MPC-438
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Project Title:
Calibration of HSM Predictive Methods on Rural State and Local Highways

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South Dakota State University

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Research Needs:
Defining safety performance expectations is a challenge for transportation agencies. The Highway Safety Manual (HSM) of the American Association of State Highway and Transportation Officials provides guidance for safety analysis using scientific and statistically sound methods (1). Given the expense of engineering studies and limited funding, safety reviews based on expected safety performance are a useful way to identify hot spots in a highway network as well as site-specific safety problems. Predictive crash models, as formulated in Equation 1, pinpoint sites with great promise for crash reduction on the basis of decades of safety research and statistical analysis.

$$N_{predicted} = N_{spf} \times C \times (CMF_1 \times \cdots \times CMF_n) \quad (1)$$

Where $N_{predicted}$ is the predicted average crash frequency for a site, N_{spf} is the predicted average crash frequency for base conditions for a site, also called safety performance function (SPF), and C is the calibration factor (C_r is for a roadway segment and C_i is for an intersection). A series of crash modification factors (CMFs) account for changes in the number of crashes due to specific site characteristics or safety treatments. Locations where the actual crash count is higher than the predicted crash count need to be further investigated for safety improvements.

Because safety conditions change over time, agencies should not use HSM models without calibration. Uncalibrated models compromise safety estimates, produce unrealistic results, and undermine accountability. Even agencies that use their own data to develop SPFs should consider calibrating the models every two to three years. HSM models must be calibrated for the results to be comparable to the estimates obtained from an agency's records.

The South Dakota Department of Transportation (SDDOT) has implemented HSM guidelines in its project development and planning process. Specifically, HSM SPFs and CMFs are used to screen South Dakota (SD) roadways in order to find problem areas for further safety review. The SDDOT also uses HSM models to compare safety design alternatives, evaluate site-specific safety issues, and program and plan future safety projects. Although calibration procedures are available in HSM Appendix A, they need to be refined or modified to accommodate SD's data availability and roadway, traffic, and crash characteristics. It is imperative to develop a SD version of HSM models using proper calibration methods and to provide guidance for future calibration activities.

Research Objectives:

The following two objectives will be addressed in this study:

1) Calibrate HSM predictive models to SD data for all rural facility types where SPFs are available and provide guidance on the selection of CMFs.
2) Develop guidelines for future calibration of HSM predictive methods.

Research Methods:

We will review SD data for all types of rural facility and identify the ones for calibration according to data availability and needs of state and local agencies. The proposed calibration method will be based on the procedures recommended in the HSM and enhanced with appropriate modifications suitable to SD situations. Beginning with an evaluation of base conditions in the HSM for each facility type, we will define and establish more realistic and representative base conditions and develop corresponding SPFs. Next, we will calibrate the CMFs by first converting them to new base conditions, and then calculating the distribution of crash types using SD crash data. The final step will be a calibration factor which accounts for all unavailable factors contributing to the disparity between predicted and observed crash frequencies (such as weather, driver and animal populations, and crash reporting threshold and practices). Moreover, statistical methods will be applied to determine whether a state-specific calibration factor should be further stratified by region (e.g. Black Hills vs. non Black Hills) or roadway ownership (State vs. local). We will use sample data provided by the SDDOT to compute the results with and without these modifications. Appropriate modifications to HSM procedures will be recommended to agencies based on the results.

Expected Outcomes:

It is anticipated that HSM crash prediction models will be calibrated using SD safety data and eventually, a SD version of HSM will be directly applicable to the SDDOT in its safety analysis, including transportation network screening for safety problem areas and safety evaluation for programmed or future highway projects. The proposed methodologies can be transferred to other state or local agencies to facilitate their own calibration efforts.

The project will develop HSM Part C predictive methods guidelines for agencies. Under the guidelines, HSM safety prediction models can be regularly updated with the latest crash data. The up-to-date information will be an important performance measure for monitoring highway safety conditions over time.

Relevance to Strategic Goals:
Road safety is vital for sustaining safe and livable communities and has implications for health promotion because it results in preventable deaths and injuries. The calibrated HSM methods will equip the transportation agencies with the most accurate safety analytical tools to make better decisions and meet safety performance goals.

The new surface transportation act, "Moving Ahead for Progress in the 21th Century" (MAP-21), requires state DOTs to set safety goals for reducing fatalities and serious injuries. State performance will affect the spending of safety funding. The outcome of the project will strengthen agency accountability in spending safety funding and enable the SDDOT to meet or exceed federal requirements.

Educational Benefits:
This research project will involve graduate students and undergraduate students in data collection and analysis, as well as the preparation of guidelines. It will provide first-hand research experience for students to master analytical techniques and practice their communication skills.

Work Plan:

The 13 project tasks are detailed below. The schedule of work by month is listed in Table at the end of the work plan.

1) Meet with the project's technical panel in Pierre, SD, to review the project scope and work plan.

Within a month of the execution of a signed contract, the research team will meet with the project's technical panel at the SDDOT office in Pierre, SD, to discuss the project's scope and work plan.

2) Review and summarize literature pertinent to the calibration of HSM predictive methods, including information about other state DOT efforts to develop or calibrate HSM SPFs.

Having gained extensive knowledge about the predictive methods in the HSM, we are familiar with the HSM SPFs calibration process. We have already collected and reviewed literature pertinent to the calibration of HSM predictive methods as well as the development of HSM SPFs. We will continue to update and summarize the relevant studies, focusing on lessons learned from states that have either calibrated HSM predictive methods or developed their own SPFs, particularly those with a significant amount of low volume roads similar to SD.

3) Apply HSM Part C calibration techniques to sample data provided by the SDDOT.

Acknowledging substantial variations from one jurisdiction to another for reasons such as climate, driver demographics, animal populations, crash reporting practices and procedures, the HSM provides specialized calibration procedures common to all Part C chapters. According to the HSM, the calibration of the Part C SPFs will yield satisfactory results that compare with predictive models directly developed with agency safety data. To prove this concept, we will use sample data provided by the SDDOT to implement the calibration process recommended in HSM Appendix A without any modifications. Sample data should contain all necessary data components for calibrating the HSM crash prediction models.

4) Review base conditions for SPFs defined in the HSM and define a set of base conditions appropriate for SPF models used on SD highways.

Task 3 is a faithful implementation of the HSM recommended calibration process using the HSM base conditions for SPFs. Generally, the type of roadway segment or intersection considered as base should be the most representative. Unfortunately, the SPFs in the HSM were developed using data from states that do not include SD, resulting in base conditions that may not be realistic and representative for SD's roadways. Using the minority to calibrate the majority may undermine calibration accuracy. Therefore, it is important to define, establish, and convert a set of base conditions applicable to SD highways.

We will review all roadway segments and intersections within each facility type defined in the HSM, such as rural two-lane two way roads, rural multilane highways, urban and suburban arterials, and freeways. Using the same controlling variables (e.g. lane width, shoulder width and type, etc.), we will determine new base conditions.

Accordingly, we propose two methods for developing SD SPFs under the defined base conditions. The first method only uses data conforming to base conditions. In this approach, the SPFs will be developed from a group of homogenous sites and the CMFs will be completely independent of SPFs. The second approach is to develop a full model using data with a broader spectrum of conditions than the base conditions, and then set the values of variables to the base conditions. Although both methods are mentioned in the HSM, one of them will be recommended to the SDDOT based on the comparison with the benchmark information from Task 3.

5) Identify the facility types for which SPFs will be calibrated based on data availability and the needs of the SDDOT and local agencies.

Although the first edition of the HSM contains 10 intersection types and five segment types, some of these are not available in SD, a predominantly rural state. Moreover, some facility types constitute a very small portion of the highway systems. A small sample size will undermine the quality of calibration because of high chance of randomness. The 1998 SDDOT study "*Identification of Abnormal Accident Patterns at Intersections*" developed expected values for 14 intersection categories by a number of factors, including area type (urban/rural), number of approaches (3-legged/4-legged), traffic control (signalized/four-way stop/two-way stop), traffic volume (above or below 15,000 daily entering volume), and city (Rapid City/Sioux Falls) (12). The study illustrated the large diversity of intersection types in SD and the extremely low number of sites in some intersection categories (such as rural multilane highways three-leg intersection with minor-road stop control and rural multilane four-leg intersection with four-way stop). SD intersections need to be reclassified to be aligned with the intersection categories defined in the HSM.

6) Recommend any necessary modifications to HSM procedures and calculate an appropriate

sample size for calibration.

The potential areas for improvement include A) define new base conditions and develop new base models; B) convert CMFs to new base conditions; C) substitute default values with state-specific values; and D) determine region-specific calibration factors. Figure 1 integrates the proposed modifications into the HSM calibration process to illustrate where they may occur.

With the definition of new base conditions and the development of new base models described in Task 4, the SPFs developed with SD data will be more accurate and reliable for predicting crash frequencies under base conditions. CMFs must be converted accordingly, as they represent quantitative changes in predicted crash frequencies resulting from site characteristic variations from base conditions.

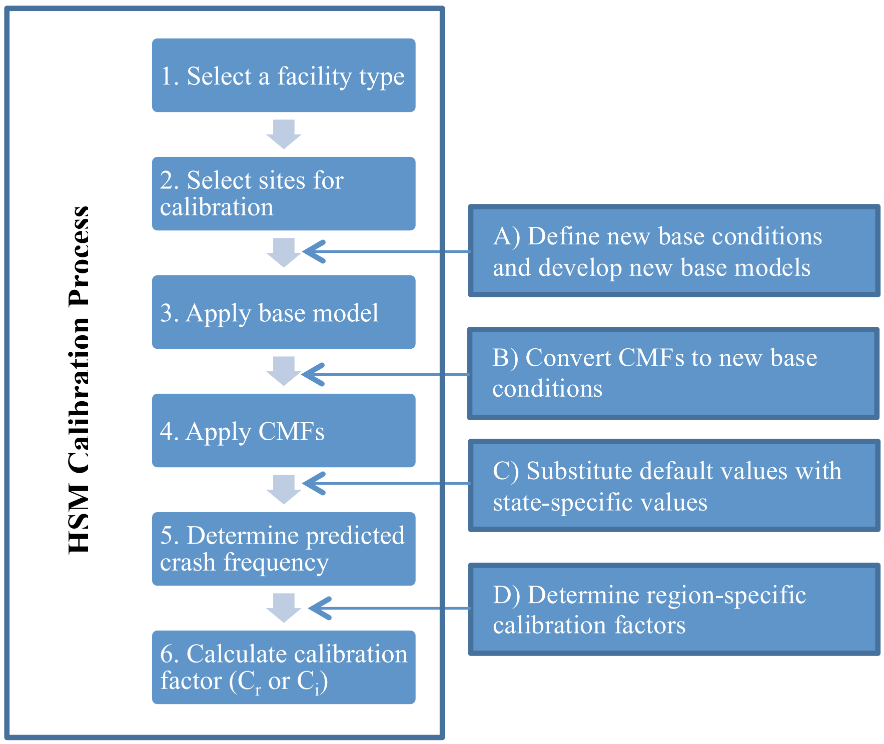

Figure 1. Proposed modifications to calibrate HSM Part C predictive methods.

Converting CMFs to the new base conditions only constitutes part of the process. The rest of the calibration will depend on the safety effectiveness of individual countermeasures. Not every safety treatment will reduce crashes of all types. For example, widening shoulders may decrease single-vehicle run-off-the-road and opposite-direction crashes, but is not necessarily effective in reducing other types of crashes. Changing crash-specific CMFs can be completed by replacing default values embedded in HSM predictive models.

Separate calibration factors may be considered for regions with distinct features such as mountain vs. plain, dry vs. wet. Moreover, although not mentioned in the HSM, safety data may be further stratified by traffic volume or site characteristics such as posted speed limit. This is discussed in greater detail in Task 9.

For each facility type, the HSM requires that the minimum sample size for the calibration data set is 30 to 50. While these sites should be randomly selected from the population for one or more years, irrespective of the number of crashes, at least 100 crashes per year per site are expected. Sensitivity analyses will be conducted for one-, two-, and three-year calibration periods. More than three years is not recommended due to possible changes on the ground, (e.g. traffic conditions, geometrics, etc.). We recommend using all available data, if possible. If only sample data are available, the HSM minimum requirements should be met or the calibration may be jeopardized.

7) Determine which CMFs are appropriate for use in calibration and provide guidance on future application of CMFs.

CMFs represent quantitative changes in predicted crash frequencies resulting from a change in site characteristics, including roadway geometrics, traffic conditions, roadside features, and traffic enforcement. To determine appropriate CMFs for SD highways, it is important to know the existing base conditions for each facility type. Task 4 defines and establishes new base conditions and SPFs, while Task 6 describes modifications to CMFs under different base conditions.

Working with SDDOT's project planning and development, we will review and summarize the safety improvement projects implemented in SD in the past five years and identify the most appropriate CMFs for further calibrations. For promising safety improvements that have not been implemented in SD, we will provide a list of candidate CMFs for consideration. The CMFs will be recommended based on their rating on the national CMF clearinghouse website at www.cmfclearinghouse.org (13).

8) Submit a technical memorandum and make a presentation to the technical panel summarizing the literature search and propose a SPF calibration methodology for approval.

We will present a technical memorandum to the technical panel for approval before proceeding to the next task. This memorandum will include the literature review, results from the sample data, calibration methodologies, and proposed modifications.

9) Upon approval of the technical panel, apply a statistical analysis to determine whether SPFs need to be developed for different regions, such as Black Hills versus non-Black Hills roads, local and state roads, or other categories deemed important by the technical panel or the literature.

One of the modifications proposed in Task 6 is stratification of the calibration factor to meet specific circumstances. The SPFs and CMFs predict crash frequency based on known site characteristics such as AADT, highway design geometrics, traffic conditions, etc. Unknown or unobserved factors can be considered by a scale factor. However, if we know the differences that contribute to crash occurrence, these differences could be considered explicitly, such as those caused by region, Black Hills versus non-Black Hills roads, roadway ownership, local and state roads, etc.

Among the many statistical methods available for detecting differences, classification and regression tree (CART) is recommended. CART is a popular data-mining technique that splits large data into more homogenous datasets based on the values of input variables. We will analyze each possible data classification variable deemed important by the technical panel or the literature and recommend those most suitable and applicable to SD.

10) Calibrate the HSM SPFs to SD data using the proposed methodology.

In this implementation step, we will apply the approved SPFs, CMFs, and stratified calibration factors to calibrate each highway facility separately. The results will be summarized in a worksheet entitled "SD version of HSM predictive methods worksheet."

11) Develop guidelines for future calibration of SPFs.

Guidelines for future calibration of SPFs will be a critical part of the final report. These guidelines will synthesize the lessons learned and key findings, and will focus on defining the data requirements, identifying key components to be calibrated, recommending calibration time intervals, and identifying appropriate sample sizes for each highway facility type. Such guidelines will help the SDDOT effectively implement the calibration processes and procedures, produce consistent and accurate safety predictions, and support and defend safety improvement investment decisions. Some critical points to be included in the guidelines are highlighted below:

a) *Calibration time interval*. Crash frequencies change over time and vary between different highway facility types. How often should calibration be performed to maintain current safety information? When will the new data become available? And when will the safety analysis be performed and safety improvement decisions be made? These key dates will align with the calibration effort. A timeline will be developed to include all important dates and activities related to calibration, as illustrated in Figure 2.

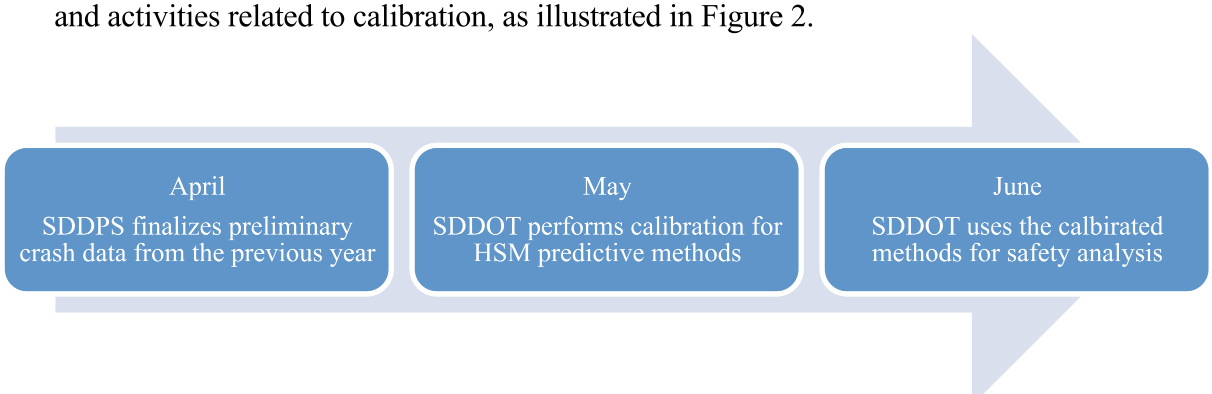

Figure 2. Hypothetical Timeline for HSM calibration.

b) *Critical components to be calibrated*. Because the base conditions represent realistic and prevailing site characteristics for each facility type in SD, and SPFs will be developed from the SD data, the coefficients of the SPFs should remain unchanged. The important components to be considered are CMFs and calibration factors. Detailed instructions will be provided on their calibration.

c) *Sample size*. Although all sites in each facility type can be used to calibrate the models, a sufficient number of sites can achieve the same level of accuracy with lower costs. It will be useful to identify the minimum required sample size for each facility type to facilitate the calibration process. Sampling strategies are especially effective for facility types whose sites vary in the required data elements contained. A number of sites can be permanently slated for calibration unless their characteristics change. If changes happen to a slated site, it will be replaced by other eligible sites.

d) *Presentation*. It is important to develop simple, clear, and consistent guidelines. Diagrams and tables will be used to elucidate the calibration process.

Finally, the guidelines must clearly address the important issues and explain the core reasons and importance of calibration to the people who will perform this activity.

12) Prepare a final report summarizing the research methodology, findings, conclusions, and recommendations.

The outcomes of all tasks will be synthesized in a comprehensive review of the project. We will prepare a final report documenting project results, findings, data requirements, methodologies, conclusions, and recommendations. This report will be submitted to the SDDOT technical panel for review and comments, and will be revised accordingly.

13) Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The research team will meet with the technical panel after the completion of Task 12 to present the outcomes of the study.

The timeline for the completion of all project tasks is outlined in Table 1.

Table 1: Schedule of Tasks

Tasks	Months								
	1	2	3	4	5	6	7	8	9
1. Develop work plan and meet technical panel	■								
2. Review literature	■	■	■						
3. Apply HSM procedures		■	■						
4. Define and establish new base conditions		■	■						
5. Identify facility types			■	■					
6. Recommend modifications			■	■	■	■			
7. Determine appropriate CMFs			■	■	■	■			
8. Present memorandum to technical panel					■	■			
9. Determine calibration factors					■	■			
10. Implement the calibration method					■	■	■	■	
11. Develop guidelines							■	■	
12. Prepare final research report							■	■	■
13. Present to review board									■

Project Cost:
Total Project Costs: $ 100,000K
MPC Funds Requested: $ 45,000K
Matching Funds: $ 55,000K Source of Matching Funds: SDDOT

TRB Keywords:
Highway Safety Manual (HSM), Calibration, Safety Performance Function (SPF), Crash Modification Factor (CMF)

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