plots and Assessment Tables

1. Select the variable(s) of interest.
2. Select the SPF(s) of interest.
3. If a CURE plot is desired, click the 'Generate Graphs' button. The CURE plot(s) will be displayed on the 'CUREPlots' tab. On the 'Results' tab, for each SPF and variable that a CURE plot is developed, the maximum absolute deviation from zero of the cumulative residuals is provided as well as the percentage of observations that are outside of the two standard deviation limits.
4. If an assessment table is desired for variables with a limited number of discrete values, click the 'Generate Tables' button. The 'TableResults' tab displays the results.



Select one or more variables to Assess against

Available Models are listed below, Select a single model or multiple models to generate graphs. These are models that have been calibrated and tested for goodness of fit

Select Variables and SPFs, then generate graphs or tables

Figure 26. Image. Example assessment creating CURE plots for two variables.

The tool presents the results in separate tabs as illustrated in Figure 27 (CURE plots) and Figure 28 (assessment tables). Note the examples shown in Figure 27 and Figure 28 are from another dataset, as the sample data shown in the previous screenshots did not include any categorical variables.

Important: If the user generates CURE plots or assessment tables and subsequently selects an additional variable to create a new CURE plot or assessment table, then the original plots or tables will be lost. For this reason, the user should select all variables of interest at the same time for creating CURE plots or assessment tables. The exception is the CURE plot for the calibrated predictions constructed when the user calibrates the SPF. These results remain on the 'Results' tab.

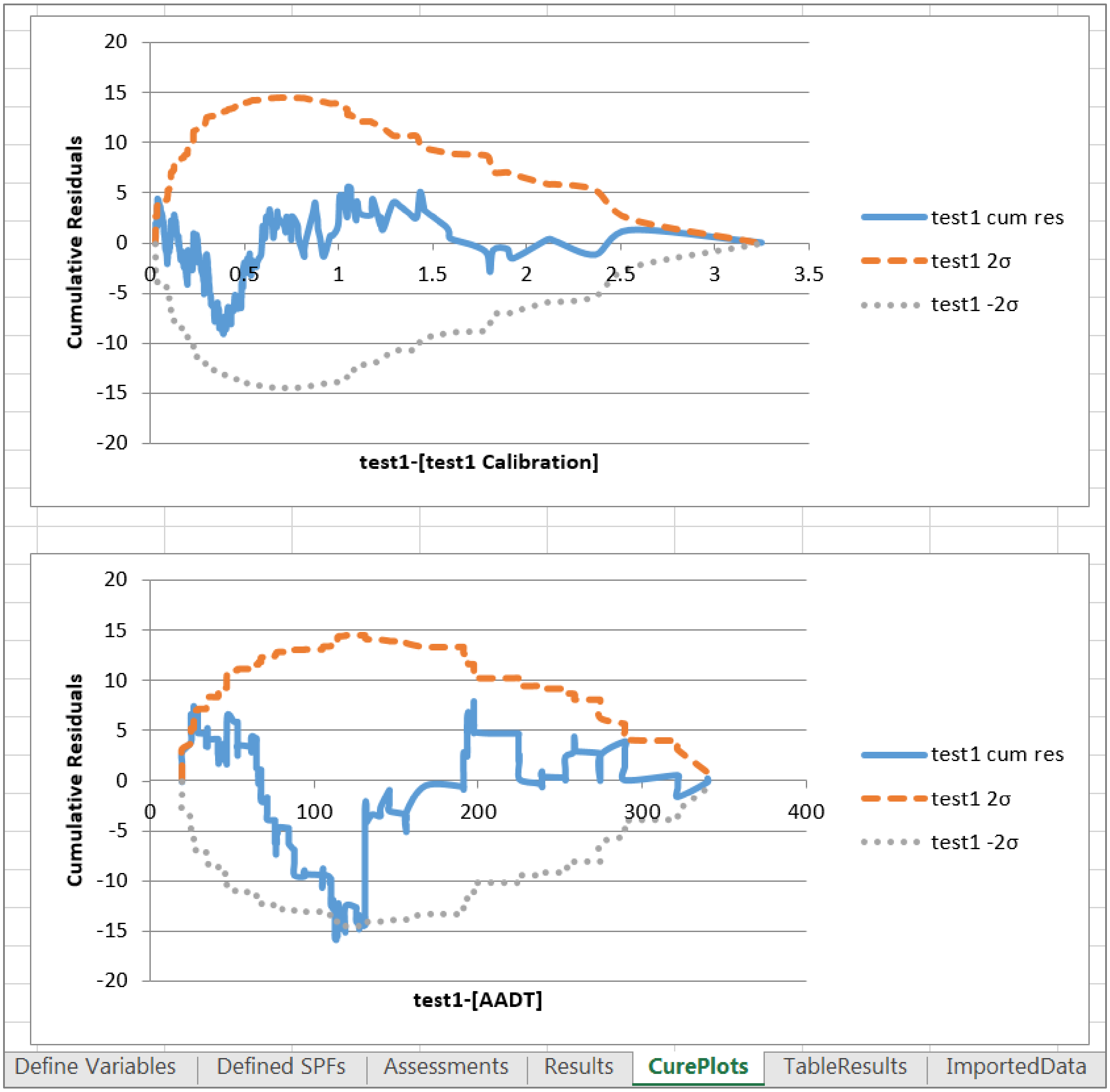
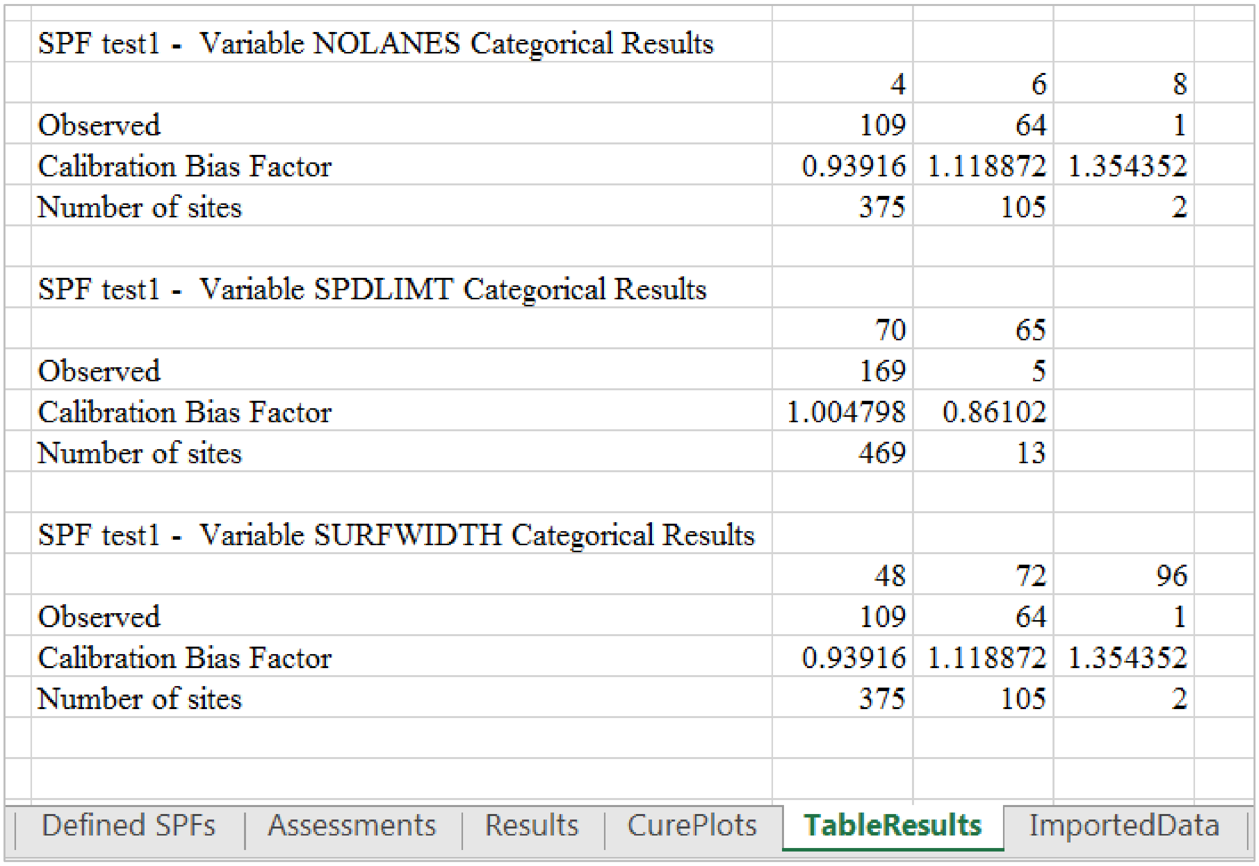


Figure 27. Image. Example CURE plots from "Generate Graphs."



SPF test1 - Variable NOLANES Categorical Results

	4	6	8
Observed	109	64	1
Calibration Bias Factor	0.93916	1.118872	1.354352
Number of sites	375	105	2

SPF test1 - Variable SPDLIMT Categorical Results

	70	65
Observed	169	5
Calibration Bias Factor	1.004798	0.86102
Number of sites	469	13

SPF test1 - Variable SURFWIDTH Categorical Results

	48	72	96
Observed	109	64	1
Calibration Bias Factor	0.93916	1.118872	1.354352
Number of sites	375	105	2

Figure 28. Image. Example assessment tables from "Generate Tables."

6. EXAMPLES

This section illustrates the use of the tool through the following three examples.

- Example 1: SPF for Motorcycle Crashes on Urban Freeways—this example demonstrates how to calibrate and assess the calibration of a single SPF.
- Example 2: SPF and CMFs for 3-Leg STOP Controlled Intersections on Rural 2-Lane Roads—this example demonstrates how to calibrate and assess the calibration of a single SPF.
- Example 3: HSM SPF and CMFs, AASHTOWare Safety Analyst™ SPF, and Custom SPF Applied to Rural 2-Lane Roads—this example demonstrates how to calibrate, assess, and compare multiple SPFs to determine which is most appropriate for application

Users can import the data for these examples from the upper-middle of the 'Define Variables' tab. Users may use these data to replicate the findings.

EXAMPLE 1: SPF FOR MOTORCYCLE CRASHES ON URBAN FREEWAYS

This example demonstrates how to calibrate and assess the calibration of a single SPF. The SPF in question is for motorcycle crashes on freeways. Figure 29 shows the equation for the SPF in question. The tool provides this SPF as "test1" in the 'Available SPFs' box once the user clicks 'Import Sample Data 1' from the upper-middle of the 'Define Variables' tab. This represents the existing SPF for calibration as shown in the Figure 30 screenshot.

$$\text{motocrash} = \text{years} * \exp^{-5.9368} * \text{length}^{0.8239} * \text{AADT}^{0.6622}$$

Figure 29. Equation. SPF for example 1.

Where:

motocrash = count of motorcycle crashes.

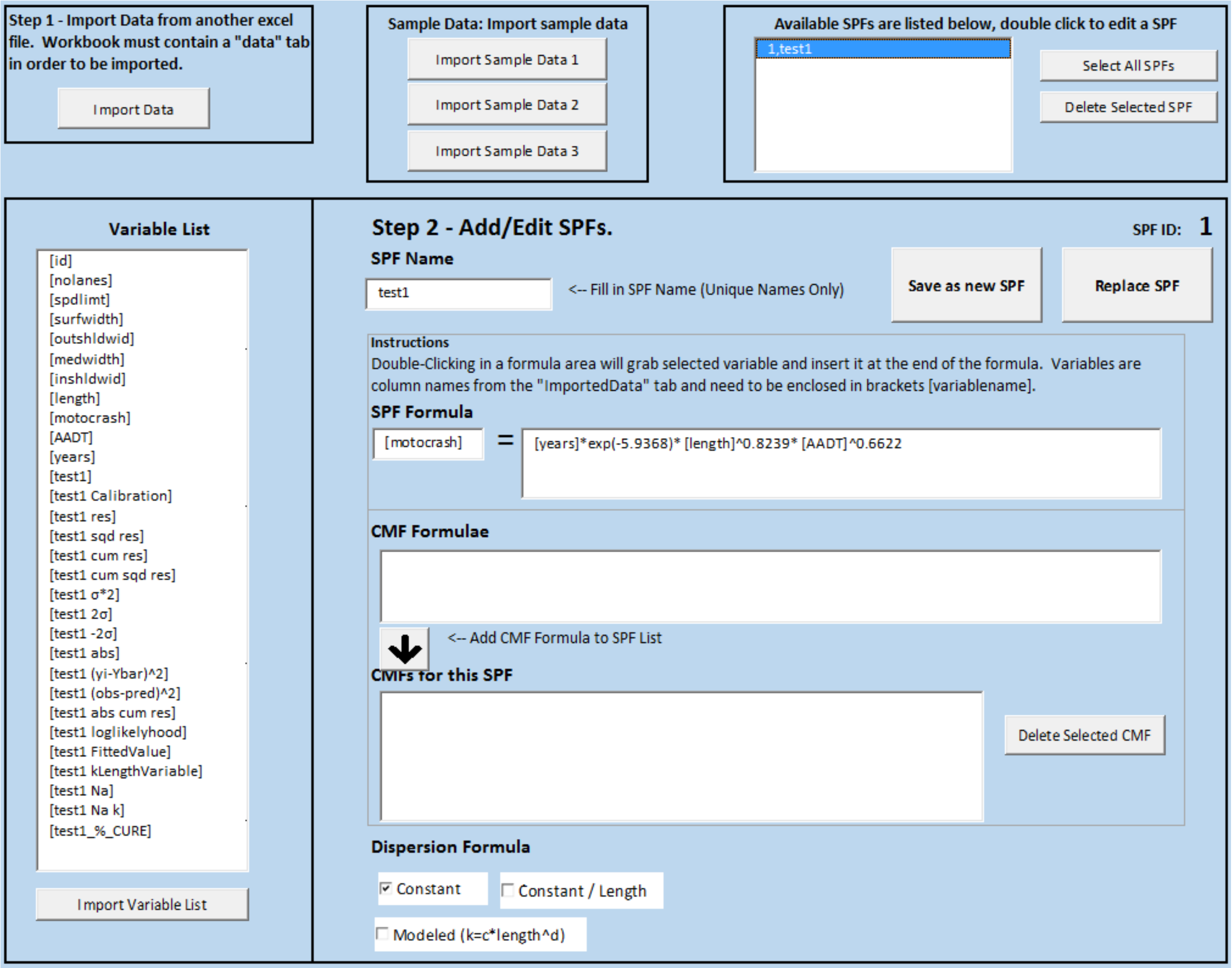
years = years of data for each site.

length = length of segment in miles.

AADT = average annual daily motorcycle volume.

Dispersion = constant.

This example uses data for 483 road segments on urban freeways. Import the data by selecting 'Import Sample Data 1' on the 'Define Variables' tab. The crash type of interest is motorcycle crashes of which there are 174, or 0.36 per segment on average, during a five-year period. Figure 30 shows the variables in the "Variable List" box. Note the data should also appear in the 'ImportedData' tab.



Step 1 - Import Data from another excel file. Workbook must contain a "data" tab in order to be imported.

Available SPFs are listed below, double click to edit a SPF

1,test1

[id]
[nolanes]
[spdlimt]
[surfwidth]
[outshldwid]
[medwidth]
[inshldwid]
[length]
[motocrash]
[AADT]
[years]
[test1]
[test1 Calibration]
[test1 res]
[test1 sqd res]
[test1 cum res]
[test1 cum sqd res]
[test1 σ*2]
[test1 2σ]
[test1 -2σ]
[test1 abs]
[test1 (yi-Ybar)^2]
[test1 (obs-pred)^2]
[test1 abs cum res]
[test1 loglikelyhood]
[test1 FittedValue]
[test1 kLengthVariable]
[test1 Na]
[test1 Na k]
[test1_%_CURE]

Step 2 - Add/Edit SPFs.

SPF ID: 1

SPF Name

test1 <-- Fill in SPF Name (Unique Names Only)

Instructions

Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula

[motocrash] = [years]*exp(-5.9368)* [length]^0.8239* [AADT]^0.6622

CMF Formulae

CMFs for this SPF

Dispersion Formula

☑ Constant
☐ Constant / Length
☐ Modeled (k=c*length^d)

Figure 30. Image. Information in ‘Define Variables’ tab for example 1.

Where:

id = identification number for segment.

nolanes = number of lanes.

spdlimt = posted speed limit in miles per hour.

surfwidth = surface width in feet.

outshldwid = outside shoulder width in feet.

medwidth = median width in feet.

inshldwid = inside shoulder width in feet.

length = length of segment in miles.

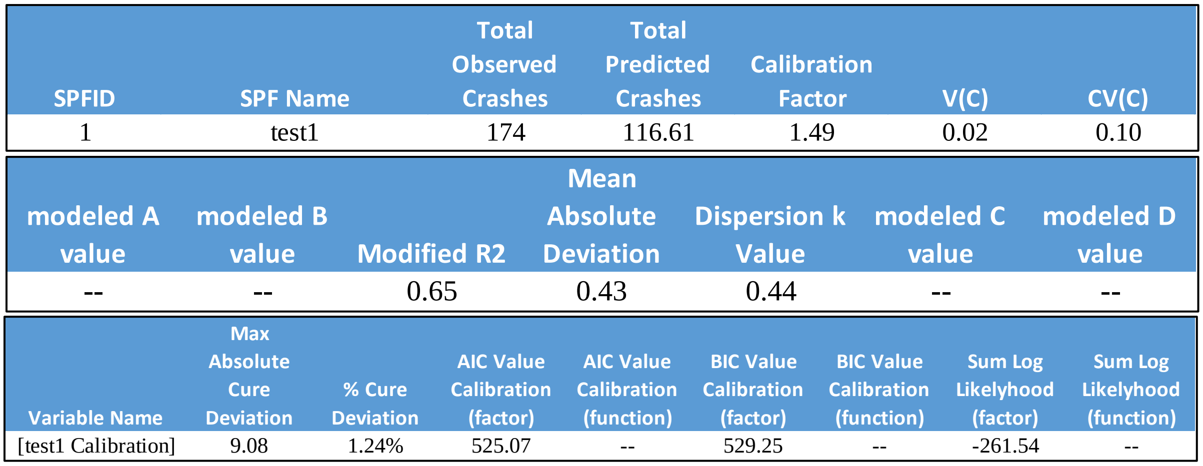
motocrash = count of motorcycle crashes.

AADT = average annual daily motorcycle volume.

years = years of data for each site.

Calibrate the SPF by selecting the SPF name (i.e., test1) from the list of ‘Available SPFs’ in the ‘Define Variables’ tab as shown in Figure 30, and then clicking ‘Estimate Calibration Factors’ or ‘Estimate Calibration Functions’ in the lower right of the same tab. Figure 31 shows a screenshot of the ‘Results’ tab, which presents the results of the calibration after clicking ‘Estimate Calibration Factors’, including the following variables.

- Calibration factor = 1.49
- Modified R^2 = 0.65
- MAD = 0.43
- Dispersion parameter = 0.44
- V(C) = 0.02
- CV(C) = 0.10
- Max Absolute Cure Deviation (for the calibrated fitted values) = 9.08
- % Cure Deviation (for the calibrated fitted values) = 1.24%



SPFID	SPF Name	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	V(C)	CV(C)
1	test1	174	116.61	1.49	0.02	0.10

modeled A value	modeled B value	Modified R2	Mean Absolute Deviation	Dispersion k Value	modeled C value	modeled D value
--	--	0.65	0.43	0.44	--	--

Variable Name	Max Absolute Cure Deviation	% Cure Deviation	AIC Value Calibration (factor)	AIC Value Calibration (function)	BIC Value Calibration (factor)	BIC Value Calibration (function)	Sum Log Likelyhood (factor)	Sum Log Likelyhood (function)
[test1 Calibration]	9.08	1.24%	525.07	--	529.25	--	-261.54	--

Figure 31. Image. Calibration results from example 1.

The calibration factor indicates the uncalibrated SPF under-predicts crashes. The calibration factor increases the predictions by approximately 50 percent. The modified R^2 of 0.65, MAD of 0.43, and dispersion parameter of 0.44 all indicate a reasonable goodness-of-fit to the data. The CV(C) is less than 0.15 indicating the calibration factor is reasonably accurate. By itself, this CV value is indicative of a successful calibration. The percent curve deviation for the fitted values is less than five percent, which also indicates a successful calibration.

To further test the goodness-of-fit, Figure 32 through Figure 36 present additional CURE plots for the continuous variables, including outside shoulder width, inside shoulder width, median width, and AADT. Users can create CURE plots from the ‘Assessments’ tab by selecting the variables of interest from the variable list, selecting the SPF of interest from the list of available SPFs, and clicking ‘Generate Graphs.’

The CURE plot for outside shoulder width indicates there is some bias in the SPF predictions at widths of 10 feet. The SPF tends to over-predict motorcycle crashes for this value of shoulder width. The user might consider separate calibration factors for different shoulder widths in this case.

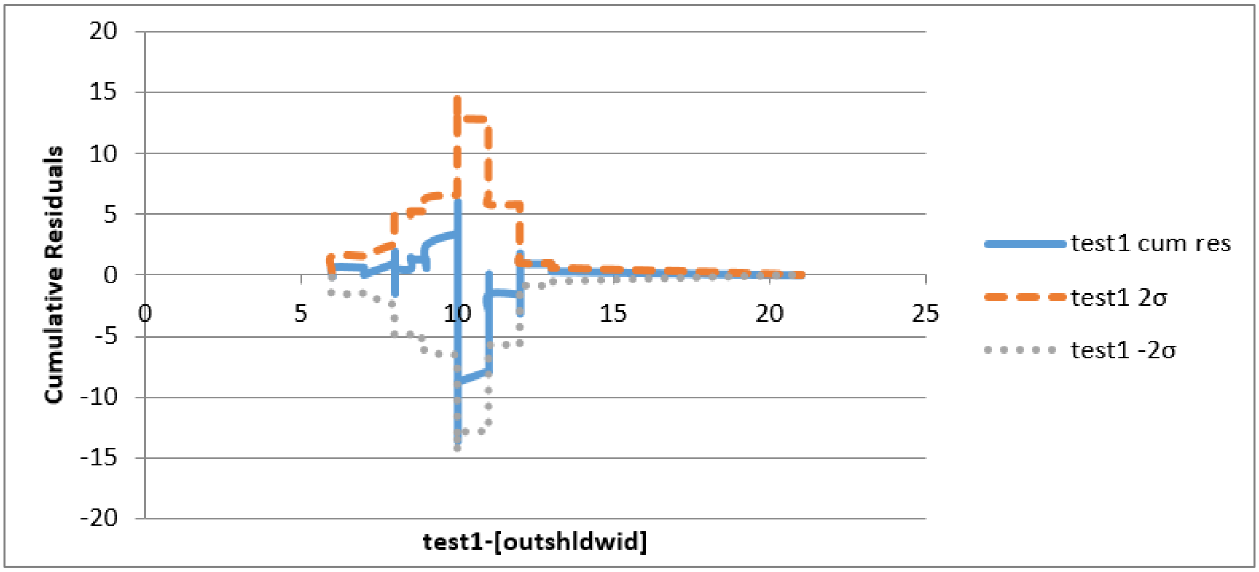


Figure 32. Chart. CURE plot for outside shoulder width for example 1.

The CURE plot for inside shoulder width indicates the SPF performs well over most of the range of values. The cumulative residuals plot only briefly exceeds the two standard deviation confidence limits for narrow shoulders, indicating an under-prediction in crashes in this range. The fit is acceptable in this case.

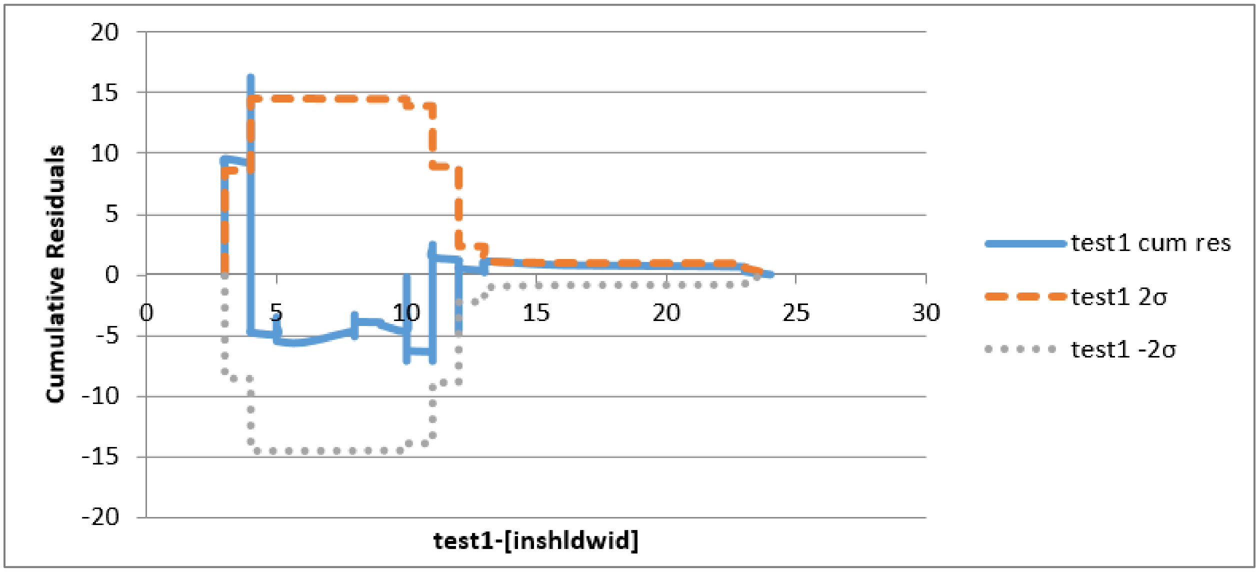


Figure 33. Chart. CURE plot for inside shoulder width for example 1.

The CURE plot for median width indicates the SPF performs reasonably well although there may be some bias or a potential outlier at low values of median width. Specifically, there is a large vertical drop at 25 feet, and a constant decreasing trend from approximately 50 feet to 150 feet, indicating a small, yet consistent, bias. The analyst should check the data for potential outliers contributing to the drop at 25 feet. If the data appear unreliable, then the analyst should remove outliers and run the calibration again.

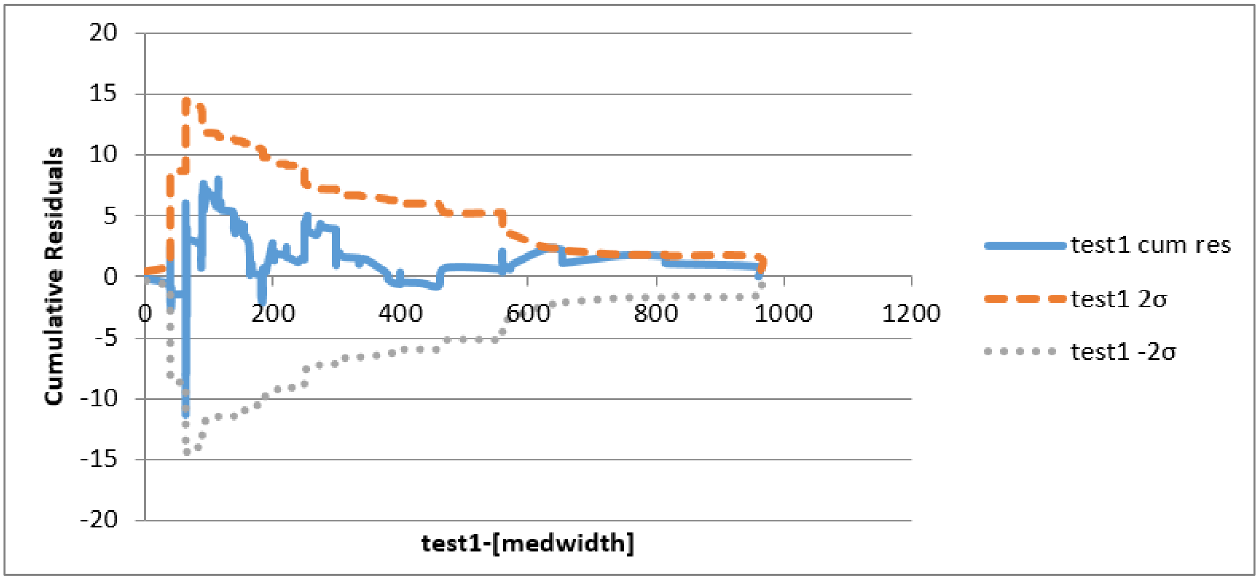


Figure 34. Chart. CURE plot for median width for example 1.

The CURE plot for motorcycle AADT indicates the SPF is performing well overall and the plot of cumulative residuals rarely exceeds the two standard deviation confidence limits. Between AADT values of approximately 75 and 120 vehicles per day, the SPF over-predicts crashes, while it tends to under-predict crashes between AADT values of 120 and 200 vehicles per day. The analyst could consider dividing the data into two datasets and develop separate calibration factors for each range, assuming sample sizes are sufficient, or develop a calibration function.

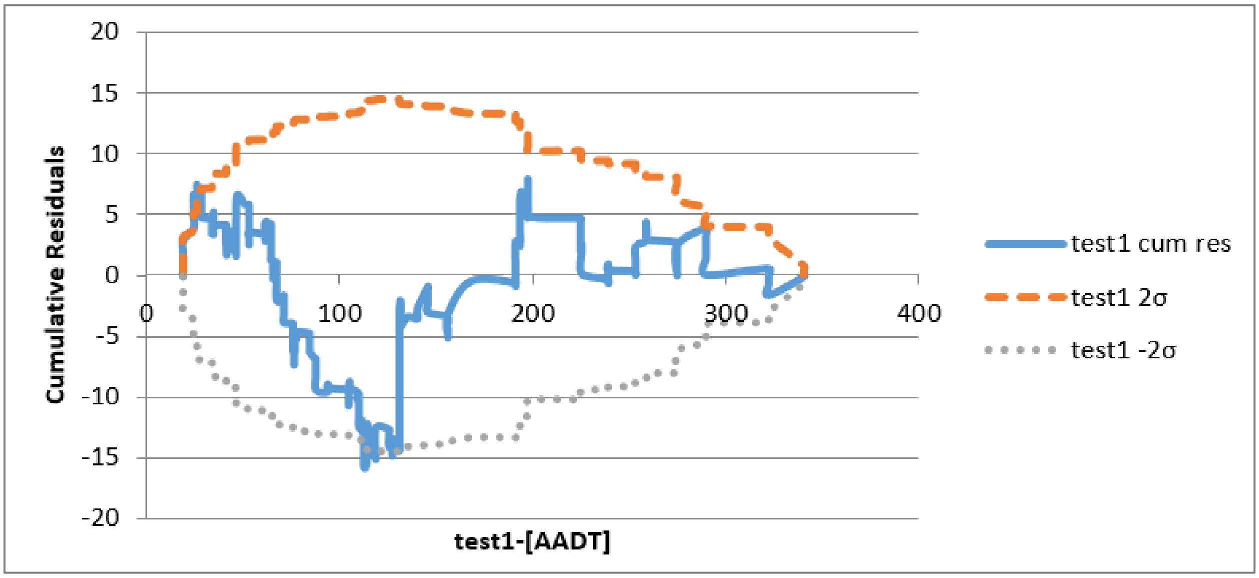


Figure 35. Chart. CURE plot for motorcycle AADT for example 1.

The CURE plot for fitted (calibrated) values indicates the SPF performs well overall and the plot of cumulative residuals rarely exceeds the two standard deviation confidence limits. According to the suggested assessment criteria, this result by itself would deem the SPF acceptable.

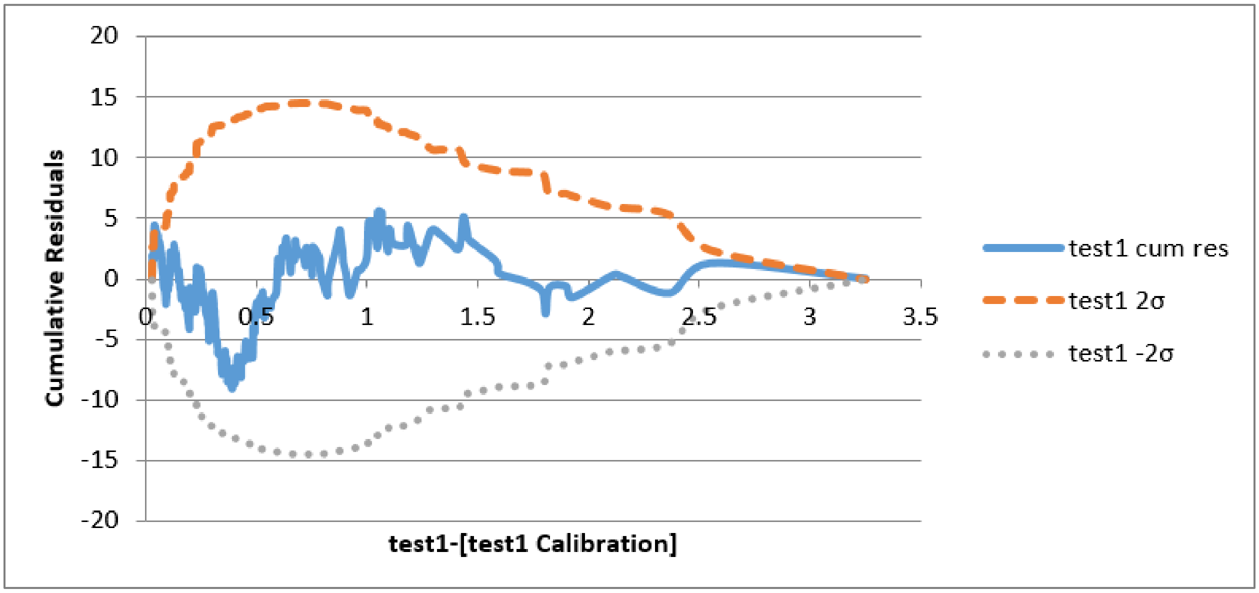
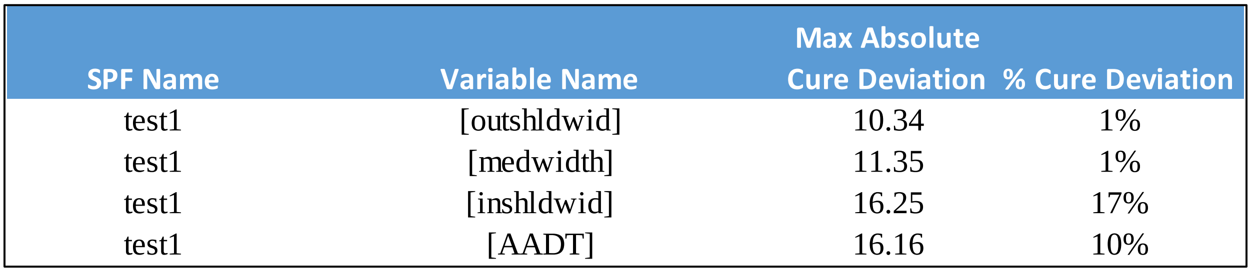


Figure 36. Chart. CURE plot for fitted (calibrated) values for example 1.

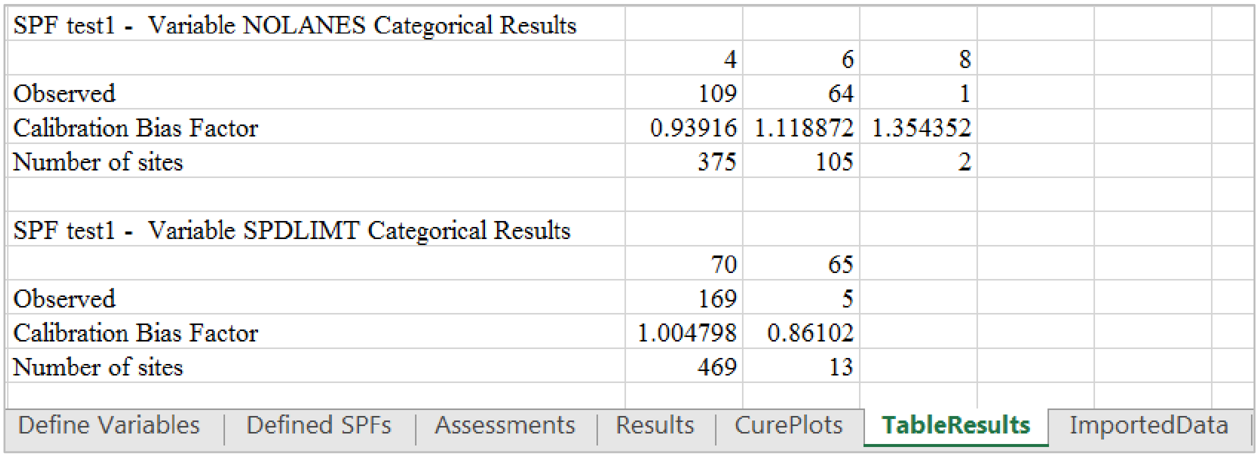
Figure 37 shows a screenshot of the summary results from the 'Results' tab based on the CURE plots selected from the 'Assessments' tab. For each CURE plot, the 'Results' tab provides the maximum absolute deviation from zero as well as the percentage of observations exceeding the two standard deviation confidence limits. The percent of ordinates exceeding the two standard deviation limits is greater than five percent for the variables related to inside shoulder width and AADT, indicating some bias in the predictions for these two variables.



SPF Name	Variable Name	Max Absolute Cure Deviation	% Cure Deviation
test1	[outshldwid]	10.34	1%
test1	[medwidth]	11.35	1%
test1	[inshldwid]	16.25	17%
test1	[AADT]	16.16	10%

Figure 37. Image. CURE plot assessment results for example 1.

It is also of interest to determine how the SPF is performing for the categorical variables: number of lanes and posted speed limit. Since these are not continuous variables, assessment tables are more appropriate than CURE plots. The user can create assessment tables from the 'Assessments' tab by selecting the variables of interest from the variable list, selecting the SPF of interest from the list of available SPFs, and clicking 'Generate Tables.' Figure 38 shows the assessment tables for motorcycle crashes.



SPF test1 - Variable NOLANES Categorical Results			
	4	6	8
Observed	109	64	1
Calibration Bias Factor	0.93916	1.118872	1.354352
Number of sites	375	105	2
SPF test1 - Variable SPDLIMT Categorical Results			
	70	65	
Observed	169	5	
Calibration Bias Factor	1.004798	0.86102	
Number of sites	469	13	

Figure 38. Image. Assessment table results for example 1.

For number of lanes, the SPF slightly over-predicts crashes for four-lane segments and under-predicts crashes for six-lane segments. There is only one crash for the eight-lane segment group; therefore, the calibration bias factor for this group is not meaningful.

For posted speed limit, the SPF does not over- or under-predict crashes for 70 mph segments. The SPF over-predicts crashes for segments with a posted speed limit of 65 mph; however, this result is based on only five crashes, which is uninformative.

EXAMPLE 2: SPF AND CMFS FOR 3-LEG STOP-CONTROLLED INTERSECTIONS ON RURAL 2-LANE ROADS

This example demonstrates how to calibrate and assess the calibration of a single SPF. The SPF in question is for three-legged, stop-controlled intersections on rural, two-lane roads. Figure 39 shows the equation for the SPF in question. The tool provides this SPF as "test2" in the 'Available SPFs' box once the user clicks 'Import Sample Data 2' from the upper-middle of the 'Define Variables' tab. This represents the existing SPF for calibration as shown in the Figure 40 screenshot:

$$\text{intcrash} = \text{years} * \exp^{-9.86} * \text{AADTMAJ}^{0.79} * \text{AADTMIN}^{0.49}$$

Figure 39. Equation. SPF for example 2.

Where:

intcrash = count of intersection-related crashes.

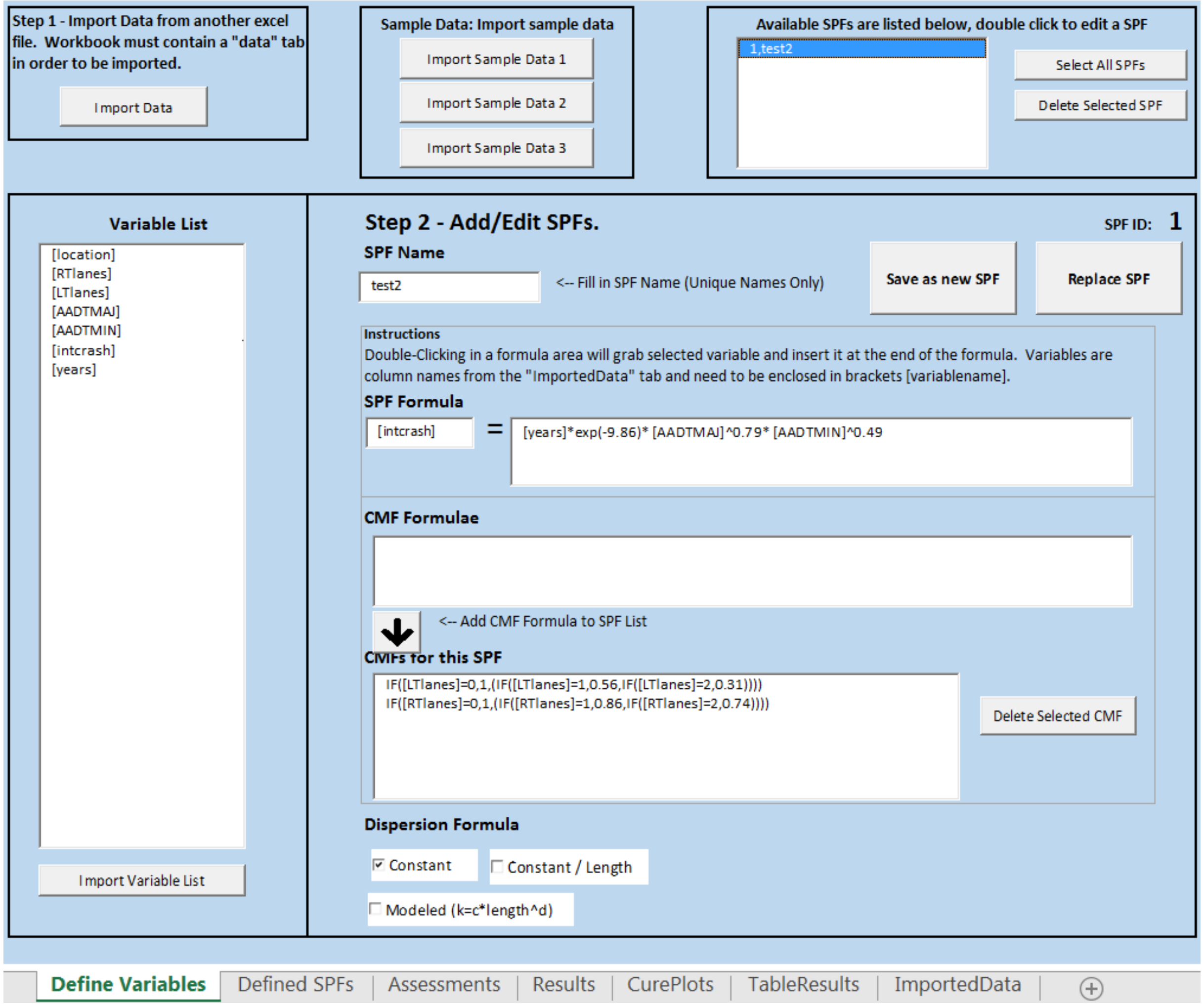
years = years of data for each site.

AADTMAJ = annual average daily traffic for major road.

AADTMIN = annual average daily traffic for minor road.

Dispersion = constant.

This example uses data for 3,534 three-legged, stop-controlled intersections on rural, two-lane roads. Import the data by selecting 'Import Sample Data 2' on the 'Define Variables' tab. The crash type of interest is total intersection-related crashes. There are 7,208 total intersection-related crashes, or 2.04 crashes on average per site, or 0.24 crashes on average per site-year. Figure 40 shows the variables in the "Variable List" box. Note the data should also appear in the 'ImportedData' tab.



Step 1 - Import Data from another excel file. Workbook must contain a "data" tab in order to be imported.

1,test2

SPF ID: 1

[location]
[RTlanes]
[LTlanes]
[AADTMAJ]
[AADTMIN]
[intcrash]
[years]

SPF Name

test2 <-- Fill in SPF Name (Unique Names Only)

Instructions

Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula

[intcrash] = [years]*exp(-9.86)* [AADTMAJ]^0.79* [AADTMIN]^0.49

<-- Add CMF Formula to SPF List

IF([LTlanes]=0,1,(IF([LTlanes]=1,0.56,IF([LTlanes]=2,0.31))))
IF([RTlanes]=0,1,(IF([RTlanes]=1,0.86,IF([RTlanes]=2,0.74))))

☑ Constant
☐ Constant / Length
☐ Modeled (k=c*length^d)

Figure 40. Image. Information in 'Define Variables' tab for example 2.

Where:

location = jurisdiction of the intersection.

RTlanes = number of right-turn lanes on major road.

LTlanes = number of left-turn lanes on major road.

AADTMAJ = annual average daily traffic for major road.

AADTMIN = annual average daily traffic for minor road.

intcrash = count of intersection-related crashes.

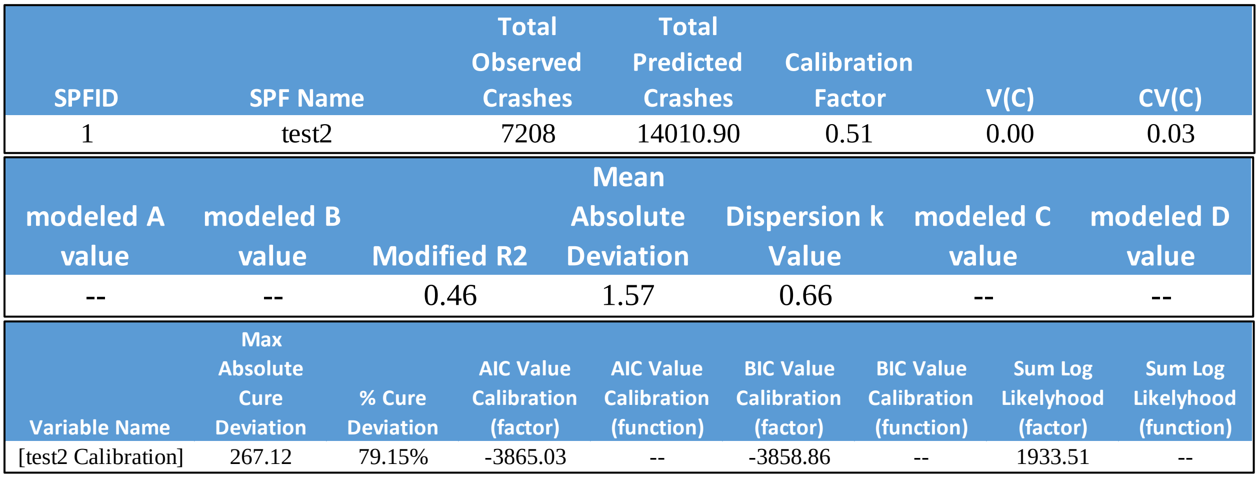
years = years of data for each site.

Relevant CMFs, some of which are visible in the Figure 40 screenshot, include the following:

- 1 left-turn lane on major road: CMF = 0.56.
- 2 left-turn lanes on major road: CMF = 0.31.
- 1 right-turn lane on major road: CMF = 0.86.
- 2 right-turn lanes on major road: CMF = 0.74.

Calibrate the SPF by selecting the SPF name (i.e., test2) from the list of 'Available SPFs' in the 'Define Variables' tab as shown in Figure 40, and then clicking 'Estimate Calibration Factors' or 'Estimate Calibration Functions' in the lower right of the same tab. Figure 41 shows a screenshot of the 'Results' tab, which presents the results of the calibration after clicking 'Estimate Calibration Factors', including the following variables.

- Calibration factor = 0.51
- Modified R^2 = 0.46
- MAD = 1.57
- Dispersion parameter = 0.66
- V(C) = 0.00
- CV(C) = 0.03
- Max Absolute Cure Deviation (for the calibrated fitted values) = 267.12
- % Cure Deviation (for the calibrated fitted values) = 79%



SPFID	SPF Name	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	V(C)	CV(C)
1	test2	7208	14010.90	0.51	0.00	0.03

modeled A value	modeled B value	Modified R2	Mean Absolute Deviation	Dispersion k Value	modeled C value	modeled D value
--	--	0.46	1.57	0.66	--	--

Variable Name	Max Absolute Cure Deviation	% Cure Deviation	AIC Value Calibration (factor)	AIC Value Calibration (function)	BIC Value Calibration (factor)	BIC Value Calibration (function)	Sum Log Likelyhood (factor)	Sum Log Likelyhood (function)
[test2 Calibration]	267.12	79.15%	-3865.03	--	-3858.86	--	1933.51	--

Figure 41. Image. Calibration results from example 2.

The calibration factor indicates the uncalibrated SPF over-predicts crashes and the calibration factor reduces the predictions by approximately 50 percent. The modified R^2 of 0.46 relatively low, but the MAD of 1.57 and dispersion parameter of 0.66 indicate a reasonable goodness-of-fit to the data. The CV(C) is less than 0.15 indicating the calibration factor is reasonably accurate despite its size, and the analyst may consider the calibrated SPF for application based on this value. The percent of ordinates exceeding the two standard deviation limits is greater than five percent for the fitted values, indicating some bias in the predictions.

To further test the goodness-of-fit, Figure 42 through Figure 44 present additional CURE plots for the continuous variables, including major road AADT and minor road AADT. Users can create CURE plots from the 'Assessments' tab by selecting the variables of interest from the variable list, selecting the SPF of interest from the list of available SPFs, and clicking 'Generate Graphs.'

The CURE plot for major road AADT shows the SPF generally over-predicts crashes for major road AADT less than 5,000 vehicles per day and under-predicts crashes for major road AADT from 12,500 to 17,500 vehicles per day. The plot of cumulative residuals strays outside the two standard deviation confidence limits for a substantial portion of the plot, indicating significant bias in SPF predictions.

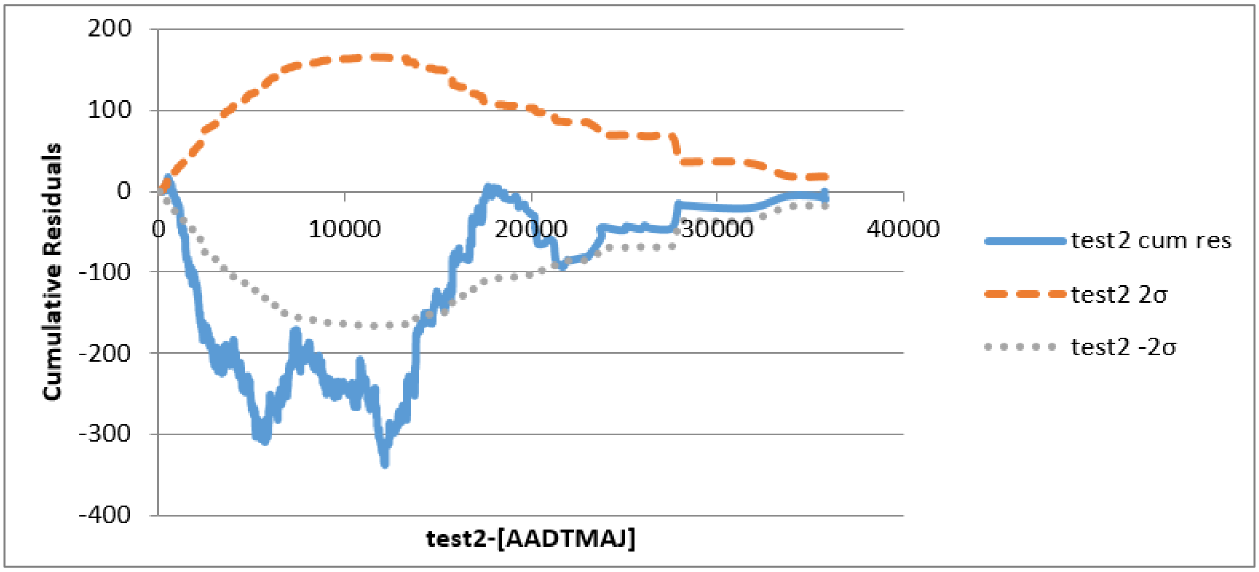


Figure 42. Image. CURE plot for major road AADT for example 2.

The CURE plot for minor road AADT shows the SPF performs well except for very low values of minor road AADT where the plot of cumulative residuals strays far outside the two standard deviation confidence limits.

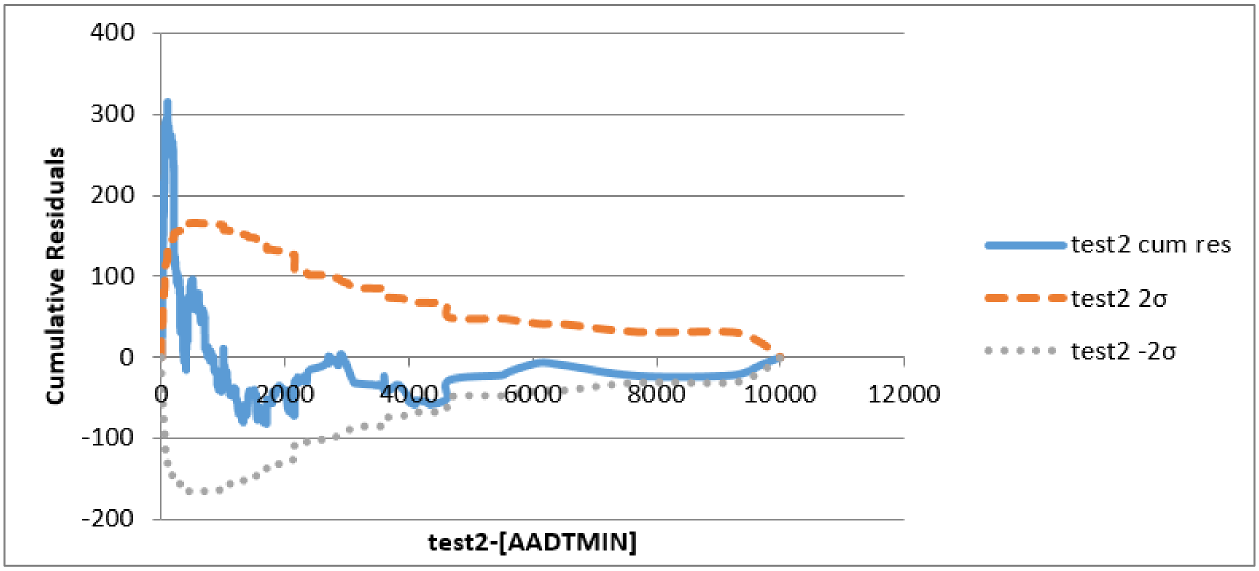


Figure 43. Image. CURE plot for minor road AADT for example 2.

The CURE plot for fitted (calibrated) values shows the cumulative residuals straying outside the two standard deviation confidence limits for a portion of the plot, indicating some bias in SPF predictions for lower fitted values.

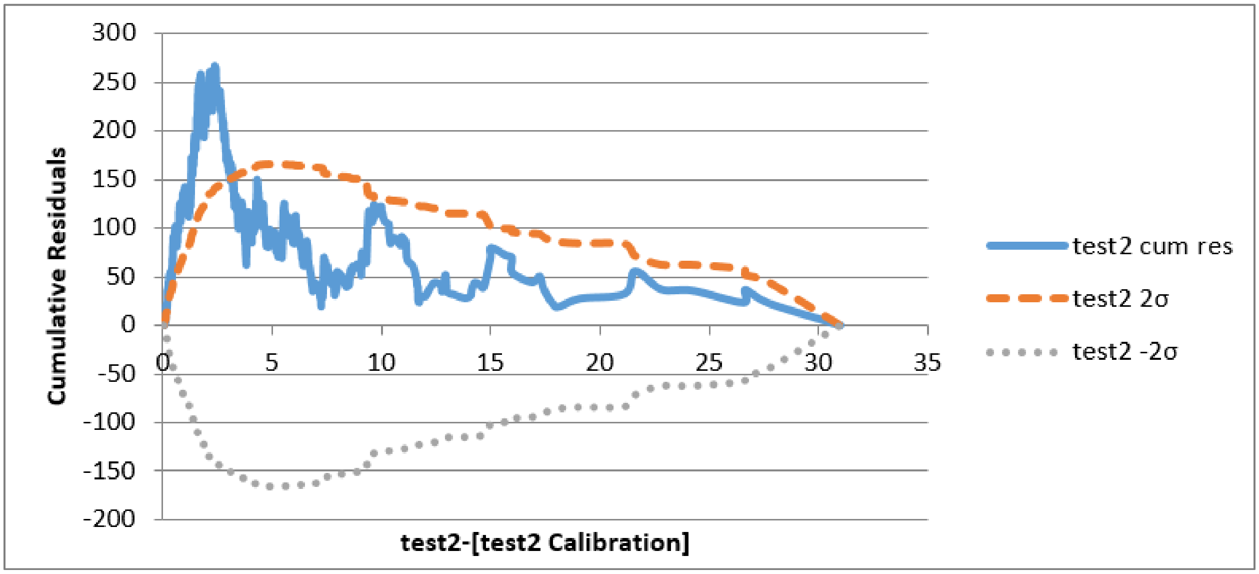
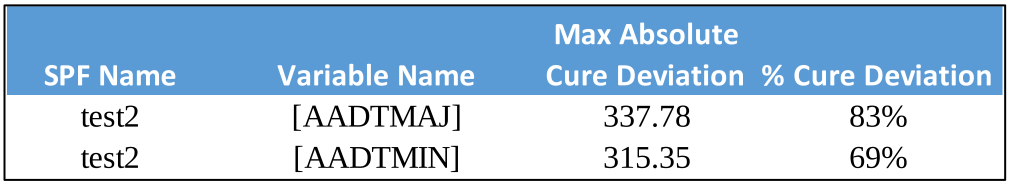


Figure 44. Image. CURE plot for fitted (calibrated) values for example 2.

Figure 45 shows a screenshot of the summary results from the 'Results' tab based on the CURE plots selected from the 'Assessments' tab. For each CURE plot, the 'Results' tab provides the maximum absolute deviation from zero as well as the percentage of observations exceeding the two standard deviation confidence limits. The percent of ordinates exceeding the two standard deviation limits is greater than five percent for both variables: major road AADT and minor road AADT, indicating substantial bias within the SPF. At first glance, the percent cure deviation for minor road AADT seems at odds with Figure 43. Evidently, a substantial number of minor road AADTs are in the range where the CURE values exceed the 2σ boundary. Even so, with a maximum deviation of the cumulative residuals in the low 300s for both major and minor AADT, and less than 300 for fitted values, this calibration may be considered acceptable given there are 7,208 crashes in the dataset and the CV was in the acceptable range.

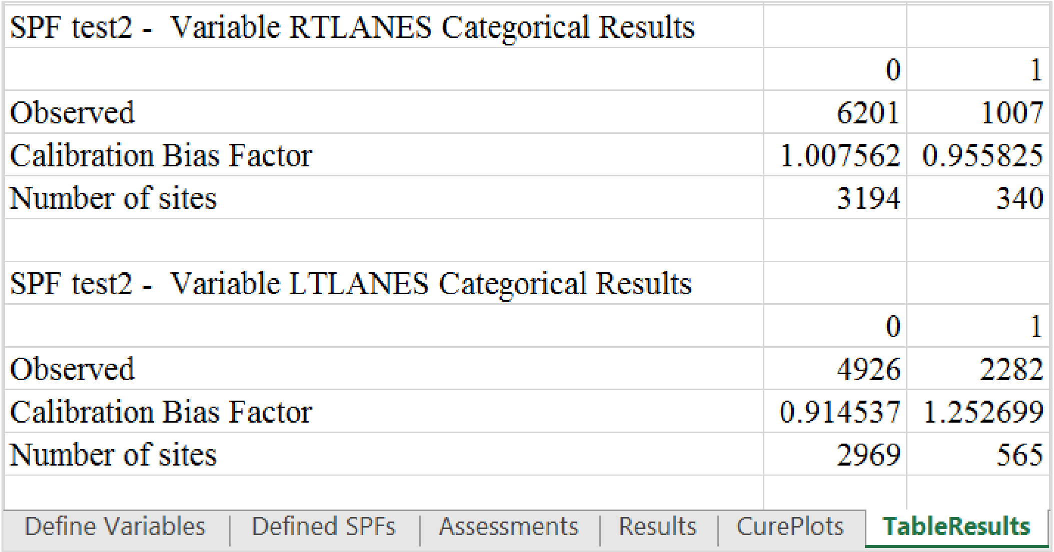


SPF Name	Variable Name	Max Absolute Cure Deviation	% Cure Deviation
test2	[AADTMAJ]	337.78	83%
test2	[AADTMIN]	315.35	69%

Figure 45. Image. CURE plot assessment results for example 2.

It is also of interest to observe how the SPF is performing for the categorical variables: right-turn lanes and left-turn lanes. Since these are not continuous variables, assessment tables are more appropriate than CURE plots. This user can create assessment tables from the 'Assessments' tab by selecting the variables of interest from the variable list, selecting the SPF of interest from the list of available SPFs, and clicking 'Generate Tables.' Figure 46 shows the assessment tables for intersection crashes.

For right turn lanes, the SPF performs well for both zero and one right turn lane on the major road as evidenced by the calibration bias factors close to 1.0. For left turn lanes, the bias factors indicate the SPF over-predicts crashes for sites without a major road left-turn lane and under-predicts crashes for sites with one major road left-turn lane. For this dataset, there were no sites with two right- or left-turn lanes on the major road.



SPF test2 - Variable RTLANES Categorical Results		
	0	1
Observed	6201	1007
Calibration Bias Factor	1.007562	0.955825
Number of sites	3194	340
SPF test2 - Variable LTLANES Categorical Results		
	0	1
Observed	4926	2282
Calibration Bias Factor	0.914537	1.252699
Number of sites	2969	565

Figure 46. Image. Assessment table results for example 2.

EXAMPLE 3: HSM SPF AND CMFS, AASHTOWARE SAFETY ANALYST™ SPF, AND CUSTOM SPF APPLIED TO RURAL 2-LANE ROADS

This example assesses and compares multiple SPFs to determine which is most appropriate for application in the given jurisdiction. The SPFs in question are for rural, two-lane roads from the HSM, AASHTOWare Safety Analyst™, and a neighboring State (State X). Figure 47 shows the equation for a custom SPF from State X. The tool provides this SPF as "test3" in the 'Available SPFs' box once the user clicks 'Import Sample Data 3' from the upper-middle of the 'Define Variables' tab. The tool also provides the HSM and AASHTOWare Safety Analyst™ SPFs as predefined SPFs.

$$\text{tot} = \text{years} * \exp^{-6.31} * \text{AADT}^{0.74} * \text{length}^{0.62}$$

Figure 47. Equation. SPF for example 3.

Where:

tot = count of crashes on a segment.

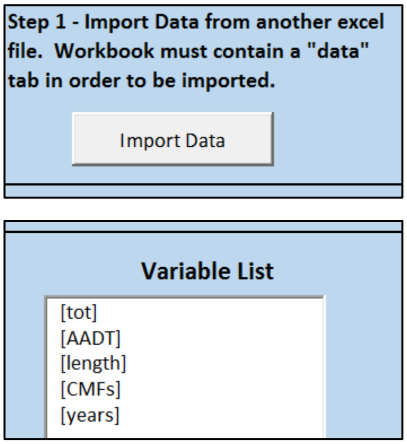
years = years of data for each site.

AADT = annual average daily traffic volume.

length = length of segment in miles.

Dispersion = variable (constant/length).

The example uses data for 509 rural, two-lane road segments for a five-year period. Import the data by selecting 'Import Sample Data 3' on the 'Define Variables' tab. The crash type of interest is total crashes. There are 753 total crashes, or 1.48 crashes on average per site, or 0.30 crashes on average per site-year. Figure 48 shows the variables in the "Variable List" box. Note the data should also appear in the 'ImportedData' tab. The column headings in the 'ImportedData' tab match the variable names in the predefined HSM and AASHTOWare Safety Analyst™ SPFs. Figure 47 specifies the variable names to match the column headings.



Step 1 - Import Data from another excel file. Workbook must contain a "data" tab in order to be imported.

Variable List

[tot]
[AADT]
[length]
[CMFs]
[years]

Figure 48. Image. Variable list on 'Define Variables' tab for example 3.

Where:

tot = count of crashes on a segment.

AADT = annual average daily traffic volume.

length = length of segment in miles.

CMFs = product of individual HSM CMFs for the segment.

years = years of data for each site.

Note the data in this example contain a variable "CMFs" that is the product of all relevant Part C CMFs from the HSM for each road segment. As such, it is not necessary to specify CMFs using the 'CMF Formulae' feature of the tool. In this case, it would have been cumbersome to use the tool to specify CMFs for lane and shoulder width since these are functions. Look-up tables are more appropriate to handle functions, a feature not currently in the tool.

To select the predefined HSM and AASHTOWare Safety Analyst™ SPFs for this example, use the filters on the right side of the 'Define Variables' tab. Select the applicable Classification, Facility Type, Crash Severity, and/or Source of interest along the right side of the 'Define Variables' tab, and then click 'Choose Default SPFs'. In this case, the 'Classification' is defined as 'Rural,' the 'Facility Type' is defined as 'Non-Freeway Segment,' the 'Crash Severity' is defined as 'KABCO[1],' and the 'Source' is defined as 'Highway Safety Manual' and 'AASHTOWare Safety Analyst.' Figure 49 shows the options and illustrates the use of the filters to select the predefined HSM and AASHTOWare Safety Analyst™ SPFs for total crashes for rural, non-freeway segments for this example.

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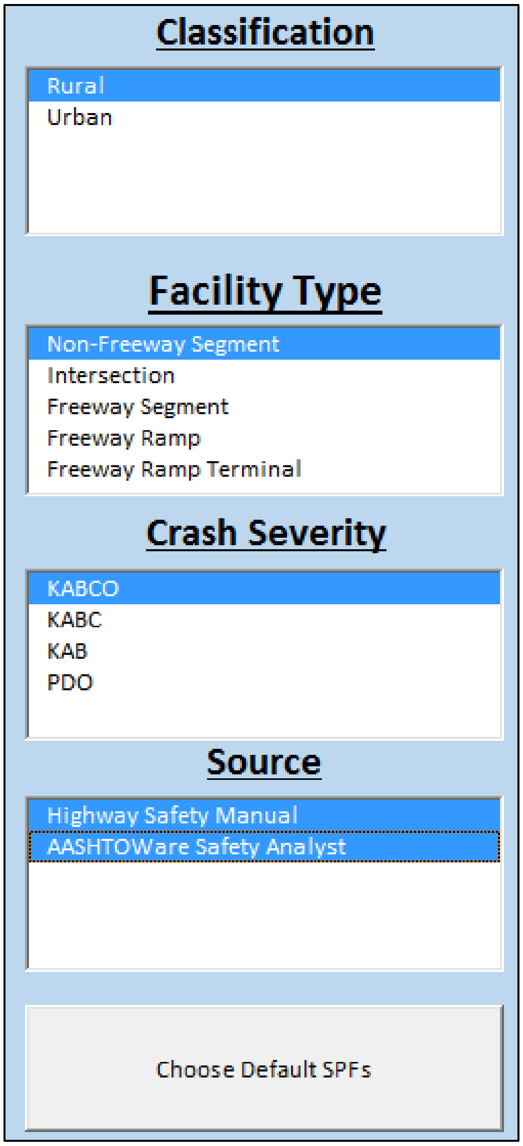
[1] KABCO refers to a scale that is used to represent injury severity in crash reporting: K is fatal injury, A is serious injury, B is minor injury, C is possible injury, and O is property damage only.



Classification

Rural
Urban

Facility Type

Non-Freeway Segment
Intersection
Freeway Segment
Freeway Ramp
Freeway Ramp Terminal

Crash Severity

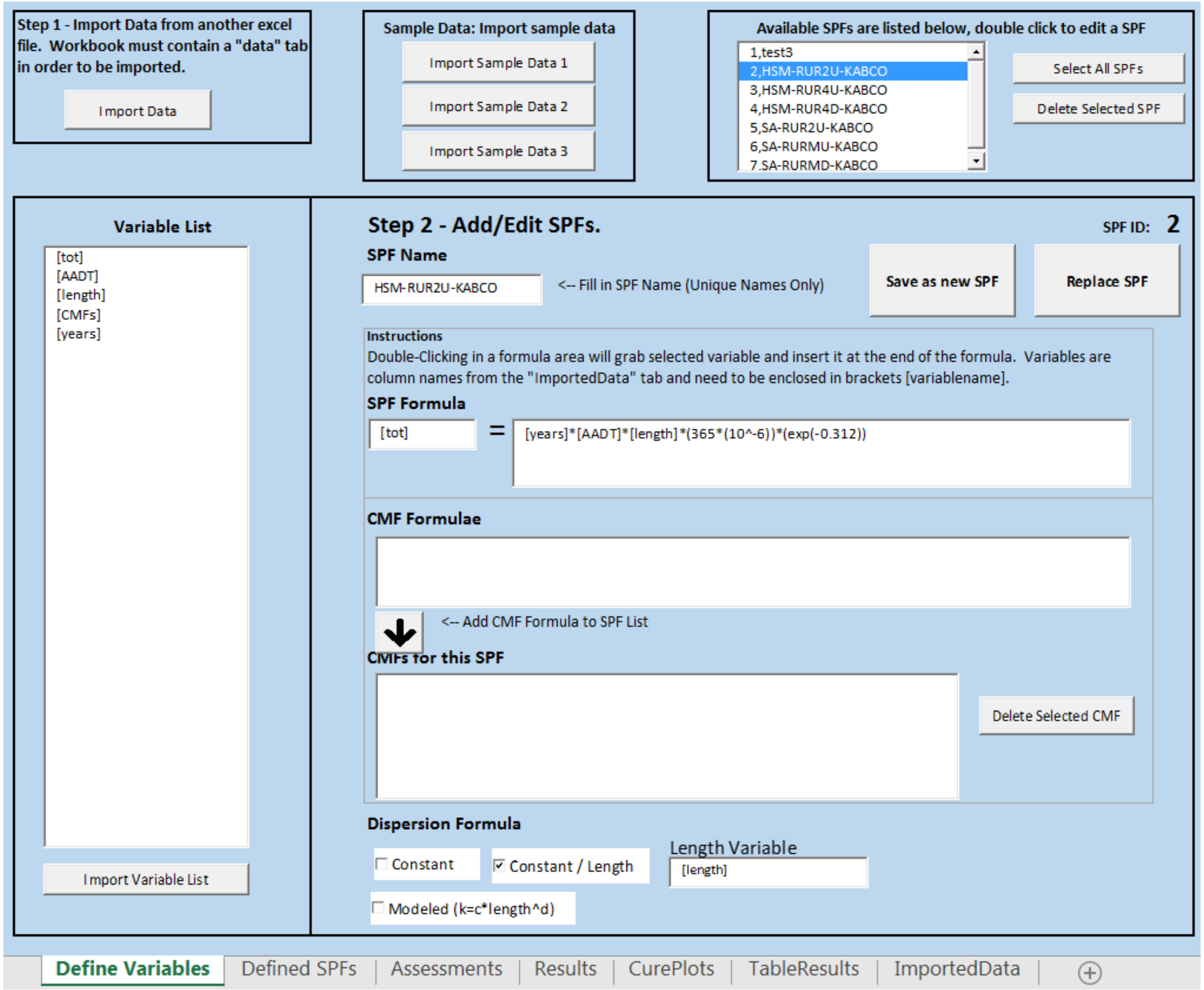
KABCO
KABC
KAB
PDO

Source

Highway Safety Manual
AASHTOWare Safety Analyst

Figure 49. Image. Selecting predefined SPFs for example 3.

Figure 50 shows the names of available SPFs in the 'Available SPFs' box with the baseline SPF from the HSM selected. The figure also shows the other two SPFs of interest in this example: "1,test3" and "5,SA-RUR2U-KABCO." Users can edit the SPFs by double clicking on the SPF name, editing the SPF formula, and clicking 'Replace SPF.' This may be necessary where a variable name in the SPF formula requires editing to match the variable name in the data. In other cases, it may be necessary to add variables such as CMFs to the baseline SPF.



Step 1 - Import Data from another excel file. Workbook must contain a "data" tab in order to be imported.

Available SPFs are listed below, double click to edit a SPF

1,test3
2,HSM-RUR2U-KABCO
3,HSM-RUR4U-KABCO
4,HSM-RUR4D-KABCO
5,SA-RUR2U-KABCO
6,SA-RURMU-KABCO
7,SA-RURMD-KABCO

Variable List

[tot]
[AADT]
[length]
[CMFs]
[years]

Step 2 - Add/Edit SPFs.

SPF ID: 2

SPF Name: HSM-RUR2U-KABCO <-- Fill in SPF Name (Unique Names Only)

Instructions

Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula

[tot] = [years]*[AADT]*[length]*(365*(10^-6))*(exp(-0.312))

CMF Formulae

<-- Add CMF Formula to SPF List

CMFs for this SPF

Dispersion Formula

☐ Constant
☑ Constant / Length
☐ Modeled (k=c*length^d)

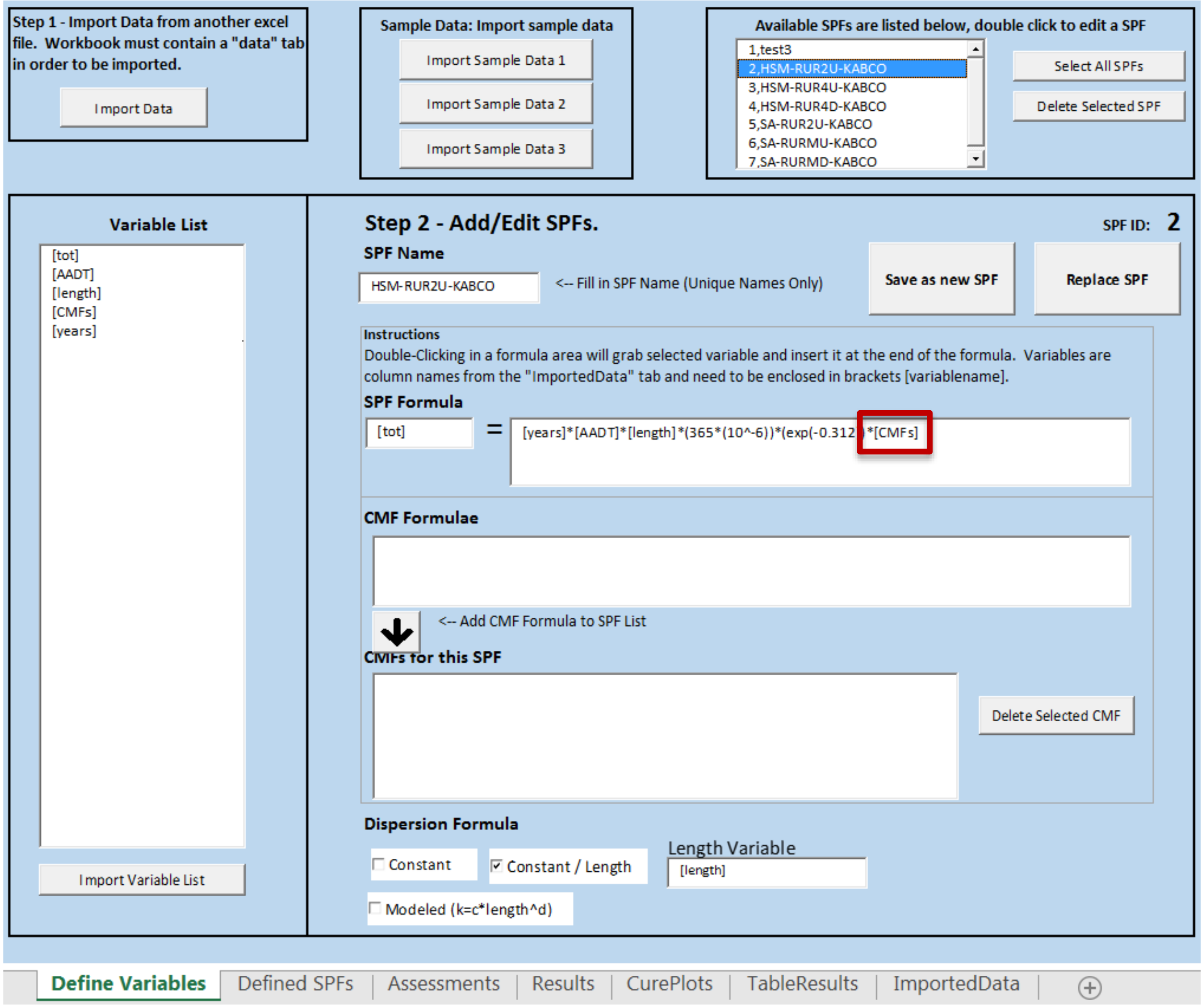
Length Variable: [length]

Figure 50. Image. Selecting predefined HSM SPF for example 3.

For this example, the user needs to edit the baseline SPF from the HSM to include the variable for CMFs. The underlying dataset includes a variable 'CMFs,' which is the product of applicable CMFs from the HSM. Note the user would need to specify the CMFs using the 'SPF Formula' feature of the tool if the underlying data did not include the variable 'CMFs.' Figure 51 shows the SPF from the HSM edited in the 'SPF Formula' box. The figure shows the variable 'CMFs' added to the SPF by typing "*" and then "[CMFs]."

Recall the user could also enter the variable "[CMFs]" by selecting the variable from the 'Variable List' and then double-clicking in the 'SPF Formula' box.

The HSM dispersion formula varies with segment length as indicated in the SPF specification in Appendix section A1. The user must save any revisions to the SPF or dispersion formula before applying the SPF. This is done by clicking 'Replace SPF' on the 'Define Variables' tab.



1,test3
2,HSM-RUR2U-KABCO
3,HSM-RUR4U-KABCO
4,HSM-RUR4D-KABCO
5,SA-RUR2U-KABCO
6,SA-RURMU-KABCO
7,SA-RURMD-KABCO

[tot]
[AADT]
[length]
[CMFs]
[years]

SPF ID: 2

SPF Name: HSM-RUR2U-KABCO

Instructions
Double-Clicking in a formula area will grab selected variable and insert it at the end of the formula. Variables are column names from the "ImportedData" tab and need to be enclosed in brackets [variablename].

SPF Formula: [tot] = [years]*[AADT]*[length]*(365*(10^-6))*(exp(-0.312)*[CMFs]

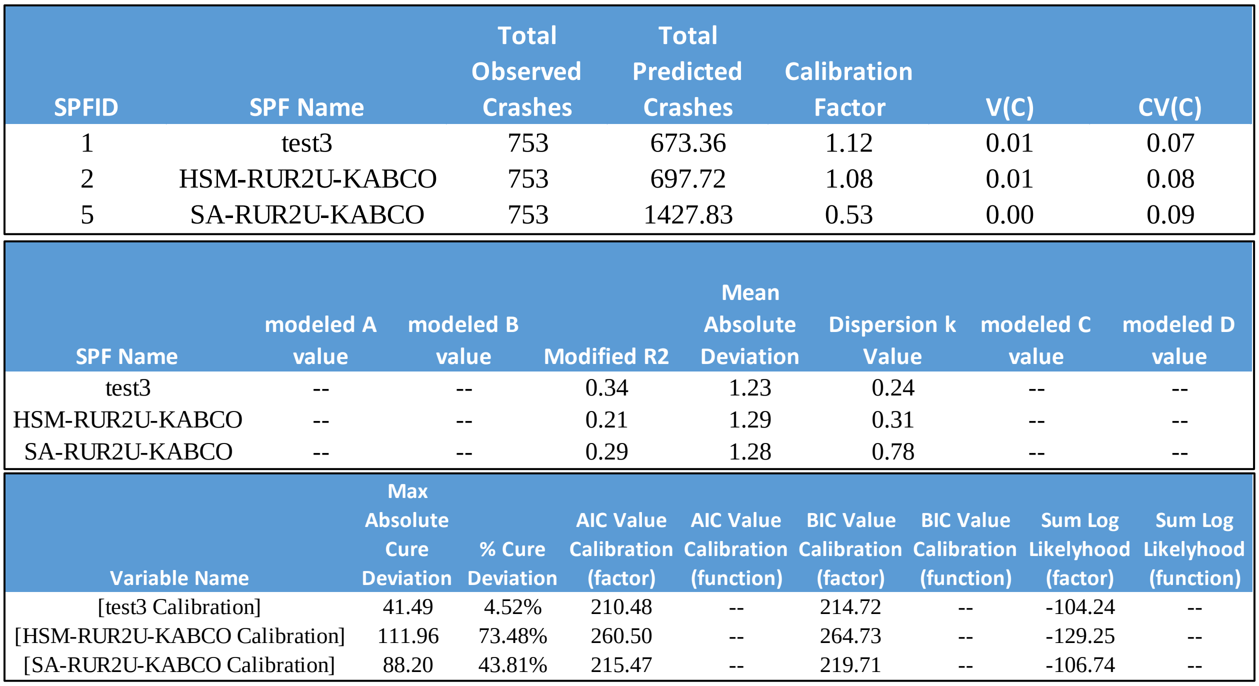
☐ Constant
☑ Constant / Length
☐ Modeled (k=c*length^d)

Length Variable: [length]

Figure 51. Image. Editing predefined HSM SPF for example 3.

The next step is to calibrate the SPFs. Users can calibrate the three SPFs simultaneously by holding ‘CTRL’ and selecting the SPFs of interest in the ‘Available SPFs’ box, and then clicking ‘Estimate Calibration Factors’ or ‘Estimate Calibration Functions’ in the lower right of the ‘Define Variables’ tab. In this example, the analyst first selects ‘Estimate Calibration Factors.’

Figure 52 presents the results of the calibration for a constant calibration factor. The calibration factor indicates the uncalibrated State X (test3) and HSM SPFs slightly under-predict crashes while the uncalibrated AASHTOWare Safety Analyst™ SPF over-predicts crashes. The State X (test3) and HSM calibration factors increase predictions by 12 percent and 8 percent, respectively, and the AASHTOWare Safety Analyst™ calibration factor reduces predictions by approximately 50 percent. The modified R^2 values are relatively low, but the MAD and dispersion parameters indicate a reasonable fit to the data. The CV(C) values are less than 0.15, indicating the calibration factors are reasonably accurate, and the user may consider the calibrated SPFs for application. The percent of ordinates exceeding the two standard deviation limits is less than five percent for the State X (test3) SPF, indicating a good fit. The percent of ordinates exceeding the two standard deviation limits is much greater than five percent for the HSM and AASHTOWare Safety Analyst™ SPFs, indicating some bias in the predictions. Comparing the AIC, BIC, and sum of log likelihood, the values suggest the State X SPF is slightly preferred.



SPFID	SPF Name	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	V(C)	CV(C)
1	test3	753	673.36	1.12	0.01	0.07
2	HSM-RUR2U-KABCO	753	697.72	1.08	0.01	0.08
5	SA-RUR2U-KABCO	753	1427.83	0.53	0.00	0.09

SPF Name	modeled A value	modeled B value	Modified R2	Mean Absolute Deviation	Dispersion k Value	modeled C value	modeled D value
test3	--	--	0.34	1.23	0.24	--	--
HSM-RUR2U-KABCO	--	--	0.21	1.29	0.31	--	--
SA-RUR2U-KABCO	--	--	0.29	1.28	0.78	--	--

Variable Name	Max Absolute Cure Deviation	% Cure Deviation	AIC Value Calibration (factor)	AIC Value Calibration (function)	BIC Value Calibration (factor)	BIC Value Calibration (function)	Sum Log Likelyhood (factor)	Sum Log Likelyhood (function)
[test3 Calibration]	41.49	4.52%	210.48	--	214.72	--	-104.24	--
[HSM-RUR2U-KABCO Calibration]	111.96	73.48%	260.50	--	264.73	--	-129.25	--
[SA-RUR2U-KABCO Calibration]	88.20	43.81%	215.47	--	219.71	--	-106.74	--

Figure 52. Image. Calibration results for example 3 (based on calibration factor).

The Calibrator automatically generates the CURE plots for fitted values and displays the plots on the Cure Plots tab. Figure 53 through Figure 55 show the CURE plots for fitted values for Example 3. The CURE plot for fitted values for the State X (test3) SPF indicates a reasonable goodness-of-fit to the data with few cumulative residuals straying outside the two standard deviation confidence limits. The sharp increase near fitted values of 4.0 indicate a potential outlier in the data. By contrast, the CURE plots for fitted values for the AASHTOWare Safety Analyst™ and HSM SPFs stray outside the two standard deviation confidence limits for a substantial portion of the plot, indicating bias in the SPF predictions.

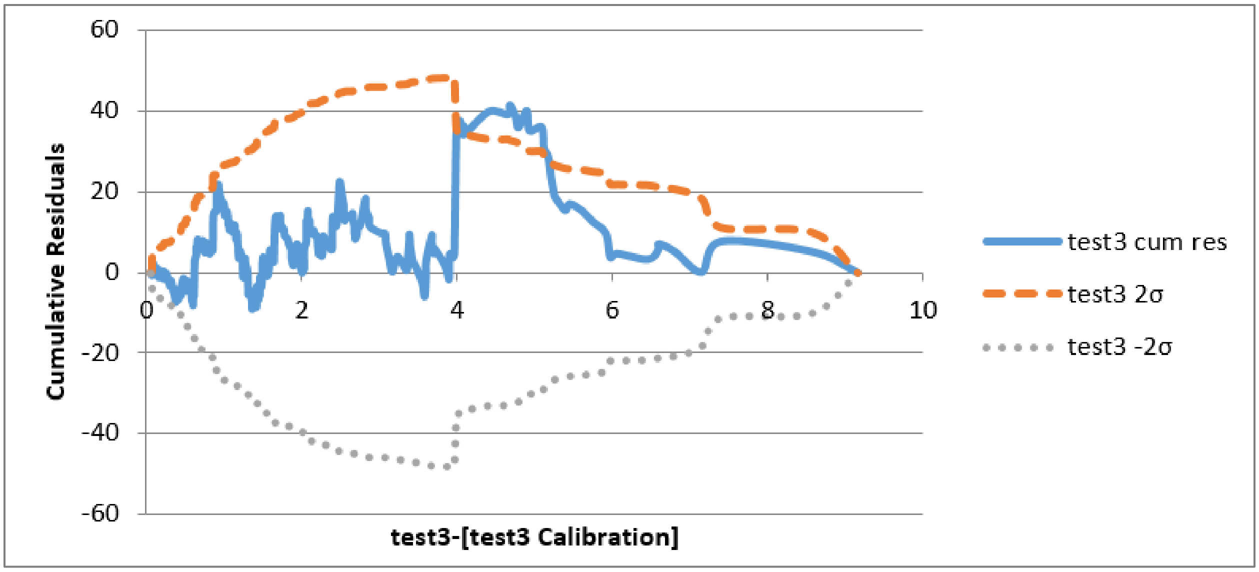


Figure 53. Image. State X CURE plot for fitted (calibrated) values for example 3 (based on constant calibration factor).

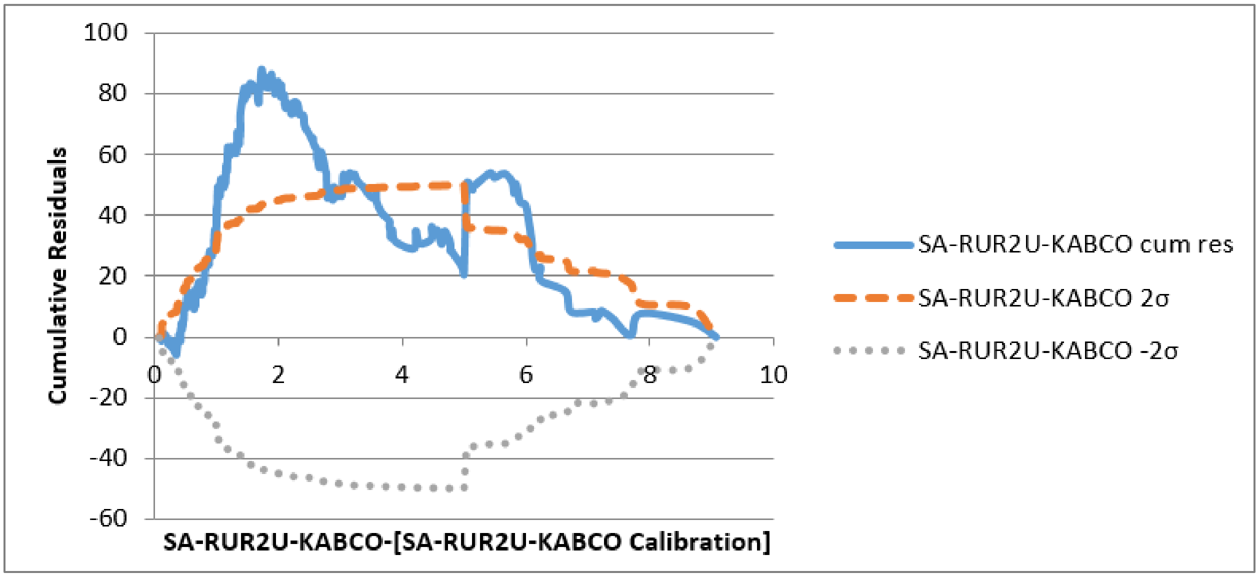


Figure 54. Image. AASHTOWare Safety Analyst™ CURE plot for fitted (calibrated) values for example 3 (based on constant calibration factor).

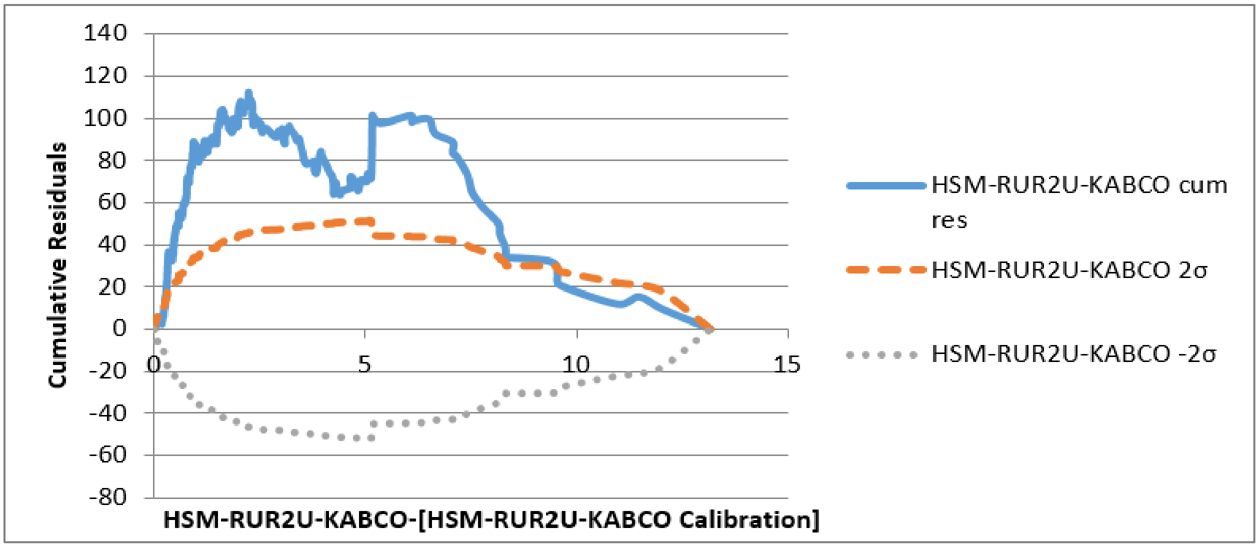
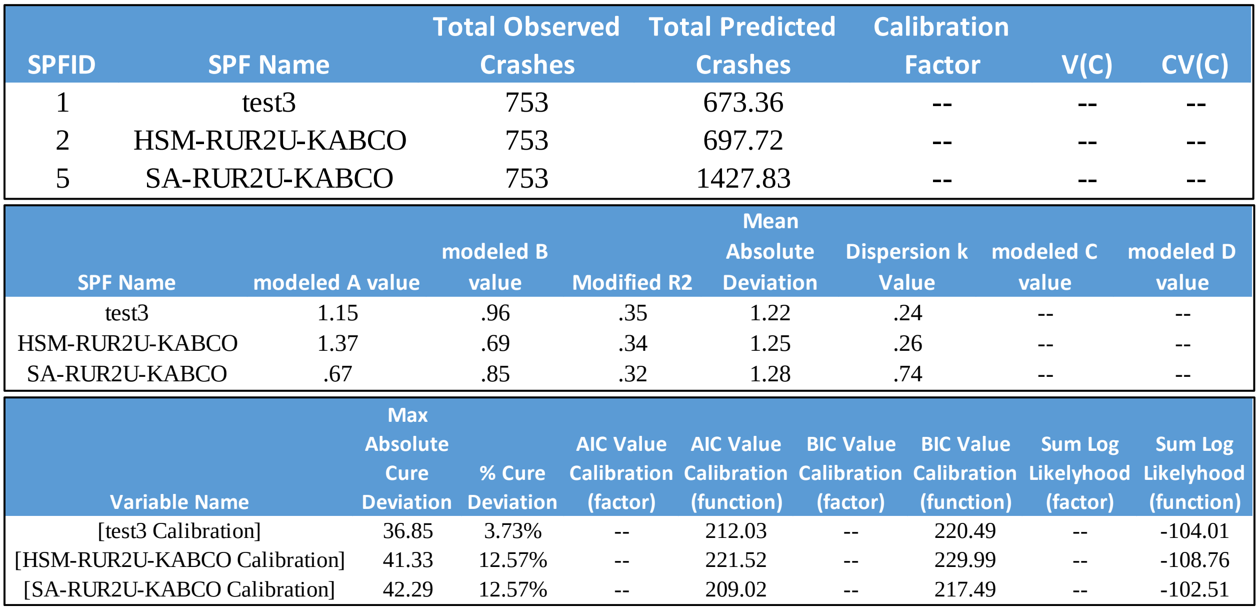


Figure 55. Image. HSM CURE plot for fitted (calibrated) values for example 3 (based on constant calibration factor).

Figure 56 through Figure 59 show equivalent results to Figure 52 through Figure 55, but this is based on a calibration function instead of a calibration factor. To estimate a calibration function, start on the 'Define Variables' tab, select the SPFs of interest, and click on 'Estimate Calibration Function' in the lower right. All assessment measures for the AASHTOWare Safety Analyst™ and HSM calibrated SPFs indicate a marked improvement after calibrating a function rather than a factor. This is particularly true for the HSM SPF, which now slightly outperforms the AASHTOWare Safety Analyst™ SPF for modified R^2, mean absolute deviation, and maximum absolute cure deviation. The assessment measures remain similar for the calibrated State X SPF after calibrating a function rather than a factor.



SPFID	SPF Name	Total Observed Crashes	Total Predicted Crashes	Calibration Factor	V(C)	CV(C)
1	test3	753	673.36	--	--	--
2	HSM-RUR2U-KABCO	753	697.72	--	--	--
5	SA-RUR2U-KABCO	753	1427.83	--	--	--

SPF Name	modeled A value	modeled B value	Modified R2	Mean Absolute Deviation	Dispersion k Value	modeled C value	modeled D value
test3	1.15	.96	.35	1.22	.24	--	--
HSM-RUR2U-KABCO	1.37	.69	.34	1.25	.26	--	--
SA-RUR2U-KABCO	.67	.85	.32	1.28	.74	--	--

Variable Name	Max Absolute Cure Deviation	% Cure Deviation	AIC Value Calibration (factor)	AIC Value Calibration (function)	BIC Value Calibration (factor)	BIC Value Calibration (function)	Sum Log Likelyhood (factor)	Sum Log Likelyhood (function)
[test3 Calibration]	36.85	3.73%	--	212.03	--	220.49	--	-104.01
[HSM-RUR2U-KABCO Calibration]	41.33	12.57%	--	221.52	--	229.99	--	-108.76
[SA-RUR2U-KABCO Calibration]	42.29	12.57%	--	209.02	--	217.49	--	-102.51

Figure 56. Image. Calibration results for example 3 (based on calibration function).

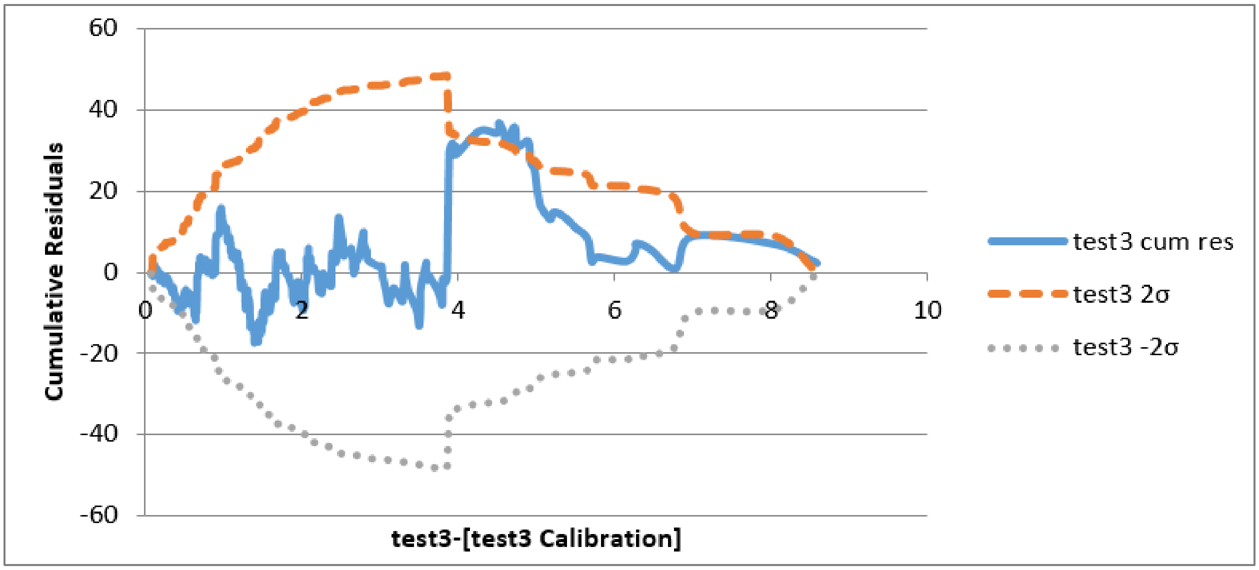


Figure 57. Image. State X CURE plot for fitted (calibrated) values for example 3 (based on calibration function).

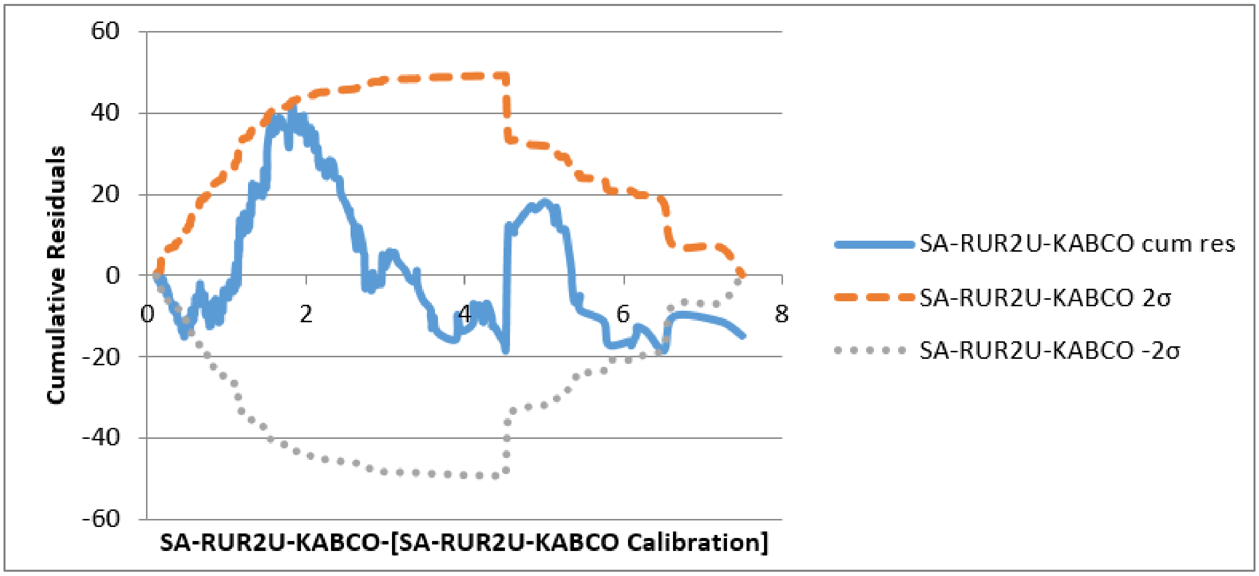


Figure 58. Image. AASHTOWare Safety Analyst™ CURE plot for fitted (calibrated) values for example 3 (based on calibration function).

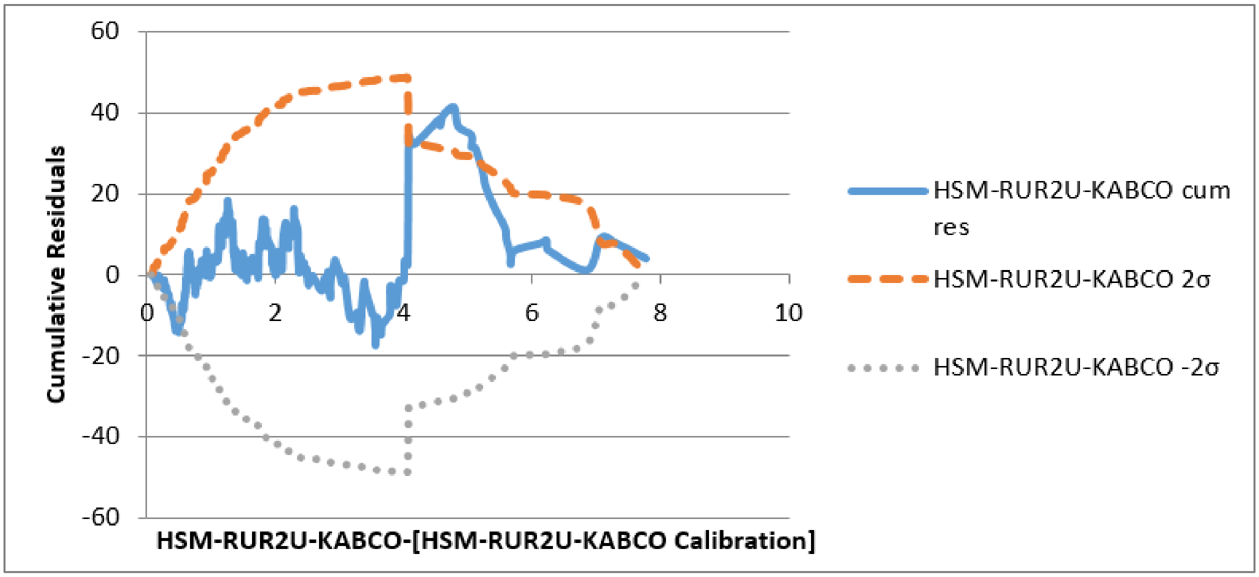


Figure 59. Image. HSM CURE plot for fitted (calibrated) values for example 3 (based on calibration function).

If the analyst desires additional CURE plots to further test the goodness-of-fit, they can go to the ‘Assessments Tab,’ select the variable(s) of interest from the variable list, select the SPF(s) of interest from the list of available SPFs, and click ‘Generate Graphs.’

The final step is to compare and select an appropriate SPF by 1) determining which of the SPFs, if any, are suitable, and 2) selecting which of the suitable SPFs is most appropriate for the given dataset. Recall from the section, *Summary of SPF Assessment*, an SPF with a constant calibration factor is acceptable if either of the following conditions is met:

1) Five percent or less of CURE plot ordinates for *fitted* values (after applying the calibration factor) exceed the 2σ limits, or
2) The CV of the constant calibration factor is less than 0.15.

Table 3 presents a summary of the calibration results for the three SPFs in question based on a constant calibration factor. Considering the percent CURE deviation, only the calibrated State X SPF is within the acceptable range of CURE plot ordinates for *fitted* values exceeding the 2σ limits. Considering the CV(C) parameter, the values for all three SPFs are less than the 0.15 threshold, indicating a reasonable goodness-of-fit. Based on the CV(C) parameter, the analyst may retain all three SPFs for further comparison.

Table 3. Comparison of multiple SPFs (based on calibration factor).

Parameter	State X	S.A.	HSM	Assessment
Observed crashes	753	753	753	--
Predicted crashes	673.4	1427.8	697.7	--
Calibration factor	1.12	0.53	**1.08**	Close to 1.0
V(C)	0.01	**0.00**	0.01	Smaller values preferred
CV(C)	**0.07**	0.09	0.08	Less than 0.15 preferred
Modified R^2	**0.34**	0.29	0.21	Larger values preferred
MAD	**1.23**	1.28	1.29	Smaller values preferred
Dispersion k	**0.24**	0.78	0.31	Smaller values preferred
Max Cure Deviation	**41.49**	88.20	111.96	Smaller values preferred
% Cure Deviation	**4.52%**	43.81%	73.48%	Less than 5% preferred
AIC	**210.48**	215.47	260.50	Smaller values preferred
BIC	**214.72**	219.71	264.73	Smaller values preferred

Note: **Bold** values indicate the preferred SPF for a given parameter.

Given that all three SPFs are suitable, it is appropriate to estimate a calibration function for each SPF. The analyst may deem the function preferable to the factor if the percent of CURE plot ordinates for *fitted* values (after applying the unique calibration factors) exceeding the 2□limits is lower than that for the constant calibration factor.

Table 4 presents a summary of the calibration results for the three SPFs in question based on a calibration function. Considering the percent CURE deviation, the values improve for all three SPFs, indicating the function is preferable to the factor. The final step is to compare the relative performance of all suitable SPFs. The final column of the table indicates the preferred values for each parameter if applicable. The State X (test3) SPF performs best with respect to five of the seven measures (i.e., modified R^2, MAD, dispersion (k), max CURE deviation, and percent CURE deviation). Based on these results, the State X (test3) SPF is the preferred SPF for application.

Table 4. Comparison of multiple SPFs (based on calibration function).

Parameter	State X	S.A.	HSM	Assessment
Observed crashes	753	753	753	--
Predicted crashes	673.4	1427.8	697.7	--
Modeled A value	1.15	0.67	1.37	--
Modeled B value	0.96	0.85	0.69	--
Modified R^2	**0.35**	0.32	0.34	Larger values preferred
MAD	**1.22**	1.28	1.25	Smaller values preferred
Dispersion k	**0.24**	0.74	0.26	Smaller values preferred
Max Cure Deviation	**36.85**	42.29	41.33	Smaller values preferred
% Cure Deviation	**3.73%**	12.57%	12.57%	Less than 5% preferred
AIC	212.03	**209.02**	221.52	Smaller values preferred
BIC	220.49	**217.49**	229.99	Smaller values preferred

Note: **Bold** values indicate the preferred SPF for a given parameter.

APPENDIX: PREDEFINED SPFS

This appendix presents the predefined SPFs included in the related spreadsheet tool. Section A.1 presents the base condition SPFs from the HSM for two-lane rural roads, multilane rural roads, urban and suburban arterials, and freeways. Section A.2 presents the SPFs from AASHTOWare Safety Analyst™.

A.1. HSM BASE CONDITION SPFS

This section documents the base SPFs in the first edition of the HSM. These SPFs are already available in the spreadsheet tool (see predefined SPFs). The tool does not include the associated CMFs, and users of the tool can add CMFs as desired. Each subsection below presents the name of the predefined SPF in parentheses.

Note: In order to apply the SPFs in the spreadsheet tool, the variable names for the imported data will need to match those used in the predefined SPFs and documented here.

A.1.1 Two-Lane Rural Road Chapter

Error! Reference source not found. through **Error! Reference source not found.** provide SPFs for rural two-lane segments and intersections. The dispersion parameter is equal to k divided by segment length for the segment SPF and is equal to k for intersection SPFs. The following variable definitions apply to all SPFs in this subsection:

- length = segment length in miles.
- AADT = average annual daily traffic on road segment.
- AADTMAJ = average annual daily traffic on major road.
- AADTMIN = average annual daily traffic on minor road.

$$Total\ Crashes = years * AADT * length * 365x10^{-6} exp^{-0.312}$$

Figure 60. Equation. SPF for segments (HSM-RUR2U-KABCO).

$$Total\ Crashes = years * exp^{-9.86} AADTMAJ^{0.79} AADTMIN^{0.49}$$

Figure 61. Equation. SPF for three-leg STOP controlled intersections (HSM-RUR2-3ST-KABCO).

$$Total\ Crashes = years * exp^{-8.56} AADTMAJ^{0.60} AADTMIN^{0.61}$$

Figure 62. Equation. SPF for four-leg STOP controlled intersections (HSM-RUR2-4ST-KABCO).

$$Total\ Crashes = years * exp^{-5.13} AADTMAJ^{0.60} AADTMIN^{0.20}$$

Figure 63. Equation. SPF for four-leg signalized intersections (HSM-RUR2-4SG-KABCO).

A.1.2 Multi-Lane Rural Road Chapter

Error! Reference source not found. through **Error! Reference source not found.** provide SPFs for rural multilane undivided segments. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for rural multilane divided segments. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for three-leg STOP controlled intersections. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for four-leg STOP controlled intersections. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for four-leg signalized intersections. The dispersion parameter is equal to k divided by segment length for all segment SPFs. The dispersion parameter is equal to k for all intersection SPFs. The following variable definitions apply to all SPFs in this subsection:

- length = segment length in miles
- AADT = average annual daily traffic on road segment
- AADTMAJ = average annual daily traffic on major road
- AADTMIN = average annual daily traffic on minor road

4 Lane Undivided Segments

$$Total\ Crashes = years * exp^{-9.653} * length * AADT^{1.176}$$

Figure 64. Equation. SPF for total crashes (HSM-RUR4U-KABCO).

$$KABC\ Crashes = years * exp^{-9.410} * length * AADT^{1.094}$$

Figure 65. Equation. SPF for KABC crashes (HSM-RUR4U-KABC).

$$KAB\ Crashes = years * exp^{-8.577} * length * AADT^{0.938}$$

Figure 66. Equation. SPF for KAB crashes (HSM-RUR4U-KAB).

4 Lane Divided Segments

$$Total\ Crashes = years * exp^{-9.025} * length * AADT^{1.049}$$

Figure 67. Equation. SPF for total crashes (HSM-RUR4D-KABCO).

$$KABC\ Crashes = years * exp^{-8.837} * length * AADT^{0.958}$$

Figure 68. Equation. SPF for KABC crashes (HSM-RUR4D-KABC).

$$KAB\ Crashes = years * exp^{-8.505} * length * AADT^{0.874}$$

Figure 69. Equation. SPF for KAB crashes (HSM-RUR4D-KAB).

Three-leg STOP Controlled Intersections

$$Total\ Crashes = years * exp^{-12.526} AADTMAJ^{1.204} AADTMIN^{0.236}$$

Figure 70. Equation. SPF for total crashes (HSM-RUR4-3ST-KABCO).

$$KABC\ Crashes = years * exp^{-12.664} AADTMAJ^{1.107} AADTMIN^{0.272}$$

Figure 71. Equation. SPF for KABC crashes (HSM-RUR4-3ST-KABC).

$$KABC\ Crashes = years * exp^{-11.989} AADTMAJ^{1.013} AADTMIN^{0.228}$$

Figure 72. Equation. SPF for KAB crashes (HSM-RUR4-3ST-KAB).

Four-leg STOP Controlled Intersections

$$Total\ Crashes = years * exp^{-10.008} AADTMAJ^{0.848} AADTMIN^{0.448}$$

Figure 73. Equation. SPF for total crashes (HSM-RUR4-4ST-KABCO).

$$KABC\ Crashes = years * exp^{-11.554} AADTMAJ^{0.888} AADTMIN^{0.525}$$

Figure 74. Equation. SPF for KABC crashes (HSM-RUR4-4ST-KABC).

$$KABC\ Crashes = years * exp^{-10.734} AADTMAJ^{0.828} AADTMIN^{0.412}$$

Figure 75. Equation. SPF for KAB crashes (HSM-RUR4-4ST-KAB).

Four-leg Signalized Intersections

$$Total\ Crashes = years * exp^{-7.182} AADTMAJ^{0.722} AADTMIN^{0.337}$$

Figure 76. Equation. SPF for total crashes (HSM-RUR4-4SG-KABCO).

$$KABC\ Crashes = years * exp^{-6.393} AADTMAJ^{0.638} AADTMIN^{0.232}$$

Figure 77. Equation. SPF for KABC crashes (HSM-RUR4-4SG-KABC).

$$KAB\ Crashes = years * exp^{-12.011} (AADTMAJ + AADTMIN)^{1.279}$$

Figure 78. Equation. SPF for KAB crashes (HSM-RUR4-4SG-KAB).

A.1.3 Urban and Suburban Arterials Chapter

Error! Reference source not found. through **Error! Reference source not found.** provide SPFs for urban and suburban arterial segment crashes. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for urban and suburban arterial intersection crashes. The dispersion parameter is equal to k for all SPFs. The following are relevant site types for urban and suburban arterials:

- 2U – two-lane undivided
- 3T – 3-lane with two-way left-turn lane
- 4U – 4-lane undivided
- 4D – 4-lane divided
- 5T – 5-lane with two-way left-turn lane
- 3ST – 3-leg STOP-controlled
- 3SG – 3-leg Signalized
- 4ST – 4-leg STOP-controlled
- 4SG – 4-leg Signalized

The following variable definitions apply to all SPFs in this subsection:

- length = segment length in miles
- AADT = average annual daily traffic on road segment
- AADTMAJ = average annual daily traffic on major road
- AADTMIN = average annual daily traffic on minor road
- MAJCOMM = count of major commercial driveways
- MINCOMM = count of minor commercial driveways
- MAJIND = count of major industrial driveways
- MININD = count of minor industrial driveways
- MAJRES = count of major residential driveways
- MINRES = count of minor residential driveways
- OTHER = count of other driveways

Multiple-Vehicle Non-Driveway Segment Crashes

$$MVNONDWY\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 79. Equation. SPF for MVNONDWY crashes.

$$KABC\ MVNONDWY\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 80. Equation. SPF for KABC MVNONDWY crashes.

$$PDO\ MVNONDWY\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 81. Equation. SPF for PDO MVNONDWY crashes.

Error! Reference source not found. presents the coefficients for multiple-vehicle non-driveway segment SPFs.

Table 5. Coefficients for multiple-vehicle non-driveway segment SPFs.

SPF ID	Road Type	Crash Severity Level	a	b
HSM-URB2U-MVNONDWY-KABCO	2U	Total	-15.22	1.68
HSM-URB2U-MVNONDWY-KABC	2U	KABC	-16.22	1.66
HSM-URB2U- MVNONDWY-PDO	2U	PDO	-15.62	1.69
HSM-URB3T- MVNONDWY-KABCO	3T	Total	-12.4	1.41
HSM-URB3T- MVNONDWY-KABC	3T	KABC	-16.45	1.69
HSM-URB3T- MVNONDWY-PDO	3T	PDO	-11.95	1.33
HSM-URB4U MVNONDWY—KABCO	4U	Total	-11.63	1.33
HSM-URB4U- MVNONDWY-KABC	4U	KABC	-12.08	1.25
HSM-URB4U- MVNONDWY-PDO	4U	PDO	-12.53	1.38
HSM-URB4D- MVNONDWY-KABCO	4D	Total	-12.34	1.36
HSM-URB4D- MVNONDWY-KABC	4D	KABC	-12.76	1.28
HSM-URB4D- MVNONDWY-PDO	4D	PDO	-12.81	1.38
HSM-URB5T- MVNONDWY-KABCO	5T	Total	-9.7	1.17
HSM-URB5T- MVNONDWY-KABC	5T	KABC	-10.47	1.12
HSM-URB5T- MVNONDWY-PDO	5T	PDO	-9.97	1.17

Single-Vehicle Segment Crashes

$$SV\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 82. Equation. SPF for SV crashes.

$$KABC\ SV\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 83. Equation. SPF for KABC SV crashes.

$$PDO\ SV\ Crashes = years * exp^{a} * length * AADT^{b}$$

Figure 84. Equation. SPF for PDO SV crashes.

Error! Reference source not found. provides the coefficients for single-vehicle segment SPFs.

Table 6. Coefficients for single-vehicle segment SPFs.

SPF ID	Road Type	Crash Severity Level	a	b
HSM-URB2U-SV-KABCO	2U	Total	-5.47	0.56
HSM-URB2U-SV-KABC	2U	KABC	-3.96	0.23
HSM-URB2U- SV-PDO	2U	PDO	-6.51	0.64
HSM-URB3T- SV-KABCO	3T	Total	-5.74	0.54
HSM-URB3T- SV-KABC	3T	KABC	-6.37	0.47
HSM-URB3T- SV-PDO	3T	PDO	-6.29	0.56
HSM-URB4U SV--KABCO	4U	Total	-7.99	0.81
HSM-URB4U- SV-KABC	4U	KABC	-7.37	0.61
HSM-URB4U- SV-PDO	4U	PDO	-8.5	0.84
HSM-URB4D- SV-KABCO	4D	Total	-5.05	0.47
HSM-URB4D- SV-KABC	4D	KABC	-8.71	0.66
HSM-URB4D- SV-PDO	4D	PDO	-5.04	0.45
HSM-URB5T- SV-KABCO	5T	Total	-4.82	0.54
HSM-URB5T- SV-KABC	5T	KABC	-4.43	0.35
HSM-URB5T- SV-PDO	5T	PDO	-5.83	0.61

Multiple-Vehicle Driveway-Related Segment Crashes

$$
\begin{aligned}
MVDWY\ Crashes = {} & years \\
& * f * \left(\frac{AADT}{15{,}000}\right)^{a} (b * MAJCOMM + c * MINCOMM + d * MAJIND + e * MININD + f * MAJRES + g * MINRES + h \\
& * OTHER)
\end{aligned}
$$

Figure 85. Equation. SPF for MVDWY crashes.

$$
\begin{aligned}
& KABC\ MVDWY\ Crashes \\
& \quad = years \\
& \quad * f * \left(\frac{AADT}{15{,}000}\right)^{a} (b * MAJCOMM + c * MINCOMM + d * MAJIND + e * MININD + f * MAJRES + g * MINRES + h \\
& \quad * OTHER)
\end{aligned}
$$

Figure 86. Equation. SPF for KABC MVDWY crashes.

$$
\begin{aligned}
PDO_{\scriptscriptstyle MVDWY}\ Crashes = {} & years \\
& * f * \left(\frac{AADT}{15{,}000}\right)^{a} (b * MAJCOMM + c * MINCOMM + d * MAJIND + e * MININD + f * MAJRES + g * MINRES + h \\
& * OTHER)
\end{aligned}
$$

Figure 87. Equation. SPF for PDO MVDWY crashes.

Error! Reference source not found. provides the coefficients for multiple-vehicle driveway-related segment SPFs.

Table 7. Coefficients for multiple-vehicle driveway-related segment SPFs.

SPF ID	Road Type	Crash Severity Level	f	a	b	c	d	e	f	g	h
HSM-URB2U-MVDWY-KABCO	2U	Total	1.000	1.000	0.158	0.050	0.172	0.023	0.083	0.016	0.025
HSM-URB2U-MVDWY-KABC	2U	KABC	0.323	1.000	0.158	0.050	0.172	0.023	0.083	0.016	0.025
HSM-URB2U-MVDWY-PDO	2U	PDO	0.677	1.000	0.158	0.050	0.172	0.023	0.083	0.016	0.025
HSM-URB3T-MVDWY-KABCO	3T	Total	1.000	1.000	0.102	0.032	0.110	0.015	0.053	0.010	0.016
HSM-URB3T-MVDWY-KABC	3T	KABC	0.243	1.000	0.102	0.032	0.110	0.015	0.053	0.010	0.016
HSM-URB3T-MVDWY-PDO	3T	PDO	0.757	1.000	0.102	0.032	0.110	0.015	0.053	0.010	0.016
HSM-URB4U-MVDWY-KABCO	4U	Total	1.000	1.172	0.182	0.058	0.198	0.026	0.096	0.018	0.029
HSM-URB4U-MVDWY-KABC	4U	KABC	0.342	1.172	0.182	0.058	0.198	0.026	0.096	0.018	0.029
HSM-URB4U-MVDWY-PDO	4U	PDO	0.658	1.172	0.182	0.058	0.198	0.026	0.096	0.018	0.029
HSM-URB4D-MVDWY-KABCO	4D	Total	1.000	1.106	0.033	0.011	0.036	0.005	0.018	0.003	0.005

SPF ID	Road Type	Crash Severity Level	f	a	b	c	d	e	f	g	h
HSM-URB4D-MVDWY-KABC	4D	KABC	0.284	1.106	0.033	0.011	0.036	0.005	0.018	0.003	0.005
HSM-URB4D-MVDWY-PDO	4D	PDO	0.716	1.106	0.033	0.011	0.036	0.005	0.018	0.003	0.005
HSM-URB5T-MVDWY-KABCO	5T	Total	1.000	1.172	0.165	0.053	0.181	0.024	0.087	0.016	0.027
HSM-URB5T-MVDWY-KABC	5T	KABC	0.269	1.172	0.165	0.053	0.181	0.024	0.087	0.016	0.027
HSM-URB5T-MVDWY-PDO	5T	PDO	0.731	1.172	0.165	0.053	0.181	0.024	0.087	0.016	0.027

Multiple-Vehicle Intersection Crashes

$$MVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 88. Equation. SPF for MVINT crashes.

$$KABC\ MVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 89. Equation. SPF for KABC MVINT crashes.

$$PDO\ MVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 90. Equation. SPF for PDO MVINT crashes.

Error! Reference source not found. provides the coefficients for multiple-vehicle intersection SPFs.

Table 8. Coefficients for multiple-vehicle intersection SPFs.

SPF ID	Road Type	Crash Severity Level	a	b	c
HSM-URB3ST-MV-KABCO	3ST	Total	-13.36	1.11	0.41
HSM- URB 3ST-MV-KABC	3ST	KABC	-14.01	1.16	0.30
HSM- URB 3ST-MV-PDO	3ST	PDO	-15.38	1.2	0.51
HSM- URB 3SG-MV-KABCO	3SG	Total	-12.13	1.11	0.26
HSM- URB 3SG-MV-KABC	3SG	KABC	-11.58	1.02	0.17
HSM- URB 3SGMV-PDO	3SG	PDO	-13.24	1.14	0.30
HSM- URB 4ST-MV-KABCO	4ST	Total	-8.9	0.82	0.25
HSM- URB 4ST-MV-KABC	4ST	KABC	-11.13	0.93	0.28
HSM- URB 4ST-MV-PDO	4ST	PDO	-8.74	0.77	0.23
HSM- URB 4SG-MV-KABCO	4SG	Total	-10.99	1.07	0.23
HSM- URB 4SG-MV-KABC	4SG	KABC	-13.14	1.18	0.22
HSM- URB 4SG-MV-PDO	4SG	PDO	-11.02	1.02	0.24

Single-Vehicle Intersection Crashes

$$SVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 91. Equation. SPF for SVINT crashes.

$$KABC\ SVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 92. Equation. SPF for KABC SVINT crashes.

$$PDO\ SVINT\ Crashes = years * exp^{a} * AADTMAJ^{b} * AADTMIN^{C}$$

Figure 93. Equation. SPF for PDO SVINT crashes.

Error! Reference source not found. provides the coefficients for single-vehicle intersection SPFs.

Table 9. Coefficients for single-vehicle intersection SPFs.

SPF ID	Road Type	Crash Severity Level	a	b	c
HSM- URB 3ST-SV-KABCO	3ST	Total	-6.81	0.16	0.51
HSM- URB 3ST-SV-PDO	3ST	PDO	-8.36	0.25	0.55
HSM- URB 3SG-SV-KABCO	3SG	Total	-9.02	0.42	0.40
HSM- URB 3SG-SV-KABC	3SG	KABC	-9.75	0.27	0.51
HSM- URB 3SG-SV-PDO	3SG	PDO	-9.08	0.45	0.33
HSM- URB 4ST-SV-KABCO	4ST	Total	-5.33	0.33	0.12
HSM- URB 4ST-SV-PDO	4ST	PDO	-7.04	0.36	0.25
HSM- URB 4SG-SV-KABCO	4SG	Total	-10.21	0.68	0.27
HSM- URB 4SG-SV-KABC	4SG	KABC	-9.25	0.43	0.29
HSM- URB 4SG-SV-PDO	4SG	PDO	-11.34	0.78	0.25

A.1.3 Freeway Chapter

The freeway SPFs are not in the first edition of the HSM, but are planned for inclusion in the second edition. The final report for NCHRP Project 17-45 documents these SPFs in detail.

Error! Reference source not found. through **Error! Reference source not found.** provide SPFs freeway segment and speed change lane crashes. The dispersion parameter is equal to k divided by segment length for **Error! Reference source not found.** through **Error! Reference source not found.**. The dispersion parameter is equal to k for **Error! Reference source not found.** and **Error! Reference source not found.**. **Error! Reference source not found.** through **Error! Reference source not found.** provide SPFs for ramp segments. The dispersion parameter is equal to k divided by ramp length for all SPFs. **Error! Reference source not found.** and **Error! Reference source not found.** provide SPFs for ramp terminals. The dispersion parameter is equal to k for both SPFs. The following variables definitions apply to all SPFs in this subsection:

- L^* = effective length of freeway segment miles (see NCHRP report for details on how to calculate)
- L_{en} =length of ramp entrance
- L_{ex} =length of ramp exit
- L_R =length of ramp
- AADT = Average Annual Daily Traffic on road segment
- $AADT_r$ = Average Annual Daily Traffic on ramp segment
- $AADT_{xrd}$ = Average Annual Daily Traffic on crossroad, equal to $(AADT_{in} + AADT_{out})/2$
- $AADT_{in}$ = Average Annual Daily Traffic for crossroad leg between ramps
- $AADT_{out}$ = Average Annual Daily Traffic for crossroad leg outside interchange
- $AADT_{ex}$ = Average Annual Daily Traffic for exit ramp
- $AADT_{en}$ = Average Annual Daily Traffic for entrance ramp

Multiple-Vehicle Freeway Segment Crashes

$$KABC\ MV\ Crashes = years * L^{*}exp^{a} * \left(\frac{AADT}{1{,}000}\right)^{b}$$

Figure 94. Equation. SPF for freeway KABC MV crashes.

$$PDO\ MV\ Crashes = years * L^{*}exp^{a} * \left(\frac{AADT}{1{,}000}\right)^{b}$$

Figure 95. Equation. SPF for freeway PDO MV crashes.

Error! Reference source not found. provides the coefficients for multiple-vehicle freeway segment SPFs.

Table 10. Coefficients for multiple-vehicle freeway segment SPFs.

SPF ID	Area Type	Number of Through Lanes	Crash Severity Level	a	b
HSM-RURFWY4-MV-KABC	Rural	4	KABC	-5.975	1.492
HSM-RURFWY6-MV-KABC	Rural	6	KABC	-6.092	1.492
HSM-RURFW8-MV-KABC	Rural	8	KABC	-6.140	1.492
HSM-URBFWY4-MV-KABC	Urban	4	KABC	-5.470	1.492
HSM-URBFWY6-MV-KABC	Urban	6	KABC	-5.587	1.492
HSM-URBFWY8-MV-KABC	Urban	8	KABC	-5.635	1.492
HSM-URBFWY10-MV-KABC	Urban	10	KABC	-5.842	1.492
HSM-RURFWY4-MV-O	Rural	4	PDO	-6.880	1.936
HSM-RURFWY6-MV-O	Rural	6	PDO	-7.141	1.936
HSM-RURFW8-MV-O	Rural	8	PDO	-7.329	1.936
HSM-URBFWY4-MV-O	Urban	4	PDO	-6.548	1.936
HSM-URBFWY6-MV-O	Urban	6	PDO	-6.809	1.936
HSM-URBFWY8-MV-O	Urban	8	PDO	-6.997	1.936
HSM-URBFWY10-MV-O	Urban	10	PDO	-7.260	1.936

Single-Vehicle Freeway Segment Crashes

$$KABC\ SV\ Crashes = years * L^{*}exp^{a} * \left(\frac{AADT}{1{,}000}\right)^{b}$$

Figure 96. Equation. SPF for freeway KABC SV crashes.

$$PDO\ SV\ Crashes = years * L^{*}exp^{a} * \left(\frac{AADT}{1{,}000}\right)^{b}$$

Figure 97. Equation. SPF for freeway PDO SV crashes.

Error! Reference source not found. provides the coefficients for single-vehicle freeway segment SPFs.

Table 11. Coefficients for single-vehicle freeway segment SPFs.

SPF ID	Area Type	Number of Through Lanes	Crash Severity Level	a	b
HSM-RURFWY4-SV-KABC	Rural	4	KABC	-2.126	0.646
HSM-RURFWY6-SV-KABC	Rural	6	KABC	-2.055	0.646
HSM-RURFW8-SV-KABC	Rural	8	KABC	-1.985	0.646
HSM-URBFWY4-SV-KABC	Urban	4	KABC	-2.126	0.646
HSM-URBFWY6-SV-KABC	Urban	6	KABC	-2.055	0.646
HSM-URBFWY8-SV-KABC	Urban	8	KABC	-1.985	0.646
HSM-URBFWY10-SV-KABC	Urban	10	KABC	-1.915	0.646
HSM-RURFWY4-SV-O	Rural	4	PDO	-2.235	0.876
HSM-RURFWY6-SV-O	Rural	6	PDO	-2.274	0.876
HSM-RURFW8-SV-O	Rural	8	PDO	-2.312	0.876
HSM-URBFWY4-SV-O	Urban	4	PDO	-2.235	0.876
HSM-URBFWY6-SV-O	Urban	6	PDO	-2.274	0.876
HSM-URBFWY8-SV-O	Urban	8	PDO	-2.312	0.876
HSM-URBFWY10-SV-O	Urban	10	PDO	-2.351	0.876

Ramp Entrance Related Speed-Change Lanes Crashes

$$KABC\ Crashes = years * L_{ent}\, exp^{a} * \left(\frac{AADT}{2{,}000}\right)^{b}$$

Figure 98. Equation. SPF for ramp entrance KABC crashes.

$$PDO\ Crashes = years * L_{ent}\, exp^{a} * \left(\frac{AADT}{2{,}000}\right)^{b}$$

Figure 99. Equation. SPF for ramp entrance PDO crashes.

Error! Reference source not found. provides the coefficients for ramp entrance speed-change lane SPFs.

Table 12. Coefficients for ramp entrance speed-change lane SPFs.

SPF ID	Area Type	Number of Through Lanes	Crash Severity Level	a	b
HSM-RURFWY4-ENT-KABC	Rural	4	KABC	-3.894	1.173
HSM-RURFWY6-ENT-KABC	Rural	6	KABC	-4.154	1.173
HSM-RURFWY8-ENT-KABC	Rural	8	KABC	-4.414	1.173
HSM-URBFWY4-ENT-KABC	Urban	4	KABC	-3.714	1.173
HSM-URBFWY6-ENT-KABC	Urban	6	KABC	-3.974	1.173
HSM-URBFWY8- ENT-KABC	Urban	8	KABC	-4.234	1.173
HSM-URBFWY10- ENT-KABC	Urban	10	KABC	-4.494	1.173
HSM-RURFWY4- ENT-O	Rural	4	PDO	-2.895	1.215
HSM-RURFWY6- ENT-O	Rural	6	PDO	-3.097	1.215
HSM-RURFW8- ENT-O	Rural	8	PDO	-3.299	1.215
HSM-URBFWY4- ENT-O	Urban	4	PDO	-2.796	1.215
HSM-URBFWY6- ENT-O	Urban	6	PDO	-2.998	1.215
HSM-URBFWY8- ENT-O	Urban	8	PDO	-3.200	1.215
HSM-URBFWY10- ENT-O	Urban	10	PDO	-3.402	1.215

Ramp Exit Related Speed-Change Lanes Crashes

$$KABC\ Crashes = years * L_{ex} exp^{a} * \left(\frac{AADT}{2{,}000}\right)^{b}$$

Figure 100. Equation. SPF for ramp exit KABC crashes.

$$PDO\ Crashes = years * L_{ex} exp^{a} * \left(\frac{AADT}{2{,}000}\right)^{b}$$

Figure 101. Equation. SPF for ramp exit PDO crashes.

Error! Reference source not found. provides the coefficients for ramp exit speed-change lane SPFs.

Table 13. Coefficients for ramp exit speed-change lane SPFs.

SPF ID	Area Type	Number of Through Lanes	Crash Severity Level	a	b
HSM-RURFWY4-EXT-KABC	Rural	4	KABC	-2.679	0.903
HSM-RURFWY6-EXT-KABC	Rural	6	KABC	-2.679	0.903
HSM-RURFWY8-EXT-KABC	Rural	8	KABC	-2.679	0.903
HSM-URBFWY4-EXT-KABC	Urban	4	KABC	-2.679	0.903
HSM-URBFWY6-EXT-KABC	Urban	6	KABC	-2.679	0.903
HSM-URBFWY8- EXT-KABC	Urban	8	KABC	-2.679	0.903
HSM-URBFWY10- EXT-KABC	Urban	10	KABC	-2.679	0.903
HSM-RURFWY4- EXT-O	Rural	4	PDO	-1.798	0.932
HSM-RURFWY6- EXT-O	Rural	6	PDO	-1.798	0.932
HSM-RURFW8- EXT-O	Rural	8	PDO	-1.798	0.932
HSM-URBFWY4- EXT-O	Urban	4	PDO	-1.798	0.932
HSM-URBFWY6- EXT-O	Urban	6	PDO	-1.798	0.932
HSM-URBFWY8- EXT-O	Urban	8	PDO	-1.798	0.932
HSM-URBFWY10- EXT-O	Urban	10	PDO	-1.798	0.932

Multiple-Vehicle Crashes on Ramp Segments

$$KABC\ MV\ Crashes = years * L_R exp^{a} * \left(\frac{AADTr}{1{,}000}\right)^{b}\ exp^{\left(c*\frac{AADTr}{1{,}000}\right)}$$

Figure 102. Equation. SPF for ramp segment KABC MV crashes.

$$PDO\ MV\ Crashes = years * L_R exp^{a} * \left(\frac{AADTr}{1{,}000}\right)^{b}\ exp^{\left(c*\frac{AADTr}{1{,}000}\right)}$$

Figure 103. Equation. SPF for ramp segment PDO MV crashes.

Error! Reference source not found. provides the coefficients for multiple-vehicle ramp segment SPFs.

Table 14. Coefficients for multiple-vehicle ramp segment SPFs.

SPF ID	Area Type	Number of Ramp Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-RURRMP-ENT1-MV-KABC	Rural	1	Entrance	KABC	-5.226	0.524	0.0699
HSM-RURRMP-EXT1-MV-KABC	Rural	1	Exit	KABC	-6.692	0.524	0.0699
HSM-URBRMP-ENT1-MV-KABC	Urban	1	Entrance	KABC	-3.505	0.524	0.0699
HSM-URBRMP-EXT1-MV-KABC	Urban	1	Exit	KABC	-4.971	0.524	0.0699
HSM-URBRMP-ENT2-MV-KABC	Urban	2	Entrance	KABC	-3.023	0.524	0.0699
HSM-URBRMP-EXT2-MV-KABC	Urban	2	Exit	KABC	-4.489	0.524	0.0699
HSM-RURRMP-ENT1-MV-O	Rural	1	Entrance	PDO	-3.819	1.256	N/A
HSM-RURRMP-EXT1-MV-O	Rural	1	Exit	PDO	-4.851	1.256	N/A
HSM-URBRMP-ENT1-MV-O	Urban	1	Entrance	PDO	-3.819	1.256	N/A
HSM-URBRMP-EXT1-MV-O	Urban	1	Exit	PDO	-4.851	1.256	N/A
HSM-URBRMP-ENT2-MV-O	Urban	2	Entrance	PDO	-2.983	1.256	N/A
HSM-URBRMP-EXT2-MV-O	Urban	2	Exit	PDO	-4.015	1.256	N/A

Single-Vehicle Crashes on Ramp Segments

$$KABC\ SV\ Crashes = years * L_R exp^a * \left(\frac{AADTr}{1{,}000}\right)^b$$

Figure 104. Equation. SPF for ramp segment KABC SV crashes.

$$PDO\ SV\ Crashes = years * L_R exp^a * \left(\frac{AADTr}{1{,}000}\right)^b$$

Figure 105. Equation. SPF for ramp segment PDO SV crashes.

Error! Reference source not found. provides the coefficients for single-vehicle ramp segment SPFs.

Table 15. Coefficients for single-vehicle ramp segment SPFs.

SPF ID	Area Type	Number of Ramp Lanes	Ramp Type	Crash Severity Level	a	b
HSM-RURRMP-ENT1-SV-KABC	Rural	1	Entrance	KABC	-2.120	0.718
HSM-RURRMP-EXT1-SV-KABC	Rural	1	Exit	KABC	-1.799	0.718
HSM-URBRMP-ENT1-SV-KABC	Urban	1	Entrance	KABC	-1.966	0.718
HSM-URBRMP-EXT1-SV-KABC	Urban	1	Exit	KABC	-1.645	0.718
HSM-URBRMP-ENT2-SV-KABC	Urban	2	Entrance	KABC	-1.999	0.718
HSM-URBRMP-EXT2-SV-KABC	Urban	2	Exit	KABC	-1.678	0.718
HSM-RURRMP-ENT1-SV-O	Rural	1	Entrance	PDO	-1.946	0.689
HSM-RURRMP-EXT1-SV-O	Rural	1	Exit	PDO	-1.739	0.689
HSM-URBRMP-ENT1-SV-O	Urban	1	Entrance	PDO	-1.715	0.689
HSM-URBRMP-EXT1-SV-O	Urban	1	Exit	PDO	-1.508	0.689
HSM-URBRMP-ENT2-SV-O	Urban	2	Entrance	PDO	-1.400	0.689
HSM-URBRMP-EXT2-SV-O	Urban	2	Exit	PDO	-1.193	0.689

Crashes at Ramp Terminals

$$KABC\ MV\ Crashes = years * exp^{a} * \left(\frac{AADT_{xrd}}{1{,}000}\right)^{b} * \left(\frac{AADT_{ex}}{1{,}000} + \frac{AADT_{en}}{1{,}000}\right)^{c}$$

Figure 106. Equation. SPF for ramp terminal KABC MV crashes.

$$PDO\ MV\ Crashes = years * exp^{a} * \left(\frac{AADT_{xrd}}{1{,}000}\right)^{b} * \left(\frac{AADT_{ex}}{1{,}000} + \frac{AADT_{en}}{1{,}000}\right)^{c}$$

Figure 107. Equation. SPF for ramp terminal PDO MV crashes.

Error! Reference source not found. provides the coefficients for ramp terminal SPFs.

Table 16. Coefficients for ramp terminal SPFs.

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-SIGTERM1-2LN-KABC	2	Signalized 3 leg at Two-Quadrant Parclo A or B	KABC	-0.458	0.325	0.212
HSM-SIGTERM1-3LN-KABC	3	Signalized 3 leg at Two-Quadrant Parclo A or B	KABC	-0.298	0.325	0.212
HSM-SIGTERM1-4LN-KABC	4	Signalized 3 leg at Two-Quadrant Parclo A or B	KABC	-0.138	0.325	0.212
HSM-SIGTERM1-5LN-KABC	5	Signalized 3 leg at Two-Quadrant Parclo A or B	KABC	0.022	0.325	0.212
HSM-SIGTERM1-6LN-KABC	6	Signalized 3 leg at Two-Quadrant Parclo A or B	KABC	0.182	0.325	0.212
HSM-SIGTERM1-2LN-O	2	Signalized 3 leg at Two-Quadrant Parclo A or B	PDO	-1.537	0.592	0.516
HSM-SIGTERM1-3LN-O	3	Signalized 3 leg at Two-Quadrant Parclo A or B	PDO	-1.449	0.592	0.516
HSM-SIGTERM1-4LN-O	4	Signalized 3 leg at Two-Quadrant Parclo A or B	PDO	-1.361	0.592	0.516

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-SIGTERM1-5LN-O	5	Signalized 3 leg at Two-Quadrant Parclo A or B	PDO	-1.274	0.592	0.516
HSM-SIGTERM1-6LN-O	6	Signalized 3 leg at Two-Quadrant Parclo A or B	PDO	-1.186	0.592	0.516
HSM-SIGTERM2-2LN-KABC	2	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	KABC	-1.352	0.379	0.394
HSM-SIGTERM2-3LN-KABC	3	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	KABC	-1.192	0.379	0.394
HSM-SIGTERM2-4LN-KABC	4	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	KABC	-1.032	0.379	0.394
HSM-SIGTERM2-5LN-KABC	5	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	KABC	-0.872	0.379	0.394
HSM-SIGTERM2-6LN-KABC	6	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	KABC	-0.712	0.379	0.394
HSM-SIGTERM2-2LN-O	2	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	PDO	-2.247	0.797	0.384
HSM-SIGTERM2-3LN-O	3	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	PDO	-2.159	0.797	0.384
HSM-SIGTERM2-4LN-O	4	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	PDO	-2.071	0.797	0.384
HSM-SIGTERM2-5LN-O	5	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	PDO	-1.984	0.797	0.384
HSM-SIGTERM2-6LN-O	6	Signalized 3 leg at Diagonal exit or 4 leg at Four-quadrant Parclo A	PDO	-1.896	0.797	0.384

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-SIGTERM3-2LN-KABC	2	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	KABC	-2.068	0.265	0.905
HSM-SIGTERM3-3LN-KABC	3	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	KABC	-1.908	0.265	0.905
HSM-SIGTERM3-4LN-KABC	4	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	KABC	-1.748	0.265	0.905
HSM-SIGTERM3-5LN-KABC	5	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	KABC	-1.588	0.265	0.905
HSM-SIGTERM3-6LN-KABC	6	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	KABC	-1.428	0.265	0.905
HSM-SIGTERM3-2LN-O	2	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	PDO	-2.931	0.741	0.845
HSM-SIGTERM3-3LN-O	3	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	PDO	-2.843	0.741	0.845
HSM-SIGTERM3-4LN-O	4	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	PDO	-2.755	0.741	0.845
HSM-SIGTERM3-5LN-O	5	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	PDO	-2.668	0.741	0.845
HSM-SIGTERM3-6LN-O	6	Signalized 3 leg at Diagonal entrance or 4 leg at Four-quadrant Parclo A	PDO	-2.580	0.741	0.845
HSM-SIGTERM4-2LN-KABC	2	Signalized 4 leg terminal with diagonal ramps	KABC	-2.655	1.191	0.131
HSM-SIGTERM4-3LN-KABC	3	Signalized 4 leg terminal with diagonal ramps	KABC	-2.495	1.191	0.131

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-SIGTERM4-4LN-KABC	4	Signalized 4 leg terminal with diagonal ramps	KABC	-2.335	1.191	0.131
HSM-SIGTERM4-5LN-KABC	5	Signalized 4 leg terminal with diagonal ramps	KABC	-2.175	1.191	0.131
HSM-SIGTERM4-6LN-KABC	6	Signalized 4 leg terminal with diagonal ramps	KABC	-2.015	1.191	0.131
HSM-SIGTERM4-2LN-O	2	Signalized 4 leg terminal with diagonal ramps	PDO	-2.248	0.879	0.545
HSM-SIGTERM4-3LN-O	3	Signalized 4 leg terminal with diagonal ramps	PDO	-2.160	0.879	0.545
HSM-SIGTERM4-4LN-O	4	Signalized 4 leg terminal with diagonal ramps	PDO	-2.072	0.879	0.545
HSM-SIGTERM4-5LN-O	5	Signalized 4 leg terminal with diagonal ramps	PDO	-1.985	0.879	0.545
HSM-SIGTERM4-6LN-O	6	Signalized 4 leg terminal with diagonal ramps	PDO	-1.897	0.879	0.545
HSM-STOPTERM5-2LN-KABC	All	One-way stop-controlled at 3 leg terminal at two-quadrant parclo A or B	KABC	-2.363	0.260	0.947
HSM-STOPTERM5-3LN-KABC	All	One-way stop-controlled at 3 leg terminal at two-quadrant parclo A or B	KABC	-2.687	0.260	0.947
HSM-STOPTERM5-2LN-O	All	One-way stop-controlled at 3 leg terminal at two-quadrant parclo A or B	PDO	-3.055	0.773	0.878
HSM-STOPTERM5-3LN-O	All	One-way stop-controlled at 3 leg terminal at two-quadrant parclo A or B	PDO	-3.055	0.773	0.878

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-STOPTERM6-2LN-KABC	All	One-way stop-controlled at 3 leg terminal with diagonal exit ramp or 4 leg terminal at four-quadrant parclo A	KABC	-2.899	0.582	0.899
HSM-STOPTERM6-3LN-KABC	All	One-way stop-controlled at 3 leg terminal with diagonal exit ramp or 4 leg terminal at four-quadrant parclo A	KABC	-3.223	0.582	0.899
HSM-STOPTERM6-2LN-O	All	One-way stop-controlled at 3 leg terminal with diagonal exit ramp or 4 leg terminal at four-quadrant parclo A	PDO	-2.670	0.595	0.937
HSM-STOPTERM6-3LN-O	All	One-way stop-controlled at 3 leg terminal with diagonal exit ramp or 4 leg terminal at four-quadrant parclo A	PDO	-2.670	0.595	0.937
HSM-STOPTERM7-2LN-KABC	All	One-way stop-controlled at 3 leg terminal with diagonal entrance ramp or 4 leg terminal at four-quadrant parclo B	KABC	-2.817	0.709	0.730
HSM-STOPTERM7-3LN-KABC	All	One-way stop-controlled at 3 leg terminal with diagonal entrance ramp or 4 leg terminal at four-quadrant parclo B	KABC	-3.141	0.709	0.730
HSM-STOPTERM7-2LN-O	All	One-way stop-controlled at 3 leg terminal with diagonal entrance ramp or 4 leg terminal at four-quadrant parclo B	PDO	-2.358	0.885	0.350
HSM-STOPTERM7-3LN-O	All	One-way stop-controlled at 3 leg terminal with diagonal entrance ramp or 4 leg terminal at four-quadrant parclo B	PDO	-2.358	0.885	0.350

SPF ID	Number of Crossroad Lanes	Ramp Type	Crash Severity Level	a	b	c
HSM-STOPTERM8-2LN-KABC	All	One-way stop-controlled at 4 leg terminal with diagonal ramps	KABC	-2.740	1.008	0.177
HSM-STOPTERM8-3LN-KABC	All	One-way stop-controlled at 4 leg terminal with diagonal ramps	KABC	-3.064	1.008	0.177
HSM-STOPTERM8-2LN-O	All	One-way stop-controlled at 4 leg terminal with diagonal ramps	PDO	-2.432	0.845	0.476
HSM-STOPTERM8-3LN-O	All	One-way stop-controlled at 4 leg terminal with diagonal ramps	PDO	-2.432	0.845	0.476

A.2. AASHTOWARE SAFETY ANALYST™ SPFS

This section documents the SPFs included in the AASHTOWare Safety Analyst™ software. These SPFs are already available in the spreadsheet tool. In order to apply these SPFs directly, the variable names for the imported data will need to match those used in the predefined SPFs and documented here. **Error! Reference source not found.** and **Error! Reference source not found.** provide the AASHTOWare Safety Analyst™ SPFs for segments. **Error! Reference source not found.** and **Error! Reference source not found.** provide the AASHTOWare Safety Analyst™ SPFs for intersections. The dispersion parameter equals k for all SPFs. **Error! Reference source not found.** presents the coefficients for AASHTOWare Safety Analyst™ SPFs, including the name of the predefined SPF in the SPF ID column.

The following variable definitions apply to all SPFs in this subsection:

- length = segment length in miles
- AADT = average annual daily traffic on road segment
- AADTMAJ = average annual daily traffic on major road
- AADTMIN = average annual daily traffic on minor road

The SPF forms are:

Segments

$$Total\ Crashes = years * length * exp^{a} AADT^{b}$$

Figure 108. Equation. Safety Analyst^{TM} SPF for segment total crashes.

$$KABC\ Crashes = years * length * exp^{a} AADT^{b}$$

Figure 109. Equation. Safety Analyst^{TM} SPF for segment KABC crashes.

Intersections

$$Total\ Crashes = years * exp^{a} AADTMAJ^{b} AADTMIN^{c}$$

Figure 110. Equation. Safety Analyst^{TM} SPF for intersection total crashes.

$$KABC\ Crashes = years * exp^{a} AADTMAJ^{b} AADTMIN^{c}$$

Figure 111. Equation. Safety Analyst^{TM} SPF for intersection KABC crashes.

Table 17. Coefficients for AASHTOWare Safety Analyst™ SPFs.

SPF ID	Site Subtype	Crash Severity Level	a	b	c
SA-RUR2U-KABCO	Seg/Rur; 2-lane	Total	-3.63	0.53	N/A
SA-RUR2U-KABC	Seg/Rur; 2-lane	KABC	-4.86	0.53	N/A
SA-RURMU-KABCO	Seg/Rur; Multilane undivided	Total	-3.17	0.49	N/A
SA-RURMU-KABC	Seg/Rur; Multilane undivided	KABC	-4.20	0.50	N/A
SA-RURMD-KABCO	Seg/Rur; Multilane divided	Total	-5.05	0.66	N/A
SA-RURMD-KABC	Seg/Rur; Multilane divided	KABC	-7.46	0.72	N/A
SA-RUR4FWY-KABCO	Seg/Rur; Fwy (4 ln)	Total	-6.82	0.81	N/A
SA-RUR4FWY-KABC	Seg/Rur; Fwy (4 ln)	KABC	-8.82	0.89	N/A
SA-RUR6+FWY-KABCO	Seg/Rur; Fwy (6+ ln)	Total	-8.28	0.94	N/A
SA-RUR6+FWY-KABC	Seg/Rur; Fwy (6+ ln)	KABC	-10.25	1.03	N/A
SA-RUR4INTCHG-KABCO	Seg/Rur; Fwy in intchng area (4 ln)	Total	-7.76	0.97	N/A
SA-RUR4INTCHG-KABC	Seg/Rur; Fwy in intchng area (4 ln)	KABC	-8.86	0.96	N/A
SA-RUR6+INTCHG-KABCO	Seg/Rur; Fwy in intchng area (6+ ln)	Total	-9.63	1.06	N/A
SA-RUR6+INTCHG-KABC	Seg/Rur; Fwy in intchng area (6+ ln)	KABC	-10.48	1.04	N/A
SA-URB2U-KABCO	Seg/Urb; 2-lane arterial	Total	-7.16	0.84	N/A
SA-URB2U-KABC	Seg/Urb; 2-lane arterial	KABC	-8.84	0.89	N/A
SA-URBMU-KABCO	Seg/Urb; Multilane undivided	Total	-10.24	1.29	N/A
SA-URBMU-KABC	Seg/Urb; Multilane undivided	KABC	-12.07	1.39	N/A
SA-URBMD-KABCO	Seg/Urb; Multilane divided	Total	-11.85	1.34	N/A
SA-URBMD-KABC	Seg/Urb; Multilane divided	KABC	-14.87	1.52	N/A
SA-URBONEWAY-KABCO	Seg/Urb; One-way arterial	Total	-3.53	0.6	N/A
SA-URBONEWAY-KABC	Seg/Urb; One-way arterial	KABC	-5.15	0.65	N/A
SA-URB4FWY-KABCO	Seg/Urb; Fwy (4 ln)	Total	-7.85	1	N/A
SA-URB4FWY-KABC	Seg/Urb; Fwy (4 ln)	KABC	-8.82	1.02	N/A
SA-URB6FWY-KABCO	Seg/Urb; Fwy (6 ln)	Total	-5.96	0.78	N/A
SA-URB6FWY-KABC	Seg/Urb; Fwy (6 ln)	KABC	-7.6	0.85	N/A
SA-URB8+FWY-KABCO	Seg/Urb; Fwy (8+ ln)	Total	-16.24	1.67	N/A
SA-URB8+FWY-KABC	Seg/Urb; Fwy (8+ ln)	KABC	-19.16	1.85	N/A
SA-URB4INTCHG-KABCO	Seg/Urb; Fwy in intchng area (4 ln)	Total	-11.23	1.3	N/A
SA-URB4INTCHG-KABC	Seg/Urb; Fwy in intchng area (4 ln)	KABC	-12.89	1.38	N/A
SA-URB6INTCHG-KABCO	Seg/Urb; Fwy in intchng area (6 ln)	Total	-11.25	1.28	N/A

SPF ID	Site Subtype	Crash Severity Level	a	b	c
SA-URB6INTCHG-KABC	Seg/Urb; Fwy in intchng area (6 ln)	KABC	-13.62	1.42	N/A
SA-URB8+INTCHG-KABCO	Seg/Urb; Fwy in intchng area (8+ ln)	Total	-26.76	2.58	N/A
SA-URB8+INTCHG-KABC	Seg/Urb; Fwy in intchng area (8+ ln)	KABC	-25.63	2.42	N/A
SA-RUR-3ST-KABCO	Int/Rur; 3-leg minor-rd STOP	Total	-8.78	0.71	0.24
SA-RUR-3ST-KABC	Int/Rur; 3-leg minor-rd STOP	KABC	-9.35	0.71	0.21
SA-RUR-3STAW-KABCO	Int/Rur; 3-leg all-way STOP	Total	-12.37	1.22	0.27
SA-RUR-3STAW-KABC	Int/Rur; 3-leg all-way STOP	KABC	-10.02	1.27	-0.22
SA-RUR-3SG-KABCO	Int/Rur; 3-leg signalized	Total	-6.57	0.66	0.2
SA-RUR-3SG-KABC	Int/Rur; 3-leg signalized	KABC	-7.83	0.75	0.14
SA-RUR-4ST-KABCO	Int/Rur; 4-leg minor-rd STOP	Total	-8.96	0.65	0.47
SA-RUR-4ST-KABC	Int/Rur; 4-leg minor-rd STOP	KABC	-9.36	0.66	0.4
SA-RUR-4STAW-KABCO	Int/Rur; 4-leg all-way STOP	Total	-12.37	1.22	0.27
SA-RUR-4STAW-KABC	Int/Rur; 4-leg all-way STOP	KABC	-10.02	1.27	-0.22
SA-RUR-4SG-KABCO	Int/Rur; 4-leg signalized	Total	-6.57	0.66	0.2
SA-RUR-4SG-KABC	Int/Rur; 4-leg signalized	KABC	-7.83	0.75	0.14
SA-URB-3ST-KABCO	Int/Urb; 3-leg minor-rd STOP	Total	-5.35	0.34	0.28
SA-URB-3ST-KABC	Int/Urb; 3-leg minor-rd STOP	KABC	-8.45	0.49	0.39
SA-URB-3STAW-KABCO	Int/Urb; 3-leg all-way STOP	Total	-12.37	1.22	0.27
SA-URB-3STAW-KABC	Int/Urb; 3-leg all-way STOP	KABC	-10.02	1.27	-0.22
SA-URB-3SG-KABCO	Int/Urb; 3-leg signalized	Total	-9.85	0.97	0.18
SA-URB-3SG-KABC	Int/Urb; 3-leg signalized	KABC	-10.22	0.91	0.21
SA-URB-4ST-KABCO	Int/Urb; 4-leg minor-rd STOP	Total	-3.12	0.27	0.16
SA-URB-4ST-KABC	Int/Urb; 4-leg minor-rd STOP	KABC	-4.35	0.29	0.19
SA-URB-4STAW-KABCO	Int/Urb; 4-leg all-way STOP	Total	-12.37	1.22	0.27
SA-URB-4STAW-KABC	Int/Urb; 4-leg all-way STOP	KABC	-10.02	1.27	-0.22
SA-URB-4SG-KABCO	Int/Urb; 4-leg signalized	Total	-3.47	0.42	0.14
SA-URB-4SG-KABC	Int/Urb; 4-leg signalized	KABC	-5.11	0.49	0.16
SA-RUR-DIAMOFF-KABCO	Ramp/Rur; Diamond (off)	Total	-3.07	0.46	N/A
SA-RUR-DIAMOFF-KABC	Ramp/Rur; Diamond (off)	KABC	-4.54	0.47	N/A
SA-RUR-DIAMON-KABCO	Ramp/Rur; Diamond (on)	Total	-2.16	0.19	N/A
SA-RUR-DIAMON-KABC	Ramp/Rur; Diamond (on)	KABC	-8.12	0.86	N/A
SA-RUR-PARCLOOFF-KABCO	Ramp/Rur; Parclo loop (off)	Total	-1.15	0.26	N/A

SPF ID	Site Subtype	Crash Severity Level	a	b	c
SA-RUR-PARCLOOFF-KABC	Ramp/Rur; Parclo loop (off)	KABC	-4.29	0.59	N/A
SA-RUR-PARCLOON-KABCO	Ramp/Rur; Parclo loop (on)	Total	-5.59	0.82	N/A
SA-RUR-PARCLOON-KABC	Ramp/Rur; Parclo loop (on)	KABC	-1.3	0.24	N/A
SA-RUR-FFLOWOFF-KABCO	Ramp/Rur; Free-flow loop (off)	Total	-5.1	0.78	N/A
SA-RUR-FFLOWOFF-KABC	Ramp/Rur; Free-flow loop (off)	KABC	-4.29	0.59	N/A
SA-RUR-FFLOWON-KABCO	Ramp/Rur; Free-flow loop (on)	Total	-1.17	0.35	N/A
SA-RUR-FFLOWON-KABC	Ramp/Rur; Free-flow loop (on)	KABC	-1.3	0.24	N/A
SA-RUR-FFLOWOUT-KABCO	Ramp/Rur; Free-flow outer connection	Total	-2.83	0.49	N/A
SA-RUR-FFLOWOUT-KABC	Ramp/Rur; Free-flow outer connection	KABC	-4.89	0.61	N/A
SA-RUR-DIR-KABCO	Ramp/Rur; Direct/semi-direct connection	Total	-3.21	0.56	N/A
SA-RUR-DIR-KABC	Ramp/Rur; Direct/semi-direct connection	KABC	-4.22	0.55	N/A
SA-URB-DIAMOFF-KABCO	Ramp/Urb; Diamond (off)	Total	-3.52	0.54	N/A
SA-URB-DIAMOFF-KABC	Ramp/Urb; Diamond (off)	KABC	-3.86	0.47	N/A
SA-URB-DIAMON-KABCO	Ramp/Urb; Diamond (on)	Total	-8.2	1.03	N/A
SA-URB-DIAMON-KABC	Ramp/Urb; Diamond (on)	KABC	-8	0.86	N/A
SA-URB-PARCLOOFF-KABCO	Ramp/Urb; Parclo loop (off)	Total	-1.15	0.26	N/A
SA-URB-PARCLOOFF-KABC	Ramp/Urb; Parclo loop (off)	KABC	-3.68	0.53	N/A
SA-URB-PARCLOON-KABCO	Ramp/Urb; Parclo loop (on)	Total	-5.59	0.82	N/A
SA-URB-PARCLOON-KABC	Ramp/Urb; Parclo loop (on)	KABC	-1.34	0.24	N/A
SA-URB-FFLOWOFF-KABCO	Ramp/Urb; Free-flow loop (off)	Total	-4.6	0.73	N/A
SA-URB-FFLOWOFF-KABC	Ramp/Urb; Free-flow loop (off)	KABC	-3.68	0.53	N/A
SA-URB-FFLOWON-KABCO	Ramp/Urb; Free-flow loop (on)	Total	-0.55	0.29	N/A
SA-URB-FFLOWON-KABC	Ramp/Urb; Free-flow loop (on)	KABC	-1.34	0.24	N/A
SA-URB-FFLOWOUT-KABCO	Ramp/Urb; Free-flow outer connection	Total	-3.5	0.57	N/A
SA-URB-FFLOWOUT-KABC	Ramp/Urb; Free-flow outer connection	KABC	-6.12	0.75	N/A
SA-URB-DIR-KABCO	Ramp/Urb; Direct/semi-direct connection	Total	-1.28	0.35	N/A
SA-URB-DIR-KABC	Ramp/Urb; Direct/semi-direct connection	KABC	-2.5	0.37	N/A

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REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO). Highway Safety Manual. Washington, DC, 2010.
2. User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors. NCHRP Report HR 20-7(332), 2014. http://safety.fhwa.dot.gov/rsdp/toolbox-content.aspx?toolid=116.
3. Safety Performance Function Decision Guide: SPF Calibration vs. SPF Development. FHWA-SA-14-004, Federal Highway Administration, 2013. http://safety.fhwa.dot.gov/rsdp/toolbox-content.aspx?toolid=99.
4. Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs. FHWA-SA-14-005, Federal Highway Administration, 2013. http://safety.fhwa.dot.gov/rsdp/toolbox-content.aspx?toolid=100.
5. Hauer, E. The Art of Regression Modeling in Road Safety. Springer International Publishing Switzerland, 2015.
6. Srinivasan, R., M. Colety, G. Bahar, B. Crowther and M. Farmen. Estimation of Calibration Functions for Predicting Crashes on Rural Two-Lane Roads in Arizona. Transportation Research Record: Journal of the Transportation Research Board, No. 2583, Transportation Research Board of the National Academies, Washington, D.C., 2016, pp. 17-24.
7. Hauer, E. Statistical Road Safety Modeling. Transportation Research Record: Journal of the Transportation Research Board, No. 1897, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 81-87.
8. Shirazi, M, D. Lord, and S.R. Geedipally. Sample-Size Guidelines for Recalibrating Crash Prediction Models: Recommendations for the Highway Safety Manual. Presented at the 95th Annual Meeting of the Transportation Research Board, Washington, D.C., 2016.
9. Banihashemi, M. Sensitivity Analysis of Data Set Sizes for Highway Safety Manual Calibration Factors. Transportation Research Record: Journal of the Transportation Research Board, No. 2279, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 75-81.
10. Alluri, P., D. Saha, and A. Gan. Minimum Sample Sizes for Estimating Reliable Highway Safety Manual (HSM) Calibration Factors. Journal of Transportation Safety & Security, 2014.
11. Trieu, V., S. Park, and J. McFadden. Use of Monte Carlo Simulation for a Sensitivity Analysis of Highway Safety Manual Calibration Factors. Transportation Research Record: Journal of the Transportation Research Board, No. 2435, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 1-10.
12. Xie, F., K. Gladhill, K. K. Dixon, and C. M. Monsere. Calibration of Highway Safety Manual Predictive Models for Oregon State Highways. Transportation Research Record: Journal of the Transportation Research Board, No. 2241, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 19–28.
13. Sun, X., D. Magri, H. H. Shirazi, S. Gillella, and L. Li. Application of the Highway Safety Manual: Louisiana Experience with Rural Multilane Highways. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

14. Sacchi, E., Persaud B., and M. Bassani. Assessing International Transferability of Highway Safety Manual Crash Prediction Algorithm and Its Components. Transportation Research Record: Journal of the Transportation Research Board, No. 2279, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 90–98.
15. Fridstrom, L., Ifver, J., Ingebrigtsen, S., Kulmala, R., and Thomsen, L. K. Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. Accident Analysis and Prevention, Vol. 27, pp. 1-20. 1995.
16. Lord, D., S. R. Geedipally, B. N. Persaud, S. P. Washington, I. van Schalkwyk, J. N. Ivan, C. Lyon, and T. Jonsson. NCHRP Web-Only Document 126: Methodology to Predict the Safety Performance of Rural Multilane Highways. Transportation Research Board of the National Academies, Washington, D.C., 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w126.pdf.
17. Vogt, A., and J. Bared. Accident Models for Two-Lane Rural Segments and Intersections. Transportation Research Record: Journal of the Transportation Research Board, No. 1635, Transportation Research Board of the National Academies, Washington, D.C., 1998, pp. 18–29.
18. Srinivasan, R., Baek, J., Carter, D., Persaud, B., Lyon, C., Eccles, K., Gross, F., Lefler, N., "Safety Evaluation of Improved Curve Delineation." Report No. FHWA-HRT-09-045, Federal Highway Administration, Washington, D.C., 2009.

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