Calibrating the HSM for Transportation Planning Projects in Alaska

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ABSTRACT

The first edition of the Highway Safety Manual (HSM) was published in 2010, providing an authoritative resource to use in predicting the safety implications of different treatments at specific locations. The HSM contains Safety Performance Functions (SPFs) for specific types of roadway facilities that can be used to determine the expected number of crashes at a given location based on geometric and operational features of that location. The SPFs presented in the HSM were developed using sites representative of the United States in general; however, states and localities are encouraged to calibrate the SPFs for their local area. This paper reports on two transportation planning projects for which the HSM was used. One project involved calibrating the HSM's intersection SPFs for the Anchorage, Alaska area. In order to achieve results that could be used in developing the expected cost of crashes, the number of fatal or injury crashes (FI) and the number of property damage only crashes (PDO) were calibrated in addition to calibrating the total number of crashes. Another project, on the Kenai Peninsula of Alaska, involved two-lane two-way highway segments. Since data was not obtainable for full calibration, the Empirical Bayes methodology of the Interactive Highway Safety Design Model (IHSDM) was used to improve the model to more reliably match the specific characteristics of the study site. For this project, it was necessary to consider types of crashes in order to obtain a reliable model of the existing study site characteristics. Crash types that were especially important in adjusting the model to match the existing conditions include moose-vehicle crashes and head-on crashes. The paper reports on the calibration constants that were developed, describes the importance of using calibrated SPFs, and discusses reasons why it may be advantageous to develop unique SPFs for the Anchorage area rather than relying on calibrated SPFs from the HSM. The paper furthermore describes how the Empirical Bayes methodology improved the analysis regardless of whether or not calibration constants were available.

SAFETY IN TRANSPORTATION PLANNING

One of the main focuses of transportation engineering is increasing the safety of transportation facilities. This is reflected in initiatives like "Vision Zero" (the goal to eliminate all traffic fatalities) and is encoded into law in the most recent federal highway legislation, MAP-21, which states that one of the national goals for the Federal highway program is "to achieve a significant reduction in traffic fatalities and serious injuries on all public roads." One new tool to aid in achieving these goals, published by the American Association of State Highway and Transportation Officials (AASHTO) is the Highway Safety Manual (HSM). The HSM presents a guide to incorporating statistical methods into the process of identifying locations with safety concerns, identifying countermeasures to improve them, estimating the effect of those countermeasures to aid in decision making, and evaluating safety projects that have been constructed or implemented. Transportation planning frequently involves evaluating a set of possible alternatives to determine the effects of each on a variety of factors, including safety, capacity, construction costs, societal costs, environmental impacts, etc. The HSM methodology can aid in evaluating the safety effects of these alternatives.

The traditional method of considering safety in the planning stages of transportation projects involves cataloging the crash history over a period of 5 to 10 years and then examining the effects of each proposed countermeasure by applying crash modification factors to the historical crashes. This method doesn't take into account how historical and future traffic volumes affect crash patterns. The results under this method can also be skewed by low-probability events. The HSM method uses data from a statistically representative sample of similar locations to remove some of the bias introduced when only one location is considered in the analysis and also allows the engineer to make future crash predictions based on traffic forecasts. This paper presents two transportation planning projects in Alaska that used the HSM to quantify future crash predictions, explains how the HSM was calibrated for each project, and describes the results of the safety analysis.

APPLYING THE HSM TO ALASKA

There are a variety of reasons why the number and severity of crashes may be different for localities within Alaska when compared to the test sites used for the development of the Safety Performance Functions (SPFs) in the HSM. These characteristics include: climate (cold winters and hot or temperate summers, depending upon the specific location), lighting (few hours of sunlight in the winter and few hours of darkness in the summer), and the animal population (frequent moose-human interactions in both urban and rural areas), as well as the ability to log self-reported crashes online on the Alaska Department of Transportation and Public Facilities (DOT&PF) website. Experience with using the uncalibrated HSM to predict crashes for a number of different intersection and segment types indicates that the HSM tends to underpredict the frequency of reported crashes in Alaska. For example, Table 1 compares the uncalibrated HSM predicted crash frequency for urban segments in Alaska with the observed crash frequency at the same locations.

Segment Type	Time Period of Observation	Observed Length (miles)	Number of segments	Predicted Crash Frequency	Observed Crash Frequency
Two-lane undivided	1999 to 2010	7.28	3	84	196
Five-lane with center two-way-left-turn lane	2005 to 2009	1.61	4	1442	1724
Four-lane divided	2005 to 2009	2.12	5	257	691

Table 1 – Example comparison of uncalibrated HSM crash prediction for Alaskan highways to observed crash frequency

INTERSECTION SPF CALIBRATION FOR ANCHORAGE

The first project was a reconnaissance study evaluating nine unsignalized intersections in the South Anchorage and Hillside area of Anchorage, Alaska characterized by low density development, relatively low traffic volumes, and steep grades. DOT&PF chose the nine intersections for this study because they had one or more of the following characteristics:

- entering volumes suggesting the need for a signal warrant analysis
- a history of one or more severe crashes in a 5-year period
- a history of five or more angle crashes in a 1-year period

The study required a detailed analysis of alternatives for each of the nine intersections, comparing the benefits and costs of each alternative. Benefits for each alternative were quantified in terms of cost savings due to a reduced number of crashes and due to reduced delay. Costs were quantified as construction, maintenance, and operation costs. The net present value of the costs was estimated for a 10-year project life cycle for each alternative and a benefit-cost analysis was used to rank the alternatives.

The HSM was used to predict the future crash frequency over the 10-year project life, given future average annual daily traffic (AADT) forecasts for each leg of the intersections. As some of the intersections were relatively high crash locations and others were relatively low, it was important to ensure that the crash forecasts gave an accurate comparison between intersections.

METHODOLOGY

Kinney Engineering, LLC (KE) used the calibration procedure explained in Appendix A of the HSM Part C to calibrate the HSM for Anchorage, AK. The calibrated facility types included intersection types for urban and suburban arterials:

- unsignalized three-leg intersections with stop control on the minor-road approaches (3ST)
- signalized three-leg intersections (3SG)
- unsignalized four-leg intersections with stop control on the minor-road approaches (4ST)
- signalized four-leg intersections (4SG).

Intersections to be used in the calibration for each intersection type were selected from the DOT&PF 2010 list of named intersections. Requirements for intersections chosen for the study included:

- Located in the Municipality of Anchorage
- All approaches two-way
- Major and minor road traffic volumes available

Intersections that met these criteria were chosen randomly from the DOT&PF list. Table 2 shows the number of intersections used in the calibration and the number of total crashes at the chosen intersections by intersection type.

	3ST	3SG	4ST	4SG
Number of locations[a]	30	22[c]	30	30
Total number of crashes (2010)[b]	34[d]	241	135	421

[a] The HSM suggests that at least 30 locations of each type should be chosen for calibration, unless more sites are unavailable.
[b] The HSM suggests that the combined total number of crashes at locations chosen for calibration should be at least 100.
[c] Minor road AADT was available for only 22 signalized three-leg intersections.
[d] Only 30 stop-controlled three-leg intersections with all two-way approaches and available AADT data were identified.

Table 2 – Intersections used in the calibration analysis by intersection type

For each selected intersection, the needed information was collected for the year 2010. This information was entered into a spreadsheet prepared to implement the HSM Part C predictive method for each of these types of intersections. The predicted number of crashes and the resulting calibration factors for each intersection type are shown in Table 3.

	3ST	3SG	4ST	4SG
Predicted number of crashes (2010)	22.9	61.1	39.0	90.5
Calibration factor	1.48	3.94	3.46	4.65

Table 3 – HSM uncalibrated crash prediction and resulting calibration factor

Because accurate crash costs were vital to our study, KE also calibrated the frequency of fatal or injury (FI) crashes and property damage only (PDO) crashes in Anchorage using the same methodology. Table 4 compares the predicted number of crashes of each severity level to the actual number of crashes and shows the calibration factor by severity for each type of intersection.

	3ST		3SG		4ST		4SG	
	FI	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Actual number of crashes (2010)	9	25	79	162	49	86	148	273
Predicted number of crashes (2010)	8.6	14.3	22.5	38.6	15.2	23.8	35.6	54.9
Calibration Factor	1.05	1.75	3.51	4.20	3.22	3.60	4.16	4.97

FI = Fatal or Injury Crashes; PDO = Property Damage Only Crashes

Table 4 – Fatal or Injury and Property Damage Only crash frequency, HSM uncalibrated crash prediction, and resulting calibration factor

Results

As previously discussed, calibrating the HSM prior to performing the Empirical Bayes method significantly alters the resulting expected crash frequency. Table 5 shows how the results differ for the nine study intersections. For the 3-leg intersections where the calibration factor is not very different from 1.0, there is little difference between the uncalibrated and the calibrated crash frequency predictions. However, for the 4-leg intersections where the calibration factor is large (3.46), the uncalibrated predictions generally underestimate the crash frequency even when the Empirical Bayes method is used.

Intersection Abbreviation and Type		Observed Crashes	Predicted Crashes			
			Uncalibrated	Calibrated	Uncalibrated plus Empirical Bayes method	Calibrated plus Empirical Bayes method
ABB	3ST	32	8	12	27	29
SSB	3ST	8	6	9	8	9
ELM	3ST	10	5	7	8	10
OSH	3ST	15	9	13	15	16
COV	4ST	9	9	31	9	13
HUF	4ST	42	6	21	31	41
CAN	4ST	9	2	7	3	8
RCR	4ST	33	5	17	21	31
DEA	4ST	17	8	28	14	19

Table 5 – Comparison of predicted crashes for uncalibrated and calibrated HSM analyses (2000 through 2010)

SIGNAL ALTERNATIVES

Installation of a signal was considered as an alternative for four of the nine intersections in the study. The initial plan was to evaluate the future condition using the appropriate calibrated signal SPF to determine the effect on crashes of converting the intersections where signals could be warranted from stop control to signal control. Note that the Empirical Bayes Method could not be used with the signal control SPF because the historical data does not reflect crash patterns under signal control. In every case, the signal control SPF predicts more crashes during these years than the stop control SPF. This result is counterintuitive, however, as experience has shown that crashes tend to decrease when a signal is installed at an unsignalized location.

An alternative analysis was undertaken using crash reduction factors (CRFs) published in the Alaska Highway Safety Improvement Program (HSIP) Handbook. These CRFs have been developed using statewide Alaskan data. For the conversion of stop control to signal control, the given CRFs are 60% for all angle crashes and -25% for all rear end crashes – meaning that angle crashes tend to decrease and rear end crashes tend to increase when signal control is installed. The number of angle and rear end crashes was estimated by assuming the same percentages for future crashes as were observed in the historical data. Two of the intersections (ABB and RCR) occur on steep grades – in the absence of any data specifically targeted at the effect of signalization in areas with steep grades, it was assumed that due to the geometry, the CRFs are altered in these locations (30% for angle crashes and -50% for rear end crashes). In all cases using CRFs, installing signal control is predicted to reduce the number of crashes. Since this result meets expectations and incorporates local experience, this was the method used for examining the effect of signalization at these locations.

Table 6 compares the predicted crashes for the years 2013 to 2023 from the calibrated stop control SPFs to the predicted crashes from the calibrated signal control SPFs at applicable intersections. Table 7 shows the results when the CRFs are applied to the future crashes predicted using the calibrated stop control SPF and the Empirical Bayes method. Another benefit of using the method of applying CRFs was that it allowed the use of the Empirical Bayes method in the analysis of the signal alternatives, which ensured that the analysis could be compared across alternatives.

Intersection Abbreviation	Number of Approach Legs	Predicted Crashes (2013 to 2023)	
		Calibrated Stop Control SPF	Calibrated Signal Control SPF
ABB	3	17	28
SSB	3	10	28
CAN	4	22	41
RCR	4	22	37

Table 6 – Comparison of predicted crashes for calibrated stop control SPFs and calibrated signal control SPFs (2013 to 2023)

Intersection Abbreviation	Number of Approach Legs	Predicted Crashes (2013 to 2023)	
		Calibrated Stop Control SPF and Empirical Bayes Method	Calibrated Stop Control SPF, Empirical Bayes Method, and CRFs
ABB	3	45	41
SSB	3	9	8
CAN	4	30	12
RCR	4	40	34

Table 7 – Comparison of predicted crashes for stop control SPFs and stop control SPFs with signal CRFs applied (2013 to 2023)

Lessons Learned

The spreadsheet we used for calibrating the HSM methodologies for the four intersection types was able to be used with minor modifications for predicting crashes at the nine study intersections. This reduced the amount of effort needed to determine calibration factors and then analyze study locations.

In order to compare alternatives at individual intersections and then also to rank projects across multiple intersections, it was essential to use the same methodology for all alternatives at every intersection.

A comparison of the HSM SPFs for stop control and for signal control seems to indicate that signal control may increase crash frequency over stop control under some conditions. There appears to be some research being undertaken on this topic. For instance, Wang and Abdel-Aty recently presented a paper on the effect of major road traffic volumes on crash modification values for conversion of stop-controlled intersections to signal-controlled intersections. Their study of 33 intersections found that the conversion to signal control reduced crash frequency for all main street traffic volume levels except for main street traffic volumes between 20,000 and 25,000 vehicles per day. The study was limited by the small sample size and by the lack of data on minor road traffic volumes. Variables that have been previously found to be important, but which could not be included in the study for these reasons include: number of approach legs and minor road traffic volumes. Hopefully, more research will be done on these subjects to improve understanding of how AADT affects safety under different traffic control.

TWO-LANE HIGHWAY ANALYSIS

The second project involved a transportation planning study of an approximately 7.8-mile section of an existing two-lane two-way highway on the Kenai Peninsula of Alaska (the Sterling Highway). The Interactive Highway Safety Design Model (IHSDM) software, which executes the HSM methodology for highway segments, was used to develop a future crash frequency prediction through the year 2040 for the “do nothing” alternative.

Because crash reduction factors for the design alternatives were to be applied by crash type, it was important to ensure that that the IHSDM crash frequency predictions reflected the expected crash types, especially for overrepresented crash types that were targeted for mitigation. Thus, the IHSDM default crash types were altered to match the existing condition crash type percentages for this segment of the Sterling Highway for the years 2000 to 2010. Table 8 compares the IHSDM default crash type percentages with the existing Sterling Highway crash type percentages. Overrepresented crash types (when compared to state-wide averages) are highlighted in red. The table shows that some of the overrepresented crash types on this corridor (animal and head on crashes) are more than twice as likely on the Sterling Highway than is represented by the IHSDM default, while run off road crashes are less than half as likely.

Crash Type	IHSDM Default	Sterling Highway
Collision with Animal	12.1	45.3
Collision with Bicycle	0.2	0.0
Collision with Pedestrian	0.3	0.0
Overturned	2.5	1.1
Run Off Road	52.1	19.4
Other Single-vehicle Collision	2.1	1.3
Angle Collision	8.5	9.6
Head-on Collision	1.6	5.6
Rear-end Collision	14.2	11.4
Sideswipe	3.7	3.1
Other Multiple-vehicle Collision	2.7	3.2

NOTE: Overrepresented crash types (compared to state-wide averages) are highlighted in red.

Table 8 - Comparison of IHSDM Default and Sterling Highway Existing Crash Types (2000 to 2010)

Because the alternatives being considered were specifically focused on mitigating the overrepresented crashes (divided highway to mitigate head-on collisions and lighting to mitigate nighttime moose-vehicle collisions, for example), it was necessary to use accurate crash type percentages to reflect the true benefit of the proposed alternatives.

LESSONS LEARNED

Although calibration of the two-way highway SPF was not possible with this project, calibrating the crash types portion of the IHSDM methodology was not difficult or costly, but improved the analysis considerably and allowed for a more realistic evaluation of alternatives.

Recommendations

Where possible, the HSM SPFs should routinely be calibrated for Alaska projects because the HSM routinely under-predicts crash rates when compared to historical crash rates in Alaska. In addition, the injury severity SPFs should also be calibrated, as the HSM tends to over-predict fatal and injury crashes and under-predict property damage only crashes compared to historical severity rates in Alaska. Where it is important to the project, there is value to calibrating default values used in the HSM crash prediction methodology, including crash type, percent of nighttime crashes, etc.

Consideration should be given to developing unique SPFs for Alaska, for facility types where there is enough data. The large calibration factors needed for the intersections SPFs, for instance, may indicate that the curve represented by the SPF may not fit Alaskan data well. There are conditions in Alaska that are likely to contribute to the need for unique SPFs. These could include: the clustering of the population in urban areas with very little development between them, a different vehicle fleet make-up, consistently dark and icy conditions over several months of the year resulting in different travel speeds, etc. In addition, the range of traffic volumes on certain types of facilities may be different in Alaska than in the sites used for developing the SPFs for the HSM. When calibrating the three-legged signal SPF, for instance, we found that 10 of the 22 intersections used in the calibration had minor road AADTs that exceeded the valid range presented in the HSM for that SPF.

References

- *Highway Safety Manual*, American Association of State Highway and Transportation Officials, 2010.
- *Alaska Highway Safety Improvement Program (HSIP) Handbook,* Alaska Department of Transportation and Public Facilities, 2013.
- *MAP-21 – Moving Ahead for Progress in the 21st Century* (website), Federal Highway Administration, 2013. Accessed at http://www.fhwa.dot.gov/map21/factsheets/pm.cfm on May 1, 2014.
- *Interactive Highway Safety Design Model* (software), Federal Highway Administration, 2013.
- *Comparison of Safety Evaluation Approaches for Intersection Signalization in Florida,* Wang, Jung-Han and Mohamed A. Abdel-Aty, Transportation Research Board Annual Meeting Compendium, 2014.