Adoption of Highway Safety Manual Predictive Methodologies for Canadian Highways

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ABSTRACT

This paper is based on recent research projects for Transport Canada and the Ministry of Transportation that assessed implementation requirements for the Highway Safety Manual (HSM) predictive methods. It serves partly as an illustration of what it takes for jurisdictions to assess their implementation requirements. The focus is on two applications of predictive methods: a) evaluation of the safety impacts of alternate design scenarios using an algorithm that applies baseline safety performance functions (SPFs) and collision modification factors (CMFs) and b) estimation of the safety benefits of proposed or implemented countermeasures. For the first application, the transferability of the HSM algorithm for urban signalized intersections in Toronto is explored by assessing both the base SPFs and CMFs. In general, the recalibration exercise was successful. However, for individual variables, there is some bias indicating that the CMFs could be improved upon. For the second application, a Safety Performance Function (SPF) knowledge base was developed to enable the selection by Canadian jurisdictions of the appropriate SPF for a specific countermeasure and site type. These crash type SPFs, would be used in the economic appraisal of contemplated countermeasures and in the evaluation of implemented treatments. The use of a spreadsheet developed to facilitate the SPF selection process is illustrated.

1. INTRODUCTION

The newly released Highway Safety Manual (HSM) (1) documents state-of-the-art analytical and other tools for the safety management process, including collision prediction methodologies for assessing the safety of a road design and the safety implications of design choices, and for evaluating the safety benefits of proposed or implemented countermeasures. Many jurisdictions have recognized the importance of gearing up for the application of these tools and have undertaken research to facilitate this. Transport Canada has facilitated this research on behalf of Canadian jurisdictions to ensure that they can make maximum use of these tools as soon as possible (2, 3). Companion projects for the Ministry of Transportation, Ontario complemented this effort (4).

The HSM provides important information and methodologies for practitioners conducting highway safety analyses, including:

a) Predicting the expected collision frequency for new and existing locations
b) Evaluating the safety impacts of alternate design scenarios
c) Screening the road network for locations with a potential for safety improvements
d) Diagnosing specific safety problems by conducting site-specific investigations
e) Selection of countermeasures
f) Carrying out cost-benefit analysis for contemplated countermeasures by applying collision modification factors
g) Prioritizing safety improvement projects
h) Evaluation of safety improvements

Fundamental to several of these tasks (a, b, c, e, f, and h) are Collision (or Crash) Modification Factors (CMFs) and safety performance functions (SPFs). For example, for a) and b), the HSM predictive methodology will facilitate the evaluation of the safety impacts of alternate design scenarios by providing the required SPFs and CMFs for intersections and road segments on three roadway types: two-lane rural roads; multi-lane rural roads; and urban and suburban arterials. And a wider range of CMFs is presented in the knowledge section of the HSM for use in selecting countermeasures (e), and undertaking cost-benefit analysis (f). And SPFs are fundamental to the empirical Bayes methodology (5, 6) recommended in the HSM for evaluating proposed or implemented safety improvements (f and h).

For the design application methodology in the HSM predictive chapters, which is the subject of the first part of the paper, the SPFs are an integral part of an algorithm for predicting the expected number of collisions for a site. Therefore, the validation of the algorithm as a whole is essential. The algorithm provides for the expected number of collisions at a site to be first estimated for a set of base conditions using the documented base SPFs. Collision modification factors documented in the HSM, are then used to adjust the base model prediction to account for the effects of variables that are subject to design decisions, i.e., for conditions different from the base model conditions. For example, for urban signalized intersections, these are left-turn lanes, right-turn lanes, presence of lighting, left-turn phasing, right-turn-on-red, presence of red-light-cameras, bus stops within 1000 ft. (305 m), schools within 1000 ft. (305 m), and alcohol sales establishments within 1000 ft. (305 m). The algorithm provides for the refinement of the estimates using the collision history for an existing site in an empirical Bayes procedure, and for adjustments to be made to reflect differences in collision experience across jurisdictions. Before applying the HSM methods, Canadian jurisdictions should first undertake an assessment of the HSM SPFs and CMFs because:

- The base conditions for base model SPFs may not reflect the base condition for a Canadian jurisdiction; therefore the CMFs may need to be recalibrated for use in a Canadian jurisdiction, or Canadian-specific CMFs used if available.
- The SPFs will need to be recalibrated using data from a Canadian jurisdiction and then evaluated for satisfactory performance.
- The SPFs and CMFs are meant to be applied under certain assumptions on how collision data are coded to the roadway; if data for a Canadian jurisdiction cannot meet the same standard then some adjustments to the methods will be necessary.

The first part of the paper illustrates how a jurisdiction can explore the transferability of the HSM algorithm by assessing both the base SPFs and CMFs. Urban signalized intersections for Toronto are used as a case study. A recent paper (7) focussed on two and multi-lane rural roads.

The methodologies for evaluation of the safety impacts of contemplated countermeasures and the evaluation of implemented safety improvements are the subject of the second part of the paper. For these evaluations, Safety Performance Functions (SPFs) are required as part of the empirical Bayes methodology (5, 6). Experience has shown that it is important for these SPFs to be robust, more so than those used for other tasks such as network screening, since the safety benefit and crash effect estimates can be quite sensitive to the SPF predictions, and since the consequences of incorrect estimates can be quite serious. Typically, SPFs need to pertain to specific crash types being evaluated. Currently, the HSM SPFs used for evaluating crash types are derived by applying the proportion of a given crash type in all crashes to the default SPF based on all crashes. However, research has shown that these proportions may depend on variables such as traffic volume and, in effect, that the variable coefficients for a crash type SPF can be quite different from those for an SPF based on all crashes (8). The research for this paper sought to resolve this difficulty by developing independent crash type SPFs using databases for Canadian roads.

Also fundamental to the estimation of crash effects of a contemplated or implemented countermeasure, is that the data from which the SPFs are estimated should reflect as closely as possible the site characteristics of the sites prior to treatment. For example, if the treatment is the addition of a two-way left-turn lane to a two-lane urban road then the SPFs should be calibrated from two-lane urban road with similar traffic and roadside development but without two-way left-turn lanes.

The second part of the paper describes the development of a series of SPFs that could be used by Canadian jurisdictions for estimating the safety effects on affected crash types of contemplated or implemented countermeasures. The SPFs for urban signalized intersections are presented and discussed. Facilitating the application is a spreadsheet application tool that allows users to select the most appropriate crash type SPF for a user specified countermeasure and site type. This tool is also described.

2. INVESTIGATING THE TRANSFERABILITY OF THE HSM PREDICTIVE METHODOLOGY FOR DESIGN APPLICATIONS

2.1 Overview of the HSM collision prediction algorithm

In the HSM collision prediction algorithm a base model is first used to predict the expected number of collisions for sites meeting the base conditions. Collision modification factors assembled by a team of experts, and documented in the HSM, are then used to adjust the base model prediction to account for the effects of other variables that are subject to design decisions, i.e., for conditions different from the base model conditions. Therefore, validation of the algorithm as a whole, not just the base model, is essential.

The prediction algorithm has the following form for predicting the number of collisions (N) at a site:

$$N = C \times N_b \times CMF_1 \times CMF_2 \times CMF_3 \times \ldots..$$

where N_b is the number of collisions predicted by a base model for specified base conditions, and
CMF_1 , CMF_2 , …. are collision modification factors for differences from the base conditions.
C is a calibration factor for applying a base model from a different jurisdiction and/or time period

Base models are provided in the HSM for urban and suburban arterial facilities. Separate models are provided for estimating intersection-related and non-intersection-related collisions. For signalized intersections, models have been developed for those with three and 4–legs. Separate models are used to estimate multiple-vehicle, single-vehicle, vehicle-pedestrian and vehicle-bicycle collisions. Models are only available for total collisions. For fatal+injury collisions, and PDO collisions, the model estimates for total collisions are multiplied by appropriate severity factors for specific collision severity types. Similarly, for multi-vehicle collisions, predictions for total collisions are multiplied by the proportions of various impact types (e.g., rear-end, right angle) to obtain estimates for these types of collisions. Default impact type proportions are provided in the HSM, but a jurisdiction may substitute their own proportions.

2.2 Methodology for recalibration and evaluation of the algorithm

The basic approach is to apply the HSM recalibration procedure and evaluate the performance of the HSM models and CMFs for urban and suburban arterials when applied to data from a Canadian jurisdiction. In this recalibration procedure, the HSM SPFs and CMFs are applied to a group of sites and a calibration factor (multiplier) is calculated as the ratio of the sum of collision counts for the calibration data to the sum of the predictions.

Several goodness-of-prediction measures are used to assess performance, including:

- Value of the recalibrated overdispersion parameter
- Mean absolute deviation (average value of the absolute value of observed minus predicted collision frequencies for each site)
- Cumulative Residual plots
- Comparison of the ratio of observed to predicted values summed by categories of the variable of interest

The overdispersion parameter is recalibrated using a specially written maximum likelihood procedure. The maximum likelihood method estimates the most likely value of the overdispersion parameter. The log-likelihood is calculated for a range of possible values of overdispersion, and the value of overdispersion with the largest log-likelihood is selected. If there is no such peak in the initial range selected, then a broader range of potential values of overdispersion is used. For each of $j = 1$ to N sites, the following equations are applied:

a = (1/ overdispersion)*LOG((1/ overdispersion)/predicted);
b = ((1/ overdispersion)+observed)*LOG((1/ overdispersion)/predicted+1);

$$c = \sum_{i=1}^{observed} LOG((1/k) + i - 1)$$

where,
overdispersion = the incremental overdispersion parameter to which the calculation applies
predicted = the collision prediction from the model for site j
observed = the observed number of collisions at site j
The log-likelihood for overdispersion is then calculated as:

$$Log - likelihood = \sum_{j=1}^{N} a - \sum_{j=1}^{N} b + \sum_{j=1}^{N} c$$

How well predictions fit the data over the full range of an independent variable can be judged using a Cumulative Residual (CURE) Plot. In this method, documented by Hauer & Bamfo paper (9), the cumulative residuals (the difference between the observed and predicted collisions for each location) are plotted in increasing order for each covariate, e.g. AADT, separately. Also plotted are graphs of the 95% confidence limits. If there is no bias in the model, the plot of cumulative residuals should stay inside of these limits. The graph shows how well the model fits the data with respect to each individual covariate. It is important to not only evaluate a model based on overall measures but also to evaluate how it performs over the range of covariates. CURE plots should be constructed for each variable within the SPF. CURE plots do however require a range of values of the independent variable. Where this range does not exist a simpler comparison of observed to predicted values was undertaken.

2.3 Toronto signalized intersection data

Two separate databases were used, one for the 5-year period 2000-04 and another for 6-year period 1999-2004. For the 5-year database, data were available by collision type: angle, approaching, rear end; side-swipe, multivehicle and single vehicle. The 6-year database contained multi and single vehicle collisions, by severity, as well as pedestrian and bike collisions. Tables 1summarizes the data. For each intersection, pedestrian volumes as well as total entering AADTs for the major and minor roads are also available.

Table 1 Basic Statistics of the 1999-2004 Data for Toronto Signalized Intersections

	137 3-legged Intersections			**1691 4-legged Intersections**		
Data Element	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Major AADT	13269	3883	35723	13960	1322	37495
Minor AADT	4002	1	12098	4102	14	27936
Total Collisions	57.2	6	277	70.3	1	378
F+I Collisions	15.3	0	67	21.8	0	125
PDO Collisions	41.9	2	210	48.5	0	268
All Multivehicle Collisions	52.9	0	262	65.0	0	370
Multivehicle F+I Collisions	12.8	0	53	17.7	0	120
Multivehicle PDO Collisions	40.5	2	209	47.3	0	268
All Single Vehicle Collisions	1.2	0	8	1.2	0	9
Single Vehicle F+I Collisions	0.2	0	4	0.2	0	4
Single Vehicle PDO Collisions	1.1	0	8	1.0	0	8
Pedestrian Collisions	1.9	0	11	2.8	0	22
Bike Collisions	1.3	0	7	1.3	0	16

2.4 Transferability assessment results

The investigation was conducted for two collision types (all severities combined): all multi-vehicle collisions and rear-end collisions. First, calibration factors for adjusting the HSM models to local conditions were estimated and then applied to the HSM models to predict collisions for local sites in Toronto. These model predictions were then compared to those from models directly estimated from local site data using goodness-of-fit and other performance measures such as Cumulative Residual (CURE) plots.

The models directly estimated from local data for the primary base conditions (no turn lanes) are shown in Table 2, along with the equivalent HSM base models. The key goodness-of-fit statistics (Mean absolute deviation (MAD) and overdispersion parameter (k)) for the directly estimated and the calibrated HSM base models, along with the calibration factors (C_r) for applying the HSM models are indicated in Table 3. Illustrative CURE plots for comparison of the two models for 4-legged signalized intersections are shown in Figure 1.

Table 2: Comparison of base condition models for signalized intersections from the HSM with those estimated from Toronto data (for intersections with no turn lanes) (Model form: Collisions/year = α (Minor AADT)$^{\beta 1}$ (Major AADT)$^{\beta 2}$

Intersection/ crash type	Source	α (P- value)	β_1 (P-value)	β_2 (P-value)
3-legged Multi vehicle	HSM	5.3952E-06	1.11	0.26
	Toronto (Sample = 45)	0.001357 (0.0315)	0.6177 (0.0715)	0.3874 (<.0001)
3-legged Rear end	HSM	Applies ratio to total (0.549 and 0.546 for FI and PDO)		
	Toronto (Sample =45)	0.000007	1.1520 (0.0003)	0.2388 (0.0003)
4-legged Multi vehicle	HSM	1.6870E-05	1.07	0.23
	Toronto (Sample = 341)	5.6352E-04 (<0001)	0.5661 (<0001)	0.5581 (<0001)
4-legged Rear end	HSM	Applies ratio to total (0.450 and 0.483 for FI and PDO)		
	Toronto (Sample = 341)	2.0689E-05 (<0001)	0.8195 (<0001)	0.5310 (<0001)

Table 3: Goodness-of-fit statistics for locally estimated and calibrated HSM models

Intersection Type	Model	Type of Collision	Observed Collisions	Predicted Collisions	C_r	Mad/year	k
3-legged	HSM	Multi vehicle	7239	1292	5.60	6.03	0.56
	Toronto			8172	0.89	5.38	0.43
	HSM	Rear end	1767	3140	0.56	1.36	0.56
	Toronto			1836	0.96	1.41	0.39
4-legged	HSM	Multi vehicle	109910	22998	4.78	5.72	0.44
	Toronto			90615	1.21	4.10	0.26
	HSM	Rear end	34156	46391	0.74	2.36	0.65
	Toronto			25176	1.36	1.92	0.39

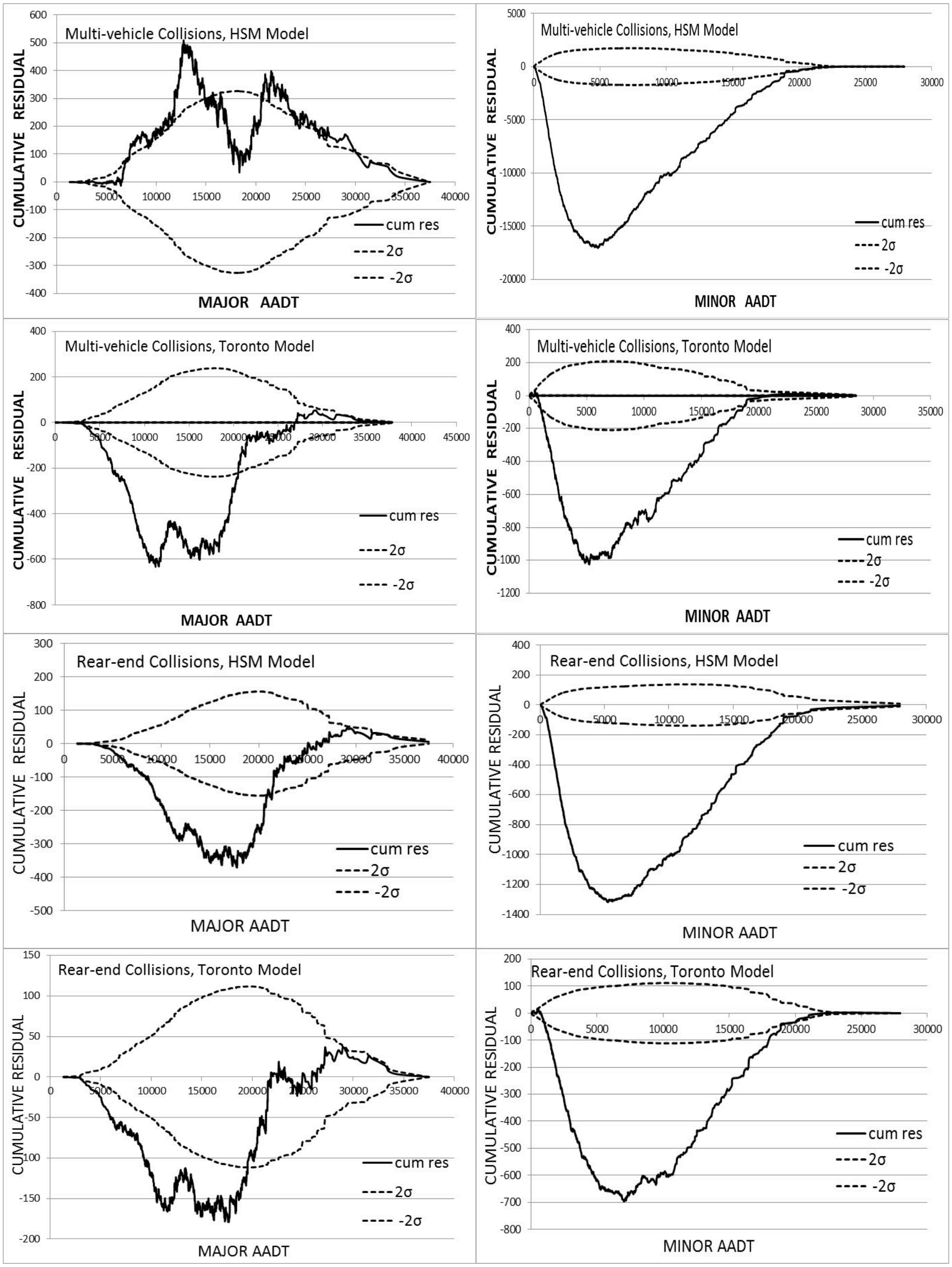

Figure 1: Comparison of CURE Plots for calibrated HSM models (top) and locally estimated models (bottom) for multi-vehicle and rear-end collisions at 4-legged signalized intersections

The goodness-of-fit measures indicate that, overall, the local Toronto model performs better than the recalibrated HSM models although the latter do perform reasonably well. The CURE plots of the HSM recalibrated models and local Toronto model for 4-legged intersections show similar patterns although the magnitude of the deviation from 0 is generally smaller for the local Toronto models. Although the plots of cumulative residuals often stray from the 95% confidence limits the magnitude is relatively small compared to the total number of crashes. The same was true for the plots for 3-legged intersections (not shown). Thus, while some bias is evident in several models, the overall fit to the data is still good.

Table 4 shows the ratios of observed to predicted collisions for the various AADT ranges. For the Toronto models, there is an observable trend of under-predicting both multi-vehicle and rear-end collisions at increasing levels of AADT at 4-legged sites; the opposite is true at 3-legged sites. For the calibrated HSM models, there is an evident over-prediction of multi-vehicle crashes at lower AADTs and an under-prediction at higher AADTs for 4-legged sites; the opposite is true for 3-legged sites. For rear-end crashes the same trend is seen for 4-legged sites but 3-legged sites exhibit over prediction for higher AADTs.

Table 4 Comparison of Observed and Predicted Multi-vehicle Collisions by AADT range

Total Entering AADT range	Intersection type		Ratio: Observed/Predicted							
			Multivehicle				Rear end			
	4-leg	3-leg	Calibrated HSM Model		Toronto Model		Calibrated HSM Model		Toronto Model	
			4-leg	3-leg	4-leg	3-leg	4-leg	3-leg	4-leg	3-leg
0 to 15000	673	74	0.85	1.36	1.03	1.03	0.50	0.67	1.02	1.16
15000 to 30000	867	46	0.93	1.19	1.18	1.02	0.66	0.64	1.27	1.04
30000 to 45000	150	17	1.45	0.48	1.52	0.52	1.30	0.37	1.92	0.63

Table 5 shows the ratios of observed to predicted collisions for intersections grouped by various left and right turn lane combinations. It is difficult to make definitive conclusions on how the presence of turning lanes is affecting the calibration factors as the numbers are quite variable and some categories contain few intersections. It can be observed, however, that the presence of turning lanes does affect the performance of the algorithm. It is possible the algorithm would perform better with CMFs developed specifically using data from the City of Toronto.

2.5 Conclusions from the evaluation of the HSM crash prediction algorithm

The investigation illustrated the data and analytical needs for applying the HSM collision prediction algorithm in a local Canadian jurisdiction. The actual results obtained in this limited exploration suggest that the performance of the HSM algorithm was mixed. Applying the algorithm with base models estimated from local data produces marginally better predictions than applying the algorithm with HSM base models calibrated to local data. More robust base models estimated from local data will undoubtedly produce better results, but the development of these models was beyond the scope of this exploratory research. Such models may be estimated by increasing the sample with the use of sites with, say one variable that does not meet the base conditions (e.g., include sites with one left turn lane), estimating model coefficients for this variable, and then substituting base condition values for these variables in the estimated models. The development of local collision impact type models for 3 and 4-legged signalized intersections, at least for the rear-end type investigated, appears feasible and desirable. For collision type predictions, the HSM algorithm merely applies the proportions of these collision types to the predictions from the algorithm for all multi-vehicle collisions. Conceptually, it seems better, as was done for this research, to estimate separate base models, where feasible, for the specific collision types. The second part of the paper is related to this issue.

Table 5 Comparison of Observed and Predicted Collisions by Number of Approaches with Turn Lanes

Approach with Turn Lanes		Intersection Type		Observed/Predicted							
				Multi vehicle				Rear-end			
				Calibrated HSM Model		Toronto Model		Calibrated HSM Model		Toronto Model	
Right Turn	Left Turn	4-leg	3-leg	4-leg	3-leg	4-leg	3-leg	4-leg	3-leg	4-leg	3-leg
0	0	343	45	0.84	1.35	1.01	1.03	0.50	0.56	0.99	0.97
1	0	50		1.10		1.18		0.68		1.17	
0	1	159	20	0.70	1.65	1.07	1.32	0.49	0.67	1.13	1.16
2	0	10		0.79		0.78		0.53		0.89	
1	1	75	27	0.65	0.99	0.94	0.88	0.50	0.62	1.12	1.07
0	2	268	10	0.84	0.50	1.10	0.53	0.58	0.42	1.16	0.71
2	1	13		0.69		0.92		0.72		1.4	
1	2	121	16	0.79	0.55	1.08	0.53	0.40	0.39	1.22	0.67
0	3	61		0.79		1.09		0.56		1.15	
2	2	87		0.82		1.07		0.41		1.14	
1	3	66		0.76		1.07		0.58		1.17	
0	4	109		1.33		1.39		0.96		1.52	
2	3	40		0.93		1.24		0.73		1.39	
3	2	14		0.79		0.98		0.55		1.04	
1	4	81		1.45		1.51		1.11		1.72	
4	2	3		0.88		0.98		0.36		0.62	
3	3	11		1.36		1.68		1.05		1.86	
2	4	82		1.49		1.53		1.24		1.85	
4	3	4		1.16		1.33		1.05		1.78	
3	4	37		1.91		1.79		1.67		2.31	
4	4	42		2.00		1.82		1.68		2.29	

3. INVESTIGATION OF CRASH TYPE SAFETY PERFORMANCE FUNCTIONS FOR HSM EVALUATION METHODOLOGIES

The objective of the investigation was to develop and recommend a series of SPFs that could be used by Canadian jurisdictions for estimating the safety effects on affected crash types of contemplated or implemented countermeasures. The research project also developed a spreadsheet application tool that facilitates the selection by users of the appropriate crash type SPF for a user specified countermeasure and site type. The development of the SPFs is described in this part of the paper along with a description of the spreadsheet tool.

3.1 Development of crash type SPFs related to countermeasures

Several tasks were undertaken to collect and analyze data to develop and assess crash type SPFs.

- First, through a survey, a list of relevant countermeasures was developed for various site types.
- Next a literature review was conducted to identify the type of crashes that are impacted (sometimes negatively) by each countermeasure.
- An assessment was then made of data available to identify the crash and site types for which it may be possible to develop independent SPFs.
- Collision, traffic and geometric data were then assembled to develop these SPFs.
- Where possible, SPFs were developed using data available for the project.
- For some treatments on urban roadways where specific collision type data were not available, a literature search was conducted and available SPFs recorded.

The purpose of this survey was to collect information on countermeasures of interest to Canadian jurisdictions. For this purpose, an e-mail was sent out to various municipalities and provinces around Canada requesting them to provide a list of countermeasures of interest to their jurisdiction. Responses were received from 3 provincial agencies (Alberta, Ontario and Saskatchewan) and four cities (Edmonton, Toronto, Winnipeg and Vancouver), identifying a total of 107 different countermeasures of interest.

A total of 54 statistically significant SPFs were estimated for 94 of the 107 countermeasures (data were not available for some countermeasures and the same model may pertain to more than one countermeasure). For illustrative purposes of his paper only the models pertaining to signalized intersections, also the focus of the first part of the paper, are presented here.

Table 6 lists the signalized intersection countermeasures for which SPFs were developed. It also lists the data source (Toronto or Ministry of Transportation, Ontario (MTO)) that was used, the crash types of interest, and a model reference number. The site types used from the City of Toronto data were both urban 3-legged and 4-legged signalized intersections, while for the MTO data only urban 4-legged signalized intersections were used since little data were available for 3-legged signalized intersections.

The SPFs developed for signalized intersections had one of the following forms:

Model Form 1: $SPF = e^{\alpha} \times Entering\ AADT^{\beta_1} \times (No. of\ Years)$

Model Form 2: $SPF = e^{\alpha} \times Major\ AADT^{\beta_1} \times Minor\ AADT^{\beta_2} \times (No. of\ Years)$

Consistent with the state-of-the-art, generalized linear modeling, with the specification of a negative binomial (NB) error structure, was used to develop the SPFs. This specification allows for the direct estimation of the NB over dispersion parameter that can be used for model assessment (the smaller the value the better is a model for the same data) and to derive empirical Bayes estimates of crash frequency that are applied in estimating the effects of implemented or contemplated countermeasures (1, 5). The models where entering AADT was used (Form 1) instead of major and minor AADT were those where the use of separate AADTs did not yield significant results. Table 7 lists the coefficient estimates and the p-values for the developed models. Goodness of fit measures in the last two columns are discussed next.

Table 6 Urban signalized intersection countermeasures for which SPFs were developed

Countermeasure	Site Type	Model Number	Site Type Notes	Crash Types	Data Source
Modify left turn phase: change from permissive or permissive/protected to protected only phasing	3-legged	1	None, Use all Sites	Total, Injury, Rear End, Angle, Left Turn	Toronto
	4-legged	2			Toronto
	4-legged	3			MTO
Convert 4-legged intersection to two 3-legged intersections	4-legged	2	None, Use all Sites	Total, Injury, Rear End, Angle Left Turn	Toronto
	4-legged	3			MTO
Install left turn lane at signalized intersections	3-legged	4	Sites with no Left Turn Lane	Total, Injury, Rear End, Angle	Toronto
	4-legged	5			Toronto
Install right turn lane at signalized intersections	3-legged	6	Sites with no Right Turn Lane	Total, Injury, Rear End, Angle	Toronto
	4-legged	7			Toronto
	4-legged	8			MTO
Provide protection for left turn movements	3-legged	9	Sites without Protected Left Turns	Total, Injury, Rear End, Angle	Toronto
	4-legged	10			Toronto

Several goodness-of-prediction measures were used to assess each candidate SPF including the following four presented here:

- Plots of the cumulative residuals (observed minus predicted crash frequencies) graphed versus each variable in the model (called "CURE" plots).
- Mean absolute deviation (MAD) (absolute value of sum of observed minus predicted crash frequencies divided by sample size).
- The estimated overdispersion parameter.
- Reasonableness and statistical significance of the estimated parameters

Table 7 lists the values of MAD for each model. It also lists the sum of observed and predicted crashes for the specific crash types and the overdispersion parameter. Illustrative CURE plots (Major AADT) for models 1, 2, and 3 for which all sites were used can be found in Figure 2.

The results in Table 7 suggest that the goodness of prediction values shown for most models are reasonable. All the models had reasonably small overdispersion parameters (i.e., less than 1) and the coefficient estimates were generally highly significant with $P < 0.0001$. The one notable exception is model 8 for which the sample size was only 30 sites and the number of observed crashes was very small. Even so, the largest P values were of the order of 0.05.

The most important observation from Table 7 is that for any given model reference, the exponents (the βs) tend to vary markedly across crash types, indicating that these models are superior to the HSM models, which assume that the exponents are identical for various crash types.

The CURE plots in Figure 2 sometimes stray beyond the 95% confidence limits, but the magnitude of the deviation is usually relatively small compared to the total number of crashes. Some bias is evident in several models, indicating consistent over or under-prediction for some ranges of AADT, but the overall fit to the data is still good, especially considering the other goodness of prediction measures in Table 7. These observations were generally applicable for almost all of the models developed for countermeasures not addressed in this paper.

Table 7 Coefficient Estimates for Crash Type SPFs

Model Reference	Sample Size	Crash Type	Coefficient Estimates			MAD	Dispersion parameter
			α	β_1	β_2		
1	137	Total	-5.3473	0.7742		26.833	0.52
		Injury	-6.4363	0.7502		6.080	0.36
		Angle	-7.1874	0.7928		7.006	0.92
		Rear End	-9.2211	1.0452		6.669	0.40
2	1691	Total	-7.7444	0.5307	0.6212	18.319	0.25
		Injury	-9.4866	0.6124	0.5956	6.519	0.23
		Angle	-6.7202	0.1573	0.7019	4.058	0.32
		Rear End	-12.2998	0.9077	0.6098	8.037	0.27
3	67	Total	-10.8855	1.1277		3.597	0.61
		Injury	-9.1424	0.8490		1.792	0.74
		Angle	-13.4302	1.2216		1.207	0.76
		Left Turn	-9.5693	0.9109		2.206	0.94
4	53	Total	-12.8750	1.5890		23.740	0.37
		Injury	-12.1600	1.3644		5.434	0.32
		Angle	-14.4493	1.5888		6.541	0.67
		Rear End	-16.0481	1.7791		6.878	0.35
5	423	Total	-7.5302	0.5416	0.5969	14.871	0.23
		Injury	-9.0293	0.5871	0.5756	4.840	0.21
		Angle	-9.1201	0.6382	0.4512	4.058	0.45
		Rear End	-11.1069	0.8515	0.5346	5.096	0.20
6	76	Total	-6.9909	0.9517		24.982	0.43
		Injury	-8.7548	0.9864		5.623	0.56
		Angle	-7.6077	0.8541		7.115	0.85
		Rear End	-9.3668	1.0520		3.830	0.14
7	978	Total	-7.4569	0.5110	0.6138	15.467	0.22
		Injury	-8.9840	0.5785	0.5762	5.535	0.22
		Angle	-8.0582	0.2546	0.7661	3.654	0.26
		Rear End	-11.6741	0.8710	0.5761	6.122	0.23
8	30	Total	-17.8150	1.8353		1.787	0.04
		Injury	-22.1310	2.1947		1.218	0.22
9	124	Total	-5.1035	0.7473		26.067	0.49
		Injury	-6.1834	0.7248		5.930	0.33
		Angle	-7.3176	0.8110		7.252	0.94
		Rear End	-8.8117	0.9983		5.877	0.37
10	1260	Total	-7.4646	0.5150	0.5998	16.134	0.28
		Injury	-9.2196	0.6033	0.5685	5.803	0.27
		Angle	-6.8509	0.1516	0.7265	3.664	0.36
		Rear End	-12.6133	0.9186	0.5743	7.839	0.30

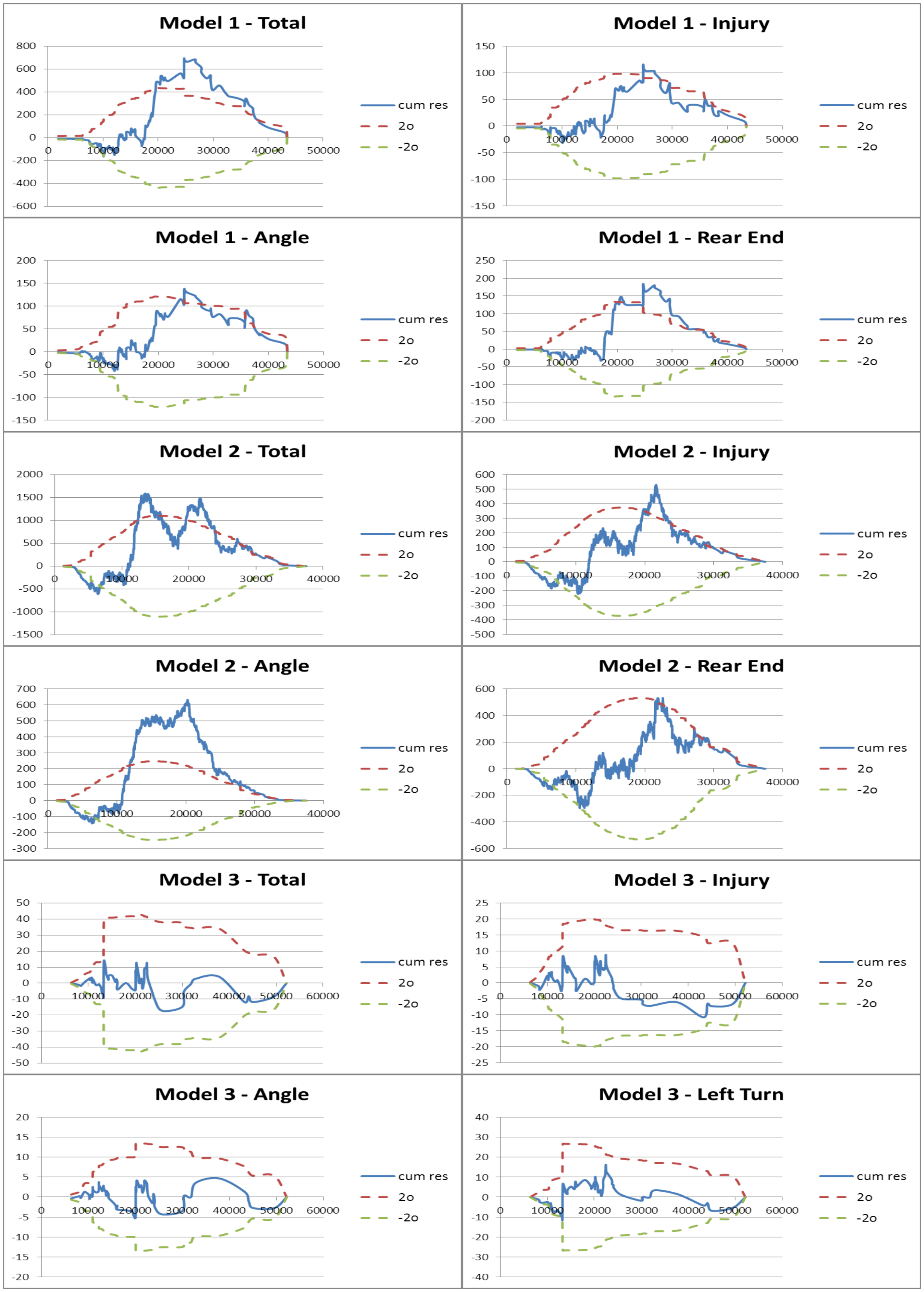

Figure 2 Sample Cure Plots for Major AADT for Models 1, 2, and 3

3.2 Application spreadsheet to identify and select SPFs pertaining to specific countermeasures

A spreadsheet kit was developed with Visual Basic in Excel to facilitate the selection of one or more appropriate crash type SPF applicable for the evaluation of a user specified countermeasure at a specific site type. It is comprised of a master file for general countermeasure selection and spreadsheet files containing individual SPFs. Figure 3 illustrates the structure of the spreadsheet kit. There are eight worksheets in the general form file:

1) General Countermeasure Selection
2) Reference List of SPFs for MTO Rural Intersection Countermeasures
3) Reference List of SPFs for MTO Urban Intersection Countermeasures
4) Reference List of SPFs for MTO Rural Segment Countermeasures
5) Reference List of SPFs for TC Rural Intersection Countermeasures
6) Reference List of SPFs for TC Urban Intersection Countermeasures
7) Reference List of SPFs for TC Rural Segment Countermeasures
8) Reference List of SPFs for Urban Segment Countermeasures

As shown in Figure 4, the General Countermeasure Selection worksheet pertains to a collection of categories for rural and urban road segments, and rural and urban intersection and interchanges. A typical worksheet for the reference list of SPFs for countermeasures is functionally a table associating countermeasures to available SPF hyperlinks in Excel. Figure 5 shows an example for urban intersections.

For each individual SPF file, there are four worksheets: 1) Data; 2) SPF's; 3) Cure Plots; and 4) Goodness of prediction measures. Figure 6 is an example illustration of worksheet 2) and pertains to urban signalized intersections. In essence, a user can start SPF searching by selecting a specific countermeasure, which leads to reference forms for positioning yoked SPF hyperlinks to locate relevant SPF files for detailed information, before returning finally to the general form to start a next round of searching.

3.3 Conclusions from the investigation of crash type safety performance functions

The objective of the project on which this part of the paper was based was to develop and recommend a series of SPFs that could be used by Canadian jurisdictions for estimating the safety effects on affected crash types of contemplated or implemented countermeasures for different typed of road facilities. Experience has shown that it is important for these SPFs to be robust, more so than those used for other tasks such as network screening, since the safety benefit and crash effect estimates can be quite sensitive to the SPF predictions, and since the consequences of incorrect estimates can be quite severe. Databases from the province of Ontario and the city of Toronto were used to develop a large number of SPFs appropriate for the list of countermeasures identified in a survey by three provincial agencies and four Canadian cities. The key conclusion is that the model exponents for AADT tend to vary markedly across crash types, indicating that these models are superior to the HSM models, which assume that the exponents are identical for various crash types. A spreadsheet application tool was developed to facilitate the selection by users of the appropriate crash type SPF for a user specified countermeasure and site type.

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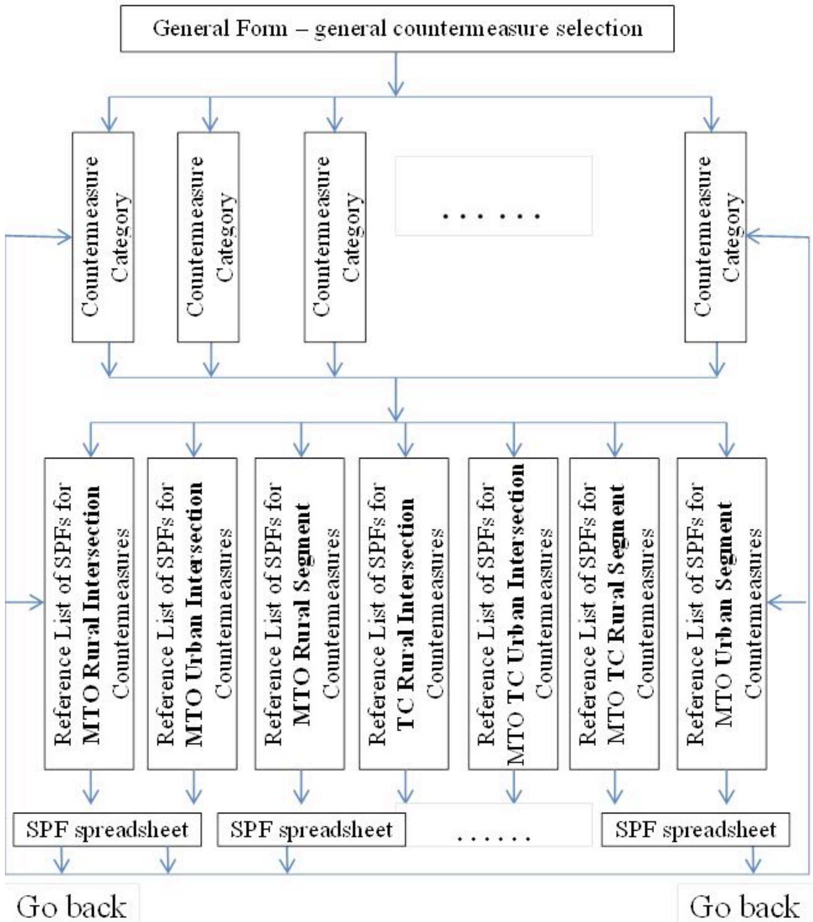

Figure 3 Flow Chart of Applicative Spreadsheet Kit

Countermeasure Safety Evaluation Tool Kit

Road Segment Countermeasure Selection Table

Countermeasure Category	Countermeasure Selection	
	Rural	Urban
On-street parking		
Lighting		
Access management		
Roadway		
Alignment		
Roadside/Shoulder Treatment		
Roadway delineation		
Roadway signs and traffic control		
Speed management		

Intersection & Interchange Countermeasure Selection Table

Countermeasure Category	Countermeasure Selection	
	Rural	Urban
Llighting		
Access management		
Intersection geometry		
Roadside		
Shoulder treatment		
Roadway delineation		
Intersection traffic control		
Interchange design		
Speed management		

Figure 4 General Countermeasure Selection Worksheet

TC No.	Treatment/Countermeasure	Countermeasure Category	Site Type	Crash Types	Reference Model Number	Comb Model Number
TC 1-x	Convert at-grade intersection to an interchange	Interchange design	Urban 3-legged signalized	Total, Injury, Rear End, Angle	TC 1-1	
			Urban 4-legged signalized		TC 1-2	
TC 2-x	Install LTL at signalized intersections	Intersection geometry	Urban 3-legged signalized	Total, Injury, Rear End, Angle	TC 2-1	
			Urban 4-legged signalized		TC 2-2	
TC 3-x	Install RTL at signalized intersections	Intersection geometry	Urban 3-legged signalized	Total, Injury, Rear End, Angle	TC 3-1	
			Urban 4-legged signalized		TC 3-2	
TC 4-x			Urban 3-legged signalized	Total, Injury, Rear End, Angle	TC 4-1	
			Urban 4-legged signalized		TC 4-2	
TC 5-x	Provide protected left turn movements	Intersection traffic control	Urban 3-legged signalized	Total, Injury, Rear End, Angle	TC 5-1	
			Urban 4-legged signalized		TC 5-2	
TC 6-x	Modify left turn phase: change from permissive or permissive/protected to protected only phasing	Intersection traffic control	Urban 3-legged signalized		TC 6-3	Comb 1
			Urban 4-legged signalized		TC 6-4	
			Urban 3-legged stop-controlled		TC 6-7	Comb 2
			Urban 4-legged stop-controlled		TC 6-8	
TC 7-x	Improve/upgrade intersection lightning at intersections	Lighting	Urban 3-legged signalized		TC 7-3	
			Urban 4-legged signalized		TC 7-4	
TC 9-x	Prohibit left turns/right turns/U-turns at intersections	Intersection traffic control	Urban 3-legged signalized	Total, Injury, Rear End	TC 9-1	Comb 1
			Urban 4-legged signalized		TC 9-2	
			Urban 3-legged stop-controlled		TC 9-3	Comb 2
			Urban 4-legged stop-controlled		TC 9-4	

Back to General Worksheet

Back to General Worksheet

Figure 5 Urban Intersection Worksheet for Reference List of SPFs for Countermeasures

$$SPF = e^{\alpha} \times MAJ\ AADT^{\beta_1} \times MIN\ AADT^{\beta_2} \times (Years)$$

Site Type: Urban 4 Legged Unsignalized
Crash Type/Severity: Total

	α	β1	β2	K
Estimate	-7.5302	0.5416	0.5969	0.233
Pr > ChiSq	<0.0001	<0.0001	<0.0001	

Site Type: Urban 4 Legged Unsignalized
Crash Type/Severity: Injury

	α	β1	β2	K
Estimate	-9.0293	0.5871	0.5756	0.2105
Pr > ChiSq	<0.0001	<0.0001	<0.0001	

Site Type: Urban 4 Legged Unsignalized
Crash Type/Severity: Angle

	α	β1	β2	K
Estimate	-11.1069	0.8515	0.5346	0.2039
Pr > ChiSq	<0.0001	<0.0001	<0.0001	

Site Type: Urban 4 Legged Unsignalized
Crash Type/Severity: Rear End

	α	β1	β2	K
Estimate	-11.1069	0.8515	0.5346	0.2039
Pr > ChiSq	<0.0001	<0.0001	<0.0001	

Back to General Worksheet

Back to TC Urban Intersection Worksheet

Figure 6 Sample Urban Intersection Worksheet for SPFs

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