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

**Interim Report**

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# CHAPTER 1. INTRODUCTION

## Background

Data-driven safety analysis (DDSA) methods, including those presented in the AASHTO *Highway Safety Manual* (HSM), AASHTOWare Safety Analyst, and other similar tools, are becoming increasingly popular due to their ability to quantitatively assess the safety performance of existing and proposed roadways. Predictive analysis—a DDSA approach—is implemented using a combination of the following statistical crash prediction models (CPM): (1) safety performance functions (SPFs); (2) severity distribution functions (SDFs); and (3) crash modification factors and functions (CMF), which are sometimes called SPF adjustment factors.

Many statistical models in current use were developed several years ago based on research using historic crash data. For example, SafetyAnalyst SPFs were developed using data collected from 1993-2001 from the Highway Safety Information System (HSIS) multistate database. Most of the models in the 1st edition of the HSM were also developed using HSIS data, with some of the models having been developed with data from the 1990s. Over time, the relationships represented by these statistical models have likely changed due to improvements in vehicle design, changes in driver behavior, variations in vehicle-miles traveled, and new geometric configurations or standards.

To ensure reliable estimates are obtained, the HSM recommends that the analyst calibrate the model to conditions in the jurisdiction for which the model is being used (in SafetyAnalyst, calibration is done automatically). Moreover, the HSM recommends that the analyst update the calibration factors annually, or every few years, to mitigate the effect of these changes over time. However, agencies are finding that:

1. Substantial resources are required to update the growing number of prediction models in the different tools,
2. The cost to maintain analysis tools cuts into construction funding and is not well known,
3. Evidence suggests that the proposed calibration approach does not always provide improvements in model reliability,
4. The number of models offered in the HSM is continuing to increase with each newly completed national research project,
5. The relatively “simple” calibration procedure recommended by the HSM may not always improve the overall reliability of the model estimate and has not been widely verified,
6. Models are not updated as often as advised.

## Objectives

As stated in the request for proposals (RFP), the objectives of this research are to:

1. Determine how frequently SPFs, SPF adjustment factors (also called CMFs in Part C of the HSM), and SDFs should be updated;
2. Determine under what conditions (e.g., changes in road environment, data, and statistical properties) SPFs, SPF adjustment factors, and SDFs require updates; and
3. Develop an implementable approach and guidance for maintaining and updating existing and future functions and factors.

## Task Structure and Progress

NCHRP 17-93 is a two-phase effort. Phase 1 includes six tasks. Task 1 included a comprehensive review of the literature on topics related to the re-estimation, calibration, and updating of CPMs and the related statistical models. Task 2 conducted a survey of the state of practice regarding crash prediction model development, availability, and implementation. With the panel’s help, Task 3 developed a prioritized list of candidate guidelines for management of crash prediction models based on funding available. Task 4 used preliminary data sources and developed initial guidelines. The goal of Task 5 is to develop a work plan for Phase 2 (along with an interim report) based on the outcomes of the previous tasks. Task 6 is an interim meeting with the NCHRP panel to discuss the work plan for Phase 2.

Phase 2 includes four tasks. Task 7 will demonstrate the proposed approach and the guidelines. Task 8 will develop a user-friendly CPM management manual along with functional specifications for automating the procedures in the manual. Task 9 will coordinate the review of these documents with AASHTO and NCHRP and the necessary revisions to the documents based on the review. Task 10 will produce the final report and other products. The proposed scheduled for this task is provided and the end of this document. Following is a brief overview of tasks that have been completed.

The review of the literature in Task 1 covered the following topics:

1. What is calibration?
2. Approaches for calibration
3. Issues associated with calibration
4. Calibration of SPFs and CMFs
5. Jurisdiction-specific SPFs versus calibrated models
6. Functional form of SPFs

Task 2 assessed the state of practice regarding crash prediction model development, availability, and implementation. The Task 2 document described the survey of state agencies and researchers that was performed to learn more about current practices with respect to CPM development and maintenance, followed by the state of practice with respect to CPM development/maintenance costs, challenges for CPM application, CPM development practices, frequency of CPM updates and strengths, and weaknesses of CPM functional forms.

Task 3 culminated in a report as part of Subtask 3.5 (Prioritized List of Candidate Guidelines for Management of Crash Prediction Models). This document presented a prioritized list of the topics for which guidance could be developed based on the funding available in Phase I of the project. After discussion with the project panel, it was decided that the topics identified in Table 1 could be addressed in Phase I as part of Task 4, with the understanding that the associated guidelines would be refined in Task 7.

Table . Prioritized List of Research Topics.

|  |  |  |  |
| --- | --- | --- | --- |
| Subtask Title | Subtask Number | Topic Number | Topic |
| When to calibrate or update | 3.1 | 1 | Calibrate if there is a change in location |
| 2 | Update if there is a change in safety over time |
| How to calibrate or update | 3.2 | 1 | Combined calibration data for similar site types |
| 2 | Reliability of extrapolating calibration factor across crash type and severity categories |
| 3 | Maintain standardized database |
| 4 | Prioritizing input data elements |
| 5 | Minimum site sample size |
| 6 | Calibrated model fit statistics |
| 7 | Selecting the calibration function |
| 8 | Calibrated model fit statistics (calibration function) |

Task 4 developed initial guidance on the topics listed in Table 1. Many of these guidance documents were submitted to the panel in 2021 and 2022. The following documents were developed as part of Task 4:

* Guidelines on the Need for Regional Calibration Factors or Calibration Factors for a Specific Year (Working Paper 6)
* Guidelines on the Use of Combined Calibration for Similar Site Types, or Crash Types and Severity Categories of Interest (Working Paper 7)
* Guidelines on Maintaining Standardized Database and Prioritizing Input Data Elements (Working Paper 8)
* Development of Guidelines for Quantifying a Reliable Local Calibration Factor (Working Paper 3)
* Guidelines Describing How to Calibrate or Update a Crash Prediction Model (Working Paper 4)
* Recommended Refinements to Calibration Function Guidance (Working Paper 5)

Working Paper 4 is intended to provide practitioner guidelines for addressing all topics in Subtask 3.2 (to varying depth). Working Paper 3 provides documentation of the research undertaken to develop these guidelines. As such, Working Paper 4 is content for the CPM Management Manual and Working Paper 3 is content for the Final Report. Working Paper 5 describes proposed refinements to Topics 7 and 8 of Subtask 3.2 that could be undertaken in Task 7. These refinements represent additional research intended to provide more depth or breadth to the guidance provided in Working Paper 4

Task 5 is this interim report. This report includes the work plan for Phase 2 with a primary focus on the plans for Task 7. An interim meeting was held virtually in November 2022. Following the meeting, NCHRP indicated that a few panel members have left the panel due to various reasons, and adding more panel members may create some issues because the new members may want to go in a different direction. For this reason, the project was terminated in early 2023.

# CHAPTER 2. WORK PLAN FOR PHASE 2

## Task 7. Demonstrate the Proposed Approach Using Test Cases

Task 7 consists of two subtasks. For the first subtask, the research team will document a series of test cases based on the guidelines developed in Phase I. These test cases will demonstrate the correct use of the guidelines. For the second subtask, the research team will use the findings from the test case development to refine the guidelines and update the test case document.

A two-pronged approach is proposed for Task 7 depending on the topic area under consideration. For topics 5 through 8 (subtask 3.2) the following approach is proposed for developing the following three test cases:

* Subtask 3.2, Topics 5 and 6. Test case to demonstrate the calculation of the minimum site sample size, calibration factor, and fit statistics.
* Subtask 3.2, Topics 7 and 8. Test case to demonstrate the selection of a calibration function, estimation of its coefficients, and assessment of fit statistics.
* Subtask 3.2, Topics 5 to 8. Comprehensive demonstration of calibration process.

For other topics, i.e., Subtask 3.1 (Topics 1 and 2) and Subtask 3.2 (Topics 1, 2, 3, and 4), empirical guidance was developed in Phase 1 and test cases using data from North Carolina were demonstrated to validate the guidance. As such, for these topics, possible refinements to the initial guidance / test cases presented in Phase 1 are provided herein.

Following panel review and approval of the proposed approaches to preparing test cases (for Subtask 3.2 – Topics 5, 6, 7, and 8) and refining the initial guidance / test cases presented in Phase 1 (for Subtask 3.1 – Topics 1 and 2 & Subtask 3.2 – Topics 1, 2, 3, and 4), the approaches will be used to guide the development of the individual test cases and/or refine the initial empirical guidance in Task 7. Further details about the approach for all topics is presented below.

### Topics 5 Through 8 of Subtask 3.2

#### Case 1. Calculate Minimum Sample Size, Calibration Factor, and Fit

###

##### Background

This test case will demonstrate the guidelines for calculating the minimum site sample size, calibration factor, and the statistics indicating the fit of the calibrated model to the calibration data. These guidelines are documented as Steps 1 to 5 in Working Paper 4 (Guidelines Describing How to Calibrate or Update a Crash Prediction Model), which was submitted to NCHRP in late 2020. The objectives of this test case are: (1) demonstrate the correct use of the guidelines and interpretation of the results, and (2) use the insights from the demonstration as a basis for further refinements to the guidelines in Subtask 7.2. These objectives can be achieved using simulated data, where the calibration database is created using real-world sites having crash counts computed using Monte-Carlo methods.

The test case will focus on the calibration of the crash prediction model (CPM) in HSM Chapter 11 for rural divided multilane highway segments. The data will describe segments of the Florida state highway system. Geometric design and traffic volume data for these segments were obtained from Florida DOT by the research team for a prior project with the DOT. Crash counts for each segment will be randomly generated using Monte-Carlo methods. The computed count will be based on the use of the Chapter 11 CPM and a specified “true” calibration factor. The guidelines will then be applied to the data to demonstrate the calculation of the sample size, calibration factor, and related fit statistics. The fact that the true calibration factor is known will facilitate a demonstration of the validity of the calibration factor produced by the guidelines.

##### Annotated Test Case Outline

This section describes the proposed annotated outline for the test case. Collectively, the annotations briefly describe the real-world set up to the test case and the intended outcomes.

###### Overview

An agency desires to locally calibrate the CPM for rural undivided multilane highway segments, as described in HSM Chapter 11. Their infrastructure database includes the data needed for the CPM’s input variables. They also have the required AADT volumes and crash counts. They desire to compute the multiplicative calibration factor *C* for this CPM. The calibration procedure described in Steps 1 to 5 of Working Paper 4 will be used for this purpose.

###### Data Requirements and Assumptions

The CPM for rural undivided multilane highway segments in HCM Chapter 11 requires the following input variables for each segment: AADT volume, segment length, lane width, right shoulder width, median width, lighting presence, and automated speed enforcement presence. Segment boundaries are defined using the guidance in Section 11.5 of HSM Chapter 11. Data indicating the presence of automated speed enforcement is not available in the agency database. However, the agency uses automated enforcement on a very limited basis. As such, it is assumed that automated speed enforcement is not present on any of the segments in the calibration database.

###### Calculations

The calculations associated with the application of Steps 1 to 5 in Working Paper 4 will be described in this section of the test case. The actions associated with each step are identified in the following list.

* Step 1 – Compute Site Sample Statistics and Assess Sample Adequacy
* Step 2 – Compute the Predicted Average Crash Frequency
* Step 3 – Compute the Calibration Factor
* Step 4 – Outlier Detection and Resolution
* Step 5 – Assess Model Fit Based on the Calibration Factor

The computed values will be accompanied by a brief discussion of the results on a step-by-step basis. The discussion will highlight any unusual findings and discuss the rationale for the decisions made.

###### Results and Interpretation

The results of the calibration activity will be described in this section. This description will include the calibration factor, CURE plot, and fit statistics. The correct use of the calibration factor will be discussed. The computed calibration factor will be compared with the true calibration factor. Any difference found will be compared with the computed standard error of the calibration factor.

#### Case 2. Calculate Calibration Function and Fit

###

##### Background

This test case will demonstrate the guidelines for estimating the coefficients in a calibration function and evaluating the statistics indicating the fit of the calibrated model to the calibration data. These guidelines are documented as Step 6 in Working Paper 4 (Guidelines Describing How to Calibrate or Update a Crash Prediction Model), which was submitted to NCHRP in late 2020. The objectives of this test case are: (1) demonstrate the correct use of the guidelines and interpretation of the results, and (2) use the insights from the demonstration as a basis for further refinements to the guidelines in Subtask 7.2. These objectives can be achieved using simulated data, where the calibration database is created using real-world sites having crash counts computed using Monte-Carlo methods.

The test case will focus on the calibration of the CPM in HSM Chapter 11 for rural divided multilane highway segments. The data will describe segments of the Florida state highway system. Geometric design and traffic volume data for these segments were obtained from Florida DOT by the research team for a prior project with the DOT. Crash counts for each segment will be randomly generated using Monte-Carlo methods. The computed count will be based on the use of the Chapter 11 CPM and the following calibration function (with specified true values for *C3* and *C4*):

Equation

$$N\_{o}=C\_{3}×\left(N\_{P,u}\right)^{C\_{4}}$$

where

*No =* observed crash count during the calibration period (crashes/period);

*Np,u =* predicted average number of crashes during the calibration period unadjusted by calibration factor (crashes/period); and

*Ci =* calibration factor *i* to adjust the CPM for local conditions.

The guidelines will then be applied to the data to demonstrate the estimation of the two calibration factors and related fit statistics. The fact that the true calibration factors are known will facilitate a demonstration of the validity of the calibration factors produced by the guidelines.

It is anticipated further refinements will be needed to the guidelines in Step 6 of Working Paper 4. These refinements relate to the following research needs:

1. Selecting the functional form of the calibration function (i.e., forms in addition to Equation 1).
2. Determining whether to use the overdispersion parameter from the original CPM or that computed using the calibration data.
3. Assessing whether the calibration function over-fits the CPM to the calibration data.

These research needs are proposed to be undertaken in Subtask 7.2. Details of research activities are described in Working Paper 5 (Recommended Refinements to Calibration Function Guidance).

##### Annotated Test Case Outline

This section describes the proposed annotated outline for the test case. Collectively, the annotations briefly describe the real-world set up to the test case and the intended outcomes.

###### Overview

An agency desires to locally calibrate the CPM for rural undivided multilane highway segments, as described in HSM Chapter 11. Their infrastructure database includes the data needed for the CPM’s input variables. They also have the required AADT volumes and crash counts. They desire to compute the calibration function for this CPM. The calibration procedure described in Step 6 of Working Paper 4 will be used for this purpose.

###### Data Requirements and Assumptions

The CPM for rural undivided multilane highway segments in HCM Chapter 11 requires the following input variables for each segment: AADT volume, segment length, lane width, right shoulder width, median width, lighting presence, and automated speed enforcement presence. Segment boundaries are defined using the guidance in Section 11.5 of HSM Chapter 11. Data indicating the presence of automated speed enforcement is not available in the agency database. However, the agency uses automated enforcement on a very limited basis. As such, it is assumed that automated speed enforcement is not present on any of the segments in the calibration database.

###### Calculations

The calculations associated with the application of Step 6 in Working Paper 4 will be described in this section of the test case. Guidance in Step 6 advises the analyst to repeat Steps 4 and 5 if the calibration function is found to provide a better fit to the data than was provided by the single multiplicative factor *C*. The actions associated with each step are identified in the following list.

* Step 4 – Outlier Detection and Resolution
* Step 5 – Assess Model Fit Based on the Calibration Factor
* Step 6 – If Applicable, Compute the Calibration Function

The computed values will be accompanied by a brief discussion of the results on a step-by-step basis. The discussion will highlight any unusual findings and discuss the rationale for the decisions made.

###### Results and Interpretation

The results of the calibration activity will be described in this section. This description will include the two calibration factors, CURE plot, and fit statistics. The correct use of the calibration function will be discussed. The computed calibration factors (associated with the function) will be compared with the true factor values. Any differences found will be compared with the computed standard error of the associated calibration factor.

#### Case 3. Comprehensive Demonstration of Calibration Process

###

##### Background

This test case will demonstrate a typical application of the guidelines for calibrating a CPM. These guidelines are documented as Steps 1 to 6 in Working Paper 4 (Guidelines Describing How to Calibrate or Update a Crash Prediction Model), which was submitted to NCHRP for review in late 2020. The objectives of this test case are: (1) demonstrate a comprehensive application of all guideline steps, and (2) use the insights from the demonstration as a basis for further refinements to the guidelines in Subtask 7.2. These objectives can be achieved using real-world data.

The test case will focus on the calibration of the CPM in HSM Chapter 10 for rural two-lane two-way highway segments. The data will describe segments of the Arizona state highway system. Geometric design, traffic volume, and crash data were obtained from Arizona DOT by the research team for a previous project with the DOT. The guidelines will be applied to the data to demonstrate the calibration project planning procedure and the calibration procedure, as described in Working Paper 4.

##### Annotated Test Case Outline

This section describes the proposed annotated outline for the test case. Collectively, the annotations briefly describe the real-world set up to the test case and the intended outcomes.

###### Overview

An agency desires to locally calibrate the CPM for rural two-lane two-way highway segments, as described in HSM Chapter 10. Their infrastructure database includes the data needed for the CPM’s input variables. They also have the required AADT volumes and crash counts. They desire to compute the best fitting calibration factor or function for this CPM. The project planning and calibration procedures described in Working Paper 4 will be used for this purpose.

###### Data Requirements and Assumptions

The CPM for rural two-lane two-way highway segments in HCM Chapter 10 requires the following input variables for each segment: AADT volume, segment length, horizontal curve radius and length, presence of spiral transition, superelevation rate variance, percent grade, lane width, shoulder width, shoulder type, lighting presence, driveway density, passing lane presence, two-way left-turn lane presence, centerline rumble strip presence, roadside hazard rating, and automated speed enforcement presence. Segment boundaries are defined using the guidance in Section 10.5 of HSM Chapter 10. Data elements in the previous list that are underlined are not available in the agency database. For these variables, default values were assumed based on agency policy.

###### Calculations

As a first step, the calibration project planning procedure described in Working Paper 4 will be applied. Through this procedure, the analyst will determine the scope of the calibration project, assess the available sample size, identify candidate study sites, and acquire all relevant data from available agency databases.

As a next step, the calibration procedure will be applied. The actions associated with each step are identified in the following list.

* Step 1 – Compute Site Sample Statistics and Assess Sample Adequacy
* Step 2 – Compute the Predicted Average Crash Frequency
* Step 3 – Compute the Calibration Factor
* Step 4 – Outlier Detection and Resolution
* Step 5 – Assess Model Fit Based on the Calibration Factor
* Step 6 – If Applicable, Compute the Calibration Function

Detailed calculations associated with each step will not be provided because they will have been described in the previous two test cases. However, the discussion of each step will provide the calculation results and will be accompanied by a brief discussion of the decisions made based on the results. The discussion will highlight any unusual findings.

###### Results and Interpretation

The results of the calibration procedure will be described in this section. This description will summarize the calibration factor or function determined to provide the best fit to the data. The correct use of the calibration factor or function will be discussed.

### Proposed Refinements to Phase 1 Empirical Guidance (topics 1 and 2 of subtask 3.1 and topics 1 through 4 of subtask 3.2)

###

#### Subtask 3.1 (Topics 1 and 2) – Guidelines on the Need for Regional Calibration Factors or Calibration Factors for a Specific Year

#####

##### Background

Practitioners are often faced with the decision on when to calibrate or update different components of the prediction model. There are two issues to consider here:

* Calibrate if the prediction model was developed in jurisdiction X, but being used in jurisdiction Y
* Recalibrate the prediction model if there is a change in safety over time

For both these issues, Working Paper 6 outlined initial guidance that practitioners can use to determine if regional calibrations are needed (instead of using the statewide calibration factor), and if separate calibration factors need to be developed in a particular year (instead of using the calibration factors from the base year).

##### Initial Guidance

The approaches discussed for both these issues in Task 4 were based on Lord et al., (2015). Lord et al., (2015) recommended the use of base SPFs (without the adjustment factors) for this purpose. A simpler method including the use of crash rates was also explored as a possible way for practitioners to identify the need for regional calibration factors or calibration factors for a specific year.

To compare the approaches recommended in Lord et al., (2015) versus using crash rates, data compiled as part of two recent projects (NCHRP Project 17-72: Update of Crash Modification Factors for the Highway Safety Manual; and NCDOT Project 2020-27: Updated and Regional Calibration Factors for Highway Safety Manual Prediction Models 2016-2019) for rural two-lane roads, rural multi-lane divided roads, and urban two-lane undivided arterials from North Carolina were utilized. The data collection for this effort was completed in Spring 2021 and have been included in the final report of these two projects. Rural two-lane roads and rural multi-lane divided roads were chosen because these two facility types had sufficient data by region and by year, whereas urban two-lane undivided arterials had sufficient data by year to do these comparisons (see Working Paper 6 for further details about the guidelines that were developed).

Analysis conducted using North Carolina data indicated that for rural two-lane roads and rural multi-lane divided roads, there is very little difference between using proxy calibration factors (the term proxy calibration factor is used for the calibration factors calculated with just the base model, i.e., without the adjustment factors) and crash rates to determine whether regional calibration factors are needed, or if calibration is needed for a specific year. However, for urban two-lane undivided arterials, the proxy calibration factors are expected to provide more reliable results about whether calibration is needed for a particular year. Data were not available to calibrate Urban 2U models by region.

The primary reason for this difference between rural facilities versus urban two-lane undivided arterials, is the relationship between crash frequency and AADT in the CPMs that were used. Based on Task 4 results, the following guidance is recommended for practitioners:

* If the relationship between AADT and crash frequency is close to a linear relationship, then crash rates may be sufficient to determine if regional calibration factors are needed, or to determine if calibration is needed for a specific year. If the SPF is a power model as in the case of Rural 2U, Rural 4D, and Urban 2U, then the power of the AADT term provides insight into whether the relationship is close to a linear relationship. If the power of the AADT term is between 0.9 and 1.1, then the relationship could be considered close to a linear relationship.
* If the power of the AADT term is less than 0.9 or greater than 1.1, or the SPF is a based on a more complex model form such as a Hoerl function (Hauer, 2015), then the approaches described in Lord et al., (2015) are expected to provide more reliable guidance regarding the need for regional calibration factors, or the need for calibration factors by year.

#####

##### Proposed Refinements to Initial Guidance

The initial guidance presented in Task 4 was developed primarily using readily available North Carolina data. Data for other urban arterial site types from North Carolina is now available and will be used in Phase 2 to further validate the initial guidance.

The research team will also try to obtain ready to use data from other States to help further refine and develop unified national guidance on the need for regional calibration factors or calibration factors for a specific year. For this purpose, data collected for urban arterials in Ohio for developing guidance for Subtask 3.2 (Topics 1 and 2) can be used alongside detailed data for rural two-lane roads in Pennsylvania that is available to the project team. Further efforts will be made to acquire permissions for using datasets used in NCHRP Projects 17-58, 17-62, 17-68, and 17-70 for developing prediction models for the upcoming 2nd Edition of the HSM.

Our goal is to complete the Task 7 analysis by the end of the year using readily available data, however, based on panel direction, further data from North Carolina can be collected as part of this project requiring additional time to complete the Task 7 analysis.

#### Subtask 3.2 (Topics 1 and 2) – Guidelines on the Use of Combined Calibration for Similar Site Types, or Crash Types and Severity Categories of Interest

#####

##### Background

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

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

For both these issues, Working Paper 7 outlined initial guidance that practitioners can use to determine if calibration data for similar site types, or crash types and severity categories of interest can be combined.

##### Initial Guidance

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

To evaluate the approach recommended by Bahar (2014), data compiled as part of two recent projects (NCHRP Project 17-72: Update of Crash Modification Factors for the Highway Safety Manual; and NCDOT Project 2020-27: Updated and Regional Calibration Factors for Highway Safety Manual Prediction Models 2016-2019) for rural two-lane roads, rural multi-lane divided roads, and urban arterials from North Carolina were utilized. The data collection for this effort was completed in Spring 2021 and have been included in the final report of these two projects.

Analysis for combined calibration data for similar site types conducted using North Carolina data indicated that for rural two-lane roads and rural multi-lane divided roads, there is very little difference between the calibration factors (and the relative calibration factor differences). The 95% confidence interval ranges for the calibration factors for these two roadway types are also very similar. However, for urban arterials, there are various instances where the relative differences between the calibration factors are high (more so for single vehicle crashes compared to multiple vehicle collisions) and the 95% confidence interval ranges for the calibration factors exhibit fairly wide ranges (due to the small sample size available for this analysis). This leads to situations where there is some overlap between the confidence intervals for different roadway types simply because the confidence intervals exhibiting a wide range.

Based on Working Paper 7, the following guidance is recommended for practitioners when identifying if prediction models developed for some roadway types be calibrated using a common database including different site types:

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

Analysis for extrapolating calibration factor across crash types of and crash severities categories using North Carolina data that for Urban Arterials indicated that there are various instances where relative differences between the calibration factors are high for single vehicle fatal & injury and property damage only crashes compared to total single vehicle crashes, for the same roadway type. This also led to the 95% confidence interval ranges for the single vehicle crashes exhibiting fairly wide ranges.

Based on Working Paper 7, the following guidance is recommended for practitioners when identifying if calibration factor for a prediction model that represents total crashes be used to obtain reliable estimates when this factor is used with a prediction model for predicting specific crash types, severity categories, or both:

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

#####

##### Proposed Refinements to Initial Guidance

The initial guidance was developed primarily using readily available North Carolina data. Data for urban arterials were also obtained from Ohio; however, it could not be used in developing initial guidance due to the need for further crash coding to place crashes in appropriate bins.

To develop final guidance in Phase 2, urban arterial data from Ohio will be used to validate the initial guidance developed using North Carolina data. Further efforts will be made to acquire permissions for using datasets used in NCHRP Projects 17-58, 17-62, 17-68, and 17-70 for developing prediction models for the upcoming 2nd Edition of the HSM.

The final guidance will also consist of a list of different roadway types, and crash types and severity categories that can be combined to estimate a common calibration factor (similar to what was presented in Task 4 initial guidance).

Our goal is to complete the Task 7 analysis by the end of the year using readily available data, however, based on panel direction, further data from North Carolina can be collected as part of this project requiring additional time to complete the Task 7 analysis.

#### Subtask 3.2 (Topics 3 and 4) – Guidelines on Maintaining Standardized Database and Prioritizing Input Data Elements

#####

##### Background

Practitioners are often faced with the decision on what input data elements to prioritize for collection for inclusion in the calibration datasets. There are two issues to consider here:

* Maintaining the calibration database over time include unified procedures for checking the currency of database variables and criteria for adding or dropping sites. Agencies should also be encouraged to retain all calibration databases that are assembled to support future updating activities.
* Prioritizing the collection of input data elements by need, safety influence, and cost to collect, where more data collection effort is expended toward including high priority data and lower priority data may be defaulted.

For both these issues, Working Paper 8 outlined initial guidance that practitioners can use to prioritize input data elements for collection for inclusion in standardized calibration datasets.

##### Initial Guidance

The approaches discussed for both these issues were based on Saleem et al. (2020) and Alluri et al. (2014) and used the random forest technique for prioritizing the collection of input data elements.

To evaluate the approaches discussed in Saleem et al. (2020) and Alluri et al. (2014), data compiled as part of two recent projects (NCHRP Project 17-72: Update of Crash Modification Factors for the Highway Safety Manual; and NCDOT Project 2020-27: Updated and Regional Calibration Factors for Highway Safety Manual Prediction Models 2016-2019) for rural two-lane roads and rural multi-lane divided roads from North Carolina, were utilized. The data collection for this effort was completed in Spring 2021 and have been included in the final report of these two projects.

The percentage increase in mean squared error (MSE) with the removal of a variable from the random-forest model are commonly displayed using random forests (Saleem et al., 2020).

Based on the random forest analysis conducted using North Carolina data for rural two-lane roads and rural multi-lane divided roads in Task 4, the following guidance is recommended to identify input data elements as those of primary, secondary, and lesser importance:

* Primary importance – % Increase in MSE of greater than 50%.
* Secondary importance – % Increase in MSE of between 20% and 50%.
* Lesser importance – % Increase in MSE of less than 20%.

Working Paper 8 also lists the data elements needed for calibrating the SPFs for rural two-lane roads and rural multi-lane divided roads along with the value types for each data element of interest as well as the units / string to be collected. Data elements of primary importance will be those that are needed to apply base condition HSM SPFs, whereas data elements of secondary or lesser importance are those needed to properly apply the CMFs to the actual conditions.

Based on the availability of funding, agencies should prioritize collecting data for data elements of primary and secondary importance, with an option of using default base conditions for data elements of lesser importance. However, if the calibration dataset is being collected for the first time, it would be recommended that a complete data assembly is undertaken to collect all required data elements in a standardized form. Agencies can then, in subsequent years, prioritize the updating of elements based on availability of funding and the importance bins.

##### Proposed Refinements to Initial Guidance

The initial guidance was developed primarily using readily available North Carolina data. Data for urban arterials from North Carolina is also now available and will be used in Phase 2 to further expand the guidance to urban arterials.

It should be noted that the data elements of primary/secondary/lesser importance may vary across States due to changes in local conditions. To overcome this issue, in Phase 2, the research team will try to obtain ready to use data from other States to help further refine and develop unified national guidance on prioritizing input data elements for collection. For this purpose, data collected for urban arterials in Ohio for developing guidance for Subtask 3.2 (Topics 1 and 2) can be used alongside detailed data for rural two-lane roads in Pennsylvania for which the research team has asked for permission to use. Further efforts will be made to acquire permissions for using datasets used in NCHRP Projects 17-58, 17-62, 17-68, and 17-70 for developing prediction models for the upcoming 2nd Edition of the HSM.

Furthermore, in Phase 2, the research team will also refine the guidelines for maintaining the calibration database over time (including possibly maintaining a national repository/clearinghouse of calibration datasets from all states) and discuss possible procedures for checking the currency of database variables and criteria for adding or dropping sites.

## Task 8 – Develop Implementation Guide

The objective of Task 8 is to develop an implementable approach and guidance for maintaining and updating existing and future safety performance functions and factors. Products of this task will include:

1. CPM Management Manual
2. Functional Specifications for Automated CPM Management System

In Task 4 Phase 1, the project team developed guidelines for calibrating and re-estimating CPMs, including:

* When to calibrate or update,
* How to calibrate or update,
* When to re-estimate, and
* How to re-estimate.

Task 7 will take those CPM management guidelines and apply test cases to them to demonstrate how to use the guidelines, how to interpret the results, and refine the proposed guidelines. As a part of this task, the project team will document the guidance developed in Phase 1 and demonstrated in Task 7, but in a user-friendly manner and a manner that can be easily implemented by agencies.

### CPM Management Manual

The CPM Management Manual will be a guidance document to help agencies implement the proposed approach to maintain and update existing and future CPM functions and factors. The approach for developing the CPM Management Manual will include the following steps.

1. **Select a target audience.** The project team will first select a target audience, so the manual is tailored to specifically meet the needs of that audience. The target audience could include highway safety engineers, analysts, and researchers.
2. **Develop an annotated outline.** Once the target audience has been identified, the project team will develop an annotated outline and determine the desired content within each chapter. Having a complete and well-defined annotated outline helps to structure the document and minimize large scale changes in later drafts. It also allows multiple authors to work in parallel to write sections and chapters. It will be shared with the Panel, and Panel comments will be integrated into the CPM Management Manual.
3. **Draft document.** Based on the annotated outline, the project team will develop the draft CPM Management Manual, which will provide an overview of quantitative safety principles and describe methods and tools for monitoring the performance of and adjusting functions and factors as appropriate. Examples and case studies will be included throughout to help demonstrate the application of the methods and any supporting tools. This will help bring guidelines to an implementation-level. We will draw on the lessons learned from discussions with agencies in prior tasks to provide tips and tricks for monitoring and updating functions and factors. Other ideas for consideration to be included in the CPM Management Manual, which will help take the guidance to the implementation-level include:
	1. Developing a checklist of what is needed to perform each activity (e.g., what data are needed to develop a calibration factor),
	2. Including a list of the steps for each activity with more detail provided later in the manual, and
	3. Clarifying what software and/or skillset are needed.

The project team will convene subject matter experts from national research and practice committees on highway safety to seek feedback on the draft CPM Management Manual as a part of Task 9, and the final document will be developed as a part of Task 10.

### Functional Specifications for Automated CPM Management System

The project team will also develop functional specifications for an Automated CPM Management System based on the guidelines (Task 4), test cases (Task 7), and CPM Management Manual (Task 8). It is important to note that the functional specifications will not be geared towards any type of software application. The document will describe flow charts, functional specifications, algorithms and equations, software design specifications, system requirements, testing protocols, implementation options, and maintenance procedures.

The Automated CPM Management System will be developed once the CPM Management Manual content is finalized, as its content will be the basis for the flow charts and equations in the Automated CPM Management System. Similar to the manual, the automated system document will be provided to the Panel for review and comment, and the document will be revised accordingly.

## Task 9 – Coordinate with NCHRP and AASHTO Committees for Review and Comment

This task will convene subject matter experts from national research and practice committees on highway safety to seek feedback on the draft CPM Management Manual to assure the research products are realistic and implementation ready. The product of this task will be a working paper that summarizes the comments received and the corresponding proposed changes to the CPM Management Manual.

The project team proposes two meetings over the course of the project. Candidate committees include TRB Standing Committee ANB20—Safety Data, Analysis and Evaluation; TRB Standing Committee ANB25—Highway Safety Performance; and AASHTO Committee on Safety. The project team also proposes a second workshop or session for feedback in conjunction with a meeting of the AASHTO Committee on Safety. One meeting will be directed at researchers and the other geared toward practitioners. These meetings will occur electronically, in conjunction with TRB Annual or Midyear Meeting, or alongside another prominent conference or meeting to reduce travel costs. The project team will work with a representative group of volunteers from the proposed TRB and AASHTO committees to get feedback.

Prior to each meeting, the project team will supply the volunteers with a detailed overview of the methodology and instructions how to implement the guidance developed in task 8. The volunteers will be asked to review and apply the methodology to the extent possible. The project team will facilitate a meeting to solicit feedback in both general terms (e.g., overall understanding of the methodology) and specifics (e.g., applicability and ease of methodology). Since the approach will have been vetted by others and the panel at this point, the meeting will seek input on glaring issues and suggestions to improve the guidance document. Following the web conference, we will summarize the discussion and prepare a response to comments, with detailed steps to addressing concerns. All suggested revisions to the research products will be approved by the project panel prior to implementing changes, if desired.

## Task 10. Develop Final Deliverables

The final deliverables will include: (1) a final report documenting the entire research effort; (2) a stand-alone document that includes guidance on updating functions and factors (CPM management manual); (3) functional specifications for an automated CPM management system; (4) prioritized recommendations for future research; (5) an info-graphic-style presentation describing the background, objectives, research approach, findings, and conclusions; (6) a stand-alone technical memorandum titled “Implementation of Research Findings and Products”; and (7) a memorandum for AASHTO with recommendations for updating functions and factors. A draft of the deliverables will be submitted to NCHRP 3 months before the end of the contract. Following panel review and comments, the final deliverables will be submitted to NCHRP by the end of the contract.

# REFERENCES

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