Calibration of the *Highway Safety Manual* Models for Québec

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EXECUTIVE SUMMARY

Subsequent to publication of the Highway Safety Manual (HSM) by the American Association of State Highway and Transportation Officials (AASHTO) in 2010, the Ministère des transports du Québec (MTQ) launched a process to calibrate the accident prediction models proposed in the manual. The objective of this process is to enhance the accuracy of the models to better reflect the context in other jurisdictions. The initial focus of the process, undertaken by the Direction de la sécurité en transport in conjunction with the MTQ's territorial branches, was rural two-lane two-way roads (HSM Chapter 10). For this type of road, the HSM supplies prediction models for three types of intersections – unsignalized three-leg with stop control on minor-road approaches, unsignalized four-leg with stop control on minor-road approaches and signalized four-leg – as well as roadway segments.

A sample of approximately 50 sites was established randomly for each type of site. The models were designed to take into account information on local conditions (e.g. geometry, traffic) as well as crash data compiled over a three-year period for the selected sites. During compilation, it was observed that the proportion of crashes involving animals was highly variable from one territorial branch to the next and even between sites within a single region. Following consultation with road safety experts at a number of territorial branches, it was agreed that the calibration factor should, for a variety of reasons, preferably be calculated excluding crashes involving animals. It was also interesting to note that in general, the calibration factors obtained did not vary sharply from the unit, indicating that accidents occur in relatively similar proportions to what is observed in the United States.

Next, the proportions of various types of accidents and severities were calculated using data from the sampling of sites selected for the calibration process. These proportions are applied to the total number of accidents calculated using the prediction model to arrive at the number of accidents of each type or severity.

Calibrating the accident prediction method from the HSM in this manner for the Québec context will assist road safety experts in conducting safety analyses more comprehensively and accurately.

INTRODUCTION

The first edition of the Highway Safety Manual (1) was published by AASHTO in summer 2010. This manual was the outcome of nearly a decade of effort by the Transportation Research Board (TRB) with the goal of publishing a reference standard for road safety. It was in the late 1990s that the TRB began forming a number of committees responsible for producing the HSM after noting the lack of a one-stop resource setting out all knowledge and methodologies in the area of safety analysis.

The objective of publication of the HSM is to provide analysis techniques and tools that can be used to quantify the potential impact on crash frequency of decisions made as part of roadway network planning, design, operation and maintenance. A secondary aim is to provide a summary of the valid research in road safety.

The HSM has four main parts, each broken down into a series of chapters on various topics. Part A has three chapters and provides an overview of the content of the HSM and the concept of road safety in general. In Part B, one chapter is devoted to each of the six steps of the roadway safety management process. These steps are: network screening, diagnosis, selecting countermeasures, economic appraisal, prioritizing projects and safety effectiveness evaluation. Part C provides a predictive method for estimating expected average crash frequency for three types of roadways: rural two-lane roads, rural multilane highways and urban and suburban arterials. Each roadway type is covered in a separate chapter in Chapters 10 through 12. Lastly, Part D of the HSM summarizes the effects in terms of road safety of various geometric and operational modifications at a site. Crash modification factors (CMFs) can be used to depict these effects on road safety quantitatively. CMFs are covered in five separate chapters organized by site type.

BACKGROUND

The methodology proposed in Part C of the HSM is based on the use of accident prediction models, also referred to as safety performance functions (SPFs). An SPF is used to estimate the expected average crash frequency for a given time period based on site characteristics. The majority of models were developed in the 2000s under the auspices of research projects conducted in the United States.

Although conditions within the highway system in Québec are quite similar to those in the rest of North America, the outcomes obtained directly using the models in the HSM could reveal significant differences in terms of total accidents actually observed on Québec highways. These differences would relate mainly to climate, animal life and accident reporting rates. The HSM offers an SPF calibration procedure to smooth out these potential differences between jurisdictions. The objective of this is to enhance the accuracy of the models to better reflect the context of other jurisdictions. Road safety analysts can consequently have access to SPFs that more accurately represent Québec to incorporate into their work, which mainly involves conducting research concerning problem sites (black spots), evaluating the effects of countermeasures (before/after studies) and determining the benefits of countermeasures proposed.

Application of the HSM model calibration procedure for Québec was undertaken by the Direction de la sécurité en transport in conjunction with the territorial branches of the MTQ. The initial focus of calibration efforts is rural two-lane two-way roads since this is the most common road type throughout the MTQ's roadway network, accounting for more than 15,000 km of roads. For this type of road, the HSM provides SPFs for three types of intersections – unsignalized three-leg with stop control on minor-road approaches, unsignalized four-leg with stop control on minor-road approaches and signalized four-leg – as well as roadway segments.

The calibration process also provides for substitution of certain values supplied in the HSM, for example, accident distribution by collision type or the proportion of accidents occurring in nighttime conditions. These values are known to vary widely from one jurisdiction to the next. As a result, it is recommended to replace the default values provided in the HSM with values calculated from local data. New values were consequently obtained through the calibration process conducted by the Direction de la sécurité en transport.

CALIBRATION PROCESS

The SPF calibration process is implemented for each of the site types in question based on the following four main steps:

1. Selecting a sample of sites
2. Collecting information about these sites for a specific period
3. Using the models from Part C of the HSM to estimate the expected crash frequency at each site
4. Calculating the calibration factor.

Each of these steps is described briefly on the following pages.

1. SELECTING A SAMPLE

Samples should be chosen randomly from among all sites of each similar type, according to the HSM. Sites should not be selected based on the number of accidents occurring at the sites; in other words, the goal of the selection process is not to simply choose the sites with the highest or lowest number of accidents. The sample should typically include 30 to 50 sites. However, if the information required for calibration is readily available for a greater number of sites, then this greater number of sites should be used for calibration purposes. If a road authority has fewer than 30 sites of a particular type, then all of these sites should preferably be used to calculate the calibration factor. Moreover, the total number of crashes observed at all sites combined should be at least 100 per year.

The HSM also indicates that the sites used for calibration should, ideally, be reasonably representative of the characteristics of the range of sites to which the models are to be applied. However, to keep the information collection process as practical as possible, formal categorization in terms of traffic flow or any other characteristic is not necessary when selecting sites for calibration. Finally, when updating calibration factors, an exercise recommended every two to three years by the HSM, the same sites may be reused.

2. COLLECTING INFORMATION

Information must be collected on road characteristics (geometry, traffic) at each selected site needed to apply the models. The mandatory data are shown in tables 1 and 2 for segments and intersections respectively.

In addition, the number of accidents observed at the selected sites during the designated period must be compiled. Accidents of all severity types should be included for calibration. The period chosen should be measured in full years to rule out any seasonal effects. The HSM does not recommend using a period exceeding three years due to potential changes at sites or in accident reporting practices within road authorities. Similarly, the designated period should generally be the same for all sites in the sample, although occasional exceptions are possible.

The accidents used for calibration should include all accidents occurring at the roadway segments or intersections selected from the sample of sites. Crashes are assigned to roadway segments or intersections following the recommendations set out in the HSM, according to which all accidents occurring within the limits of an intersection are assigned to that intersection (Figure 1, Zone A). Accidents occurring outside of the limits of the intersection (Figure 1, Zone B) are assigned either to the roadway segment in question or to the nearby intersection, depending on the nature of the accident. For example, a rear-end crash occurring 30 m from an intersection is assigned to that intersection if it was caused by a queue at the approach to the intersection. On the other hand, a turning crash occurring on approach to an access point is assigned to the roadway segment in which it took place.

3. APPLYING THE MODELS FROM PART C

In the third step, the process involves estimating the expected average crash frequency for each of the sites through use of the accident prediction models and the information collected in the previous step. In the case at hand, the models in Chapter 10 of the HSM applicable to rural two-lane two-way roads were used. The expected crash frequency is to be estimated for the designated time period, i.e. one, two or three years.

The accident prediction methodology must be applied without use of the Empirical Bayes method, or without combining the expected crash frequency obtained using the prediction models with the observed crash frequency at a site, and without use of calibration factors.

4. CALCULATING THE CALIBRATION FACTOR

The final step of the process involves calculating the calibration factor for each type of roadway element. This factor (Cr) is calculated by dividing total observed crashes by total predicted crashes for all sites selected for the sample using the following equation:

$$C_r = \frac{\sum_{All\ sites} Observed\ crashes}{\sum_{All\ sites} Predicted\ crashes}$$

COLLECTING REQUIRED DATA FOR QUÉBEC

A list of potential sites exhibiting the main targeted characteristics (rural two-lane two-way roads, type of control device at intersection) was developed for the three intersection types and the roadway segments subject to the calibration process. To this end, searches were performed in the various highway database systems maintained by the MTQ. To be classified as rural, roads had to have a posted speed limit of 80 km/h or 90 km/h. Undivided roadway segments were also selected to ensure that their average annual daily traffic (AADT) values were constant by using traffic segments already defined in the MTQ's traffic database system.

A sample of 50 sites was selected randomly from the list for each site type. In the case of signalized four-leg intersections, the total number of potential sites was only 28, and so all of these sites were selected to make up the sample.

Following random selection of the sites, the samples were reviewed to verify that the distribution among territorial branches was representative of the distribution among all sites combined. Tables 3 to 5 present the outcomes obtained for unsignalized four-leg intersections with stop control, three-leg intersections and segments. This verification was not necessary for the signalized four-leg intersections since the sample already included all sites of this type. The site sampling exercise was deemed valid overall in that it presented a distribution representative of that among all sites combined without any significant variations. If it subsequently proved necessary to make substitutions for any sites, an alternate site was selected within the same territorial branch in the interest of maintaining this distribution.

Next, more comprehensive data on geometry and traffic characteristics as depicted in Figure 1 were collected. This was the most time-consuming step of the analysis process. The information required could generally be found in the MTQ's database systems. In cases where information was either not available or too difficult to extract from the systems – for example, the presence of passing lanes, lighting or access density – video surveys were consulted.

In light of the very strong correlation between traffic flow and observed crashes at a site, special care was taken to obtain AADT data. For intersections for which traffic counts were available in the MTQ's database system, values were adjusted to ensure that they corresponded to AADT values for the median year (2007) of the designated time period (2006-2008). For the majority of other intersections for which traffic data did not exist, traffic counts conducted in 2011 and 2012 and then adjusted to arrive at AADT values for the median year were used. AADTs for traffic segments on branches of the main road and estimated AADTs on secondary roads were also used in some cases. For segments, AADTs for the corresponding traffic segment for each year of the designated period were used.

Information collected concerning geometry and traffic characteristics was reviewed by the territorial branches. In some cases, corrections were made to the data; in others, sites found to be non-relevant were replaced. The validation process at the territorial branch level was also undertaken to ensure that no significant changes had been made to any of the sites between 2006 and 2008.

With respect to crash data, searches were conducted in the MTQ's accident database system with a view to compiling data on crashes at each selected site between 2006 and 2008. The scanned reports for all accidents were reviewed to ensure that each accident was relevant, to verify the accuracy of the location and to correct any data input errors.

During preliminary analysis of data relating to the number of accidents observed at each site, it was observed that the proportion of crashes involving animals was highly variable from one territorial branch to the next and even between sites within a single region. Territorial branches where the proportions were high were Mauricie-Centre-du-Québec, Chaudière-Appalaches, Estrie and Outaouais. Similar phenomena were observed in Est-de-la-Montérégie and Ouest-de-la-Montérégie, although on a lesser scale. This variation had fairly significant impact on the calibration factor value, particularly for segments, and created certain challenges with regard to settling on a definitive calibration factor. The use of a single value would have resulted in underestimation of crash numbers in some locations and overestimation in others.

After consulting road safety experts at several territorial branches, it was deemed preferable to use a single calibration factor but to exclude accidents involving animals from the calculation. This approach is in keeping with the general practice at the territorial branch level whereby accidents involving animals are excluded from road safety analyses conducted for the purpose of identifying weak points in the highway infrastructure. Collisions with large animals pose a specific problem that can be made subject to dedicated study which, however, is not generally undertaken as part of site analysis, which relies on use of accident prediction models from the HSM.

OUTCOMES

First, calibration factors applicable to the accident prediction models were calculated for the four types of elements relating to rural two-lane two-way roads. The outcomes are presented in Table 6. It is to be noted that the minimum objective of 100 crashes observed per year was not achieved for intersections with stop control (four-leg and three-leg). Based on the average number of crashes observed at these sites, nearly 200 additional sites would have to have been added to the sample to reach the recommended number of accidents. In light of the significant additional effort required to add this quantity of sites, the decision was made to update the calibration process at a later date to include a greater number of sites for both of these intersection types.

The calibration factors in Table 6 should be incorporated into equations 10-2 (segments) and 10-3 (intersections) from the HSM respectively when calculating the number of crashes predicted by the models. It is interesting to note that the calibration factors do not vary sharply from the unit (except possibly in the case of unsignalized four-leg intersections with stop control), indicating that accidents occur in relatively similar proportions to what is observed in the United States.

Next, the proportions of various types of accidents and severities were calculated using data from the sampling of sites selected for the calibration process. These proportions are applied to the total number of accidents calculated using the prediction model to arrive at the number of accidents of each type or severity. Tables 7 and 8 present the proportions of accidents by type for segments and intersections respectively. In Table 8, the nil values obtained for the proportion of accidents involving cyclists and pedestrians at unsignalized four-leg intersections with stop control are due to the low numbers of accidents in the sample. The use of a value of 0.1%, or the proportion indicated in the HSM, is suggested in this situation.

Table 9, meanwhile, presents the proportions of accidents by severity for segments and intersections. Here once again, the resulting proportions of less than 1% are attributable to the low number of accidents in the sample. The use of a value of 1% is recommended in this case.

CONCLUSION

The objective of the calibration exercise carried out by the MTQ's Direction de la sécurité en transport was to develop calibration factors for Québec for the four SPFs relating to rural two-lane two-way roads as published in the HSM. This exercise revealed that the context of accidents in Québec is not very different from that in the United States insofar as the resulting calibration factors ranged between 0.76 and 1.07.

The calibration exercise also involved establishing the proportions of the various accident types and severities based on data for the sites in the sample. This information will prove useful when applying accident prediction models in terms of establishing their distribution by type or severity.

The Direction de la sécurité en transport plans to continue calibration of the accident prediction models in the HSM. The models in Chapter 11 on rural multilane highways are currently undergoing calibration. The models in Chapter 12 for urban and suburban arterials will also be subject to calibration in the future.

Calibrating the accident prediction method from the HSM in this manner for the Québec context will assist road safety experts in conducting safety analyses more comprehensively and accurately for Québec. This method is currently being incorporated into practices at the MTQ, particularly with a view to identifying sites with potential for improvement and estimating safety impacts during the project assessment process and as part of before/after studies following implementation of countermeasures.

REFERENCE

(1) AASHTO, American Association of State Highway and Transportation Officials, 2010, *Highway Safety Manual*, 1st Edition, Washington, D.C.

Table 1 Geometric and traffic data required for segment calibration

- Segment length - AADT* - Curve length - Curve radius - Spiral transitions - Superelevation variance - Grade - Lane width - Shoulder type	- Shoulder width - Lighting - Access density - Passing lanes - Two-way left turn lane - Centreline rumble strips - Roadside hazard rating - Automated speed enforcement

* average annual daily traffic

Table 2 Geometric and traffic data required for intersection calibration

- AADT* for main road - AADT* for secondary road - Intersection skew angle	- Number of left turn lanes - Number of right turn lanes - Lighting

* average annual daily traffic

Table 3 Distribution of unsignalized four-leg intersections with stop control by territorial branch

Territorial Branch	Sample		Overall Distribution
	Number of Sites	%	
Abitibi-Témiscamingue	5	10%	9%
Bas-Saint-Laurent-Gaspésie-Iles-de-la-Madeleine	8	16%	14%
Chaudière-Appalaches	5	10%	12%
Côte-Nord	0	0%	1%
Capitale-Nationale	1	2%	3%
Estrie	5	10%	10%
Est-de-la-Montérégie	7	14%	10%
Laurentides-Lanaudière	5	10%	11%
Laval-Mille-Iles	0	0%	<1%
Mauricie-Centre-du-Québec	5	10%	11%
Outaouais	2	4%	7%
Ouest-de-la-Montérégie	3	6%	6%
Saguenay-Lac-Saint-Jean-Chibougamau	4	8%	7%
TOTAL	50	100%	100%

Table 4 Distribution of unsignalized three-leg intersections with stop control by territorial branch

Territorial Branch	Sample		Overall Distribution
	Number of Sites	%	
Abitibi-Témiscamingue	3	6%	7%
Bas-Saint-Laurent-Gaspésie-Iles-de-la-Madeleine	4	8%	14%
Chaudière-Appalaches	6	12%	9%
Côte-Nord	2	4%	2%
Capitale-Nationale	1	2%	4%
Estrie	4	8%	11%
Est-de-la-Montérégie	5	10%	7%
Laurentides-Lanaudière	9	17%	18%
Laval-Mille-Iles	0	0%	1%
Mauricie-Centre-du-Québec	8	15%	10%
Outaouais	4	8%	7%
Ouest-de-la-Montérégie	4	8%	6%
Saguenay-Lac-Saint-Jean-Chibougamau	2	4%	6%
TOTAL	52	100%	100%

Table 5 Distribution of segments by territorial branch

Territorial Branch	Sample		Overall Distribution
	Number of km	%	
Abitibi-Témiscamingue	21	12%	13%
Bas-Saint-Laurent-Gaspésie-Iles-de-la-Madeleine	26	16%	15%
Chaudière-Appalaches	20	12%	11%
Côte-Nord	5	3%	7%
Capitale-Nationale	3	2%	4%
Estrie	17	10%	8%
Est-de-la-Montérégie	11	7%	6%
Laurentides-Lanaudière	11	7%	8%
Laval-Mille-Iles	1	1%	<1%
Mauricie-Centre-du-Québec	21	12%	9%
Outaouais	4	2%	6%
Ouest-de-la-Montérégie	11	7%	4%
Saguenay-Lac-Saint-Jean-Chibougamau	15	9%	9%
TOTAL	166	100%	100%

Table 6 Calibration factors for rural two-lane two-way roads

Element	Total Observed Crashes (3 years)	Total Predicted Crashes (3 years)	Calibration Factor (C_r)
Segments	337	316	1.07
3-leg intersections with stop control	83	92	0.90
4-leg intersections with stop control	146	193	0.76
Signalized 4-leg intersections	415	427	0.97

Table 7 Proportion of accidents by type for segments

Accident Type	Proportion (%)
Single-vehicle	
Cyclist	0.3
Pedestrian	0.6
Overturned	9.5
Ran off road	51.0
Other	3.9
Total single-vehicle	65.3
Multiple-vehicle	
Angle	4.1
Head-on	6.2
Opposite left-turn	2.7
Rear-end	15.7
Sideswipe	1.2
Other	4.8
Total multiple-vehicle	34.7
Total	100

Table 8 Proportion of accidents by type for intersections

Accident Type	Proportion (%)		
	3-leg (stop control)	4-leg (stop control)	4-leg (signalized)
Single-vehicle			
Cyclist	2.4	0	0.5
Pedestrian	1.2	0	0.5
Overturned	7.2	0.7	1.0
Ran off road	41.0	18.5	10.3
Other	1.2	0.7	1.7
Total single-vehicle	53.0	19.9	14.0
Multiple-vehicle			
Angle	12.1	39.7	21.7
Head-on	6.0	3.4	1.7
Opposite left-turn	6.0	8.9	12.1
Rear-end	15.7	9.6	38.1
Sideswipe	2.4	10.3	6.7
Other	4.8	8.2	5.7
Total multiple-vehicle	47.0	80.1	86.0

Table 9 Proportion of accidents by severity for rural two-lane two-way roads

Element Type	Accident Severity			
	Fatal	Serious	Minor	PDO
Segment	2%	5%	27%	66%
3-leg (stop control)	<1%	3%	25%	72%
4-leg (stop control)	2%	6%	34%	58%
4-leg (signalized)	<1%	4%	27%	69%

Figure 1 Zones used to assign accidents to intersections or segments (according to HSM)