Assessment of the Crash Modification Factors in the Highway Safety Manual for use in Canada

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ABSTRACT

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The release of the Highway Safety Manual (HSM) can have a significant impact on the success of Canada's Road Safety Vision successor plan for 2015 by enabling Canadian jurisdictions to benefit from the extensive research conducted during the compilation of the Manual. So an assessment of the applicability of this Manual in Canada is particularly timely. A major part of the HSM is a comprehensive list of Crash Modification Factors (CMFs), which is a compilation from past studies of the safety effects of various road treatments. The HSM implemented a very rigorous inclusion/exclusion process for reviewing the accuracy of the CMFs to determine their suitability for inclusion in the HSM. Part of the review, was to apply correction factors to any CMFs that were suspected of being subject to biases such as regression to the mean (RTM). This methodology is reviewed in this paper in the light of recent research on the extent of RTM bias. Then the CMFs listed in the HSM were compared to those currently used by Canadian jurisdictions. The results show that the CMFs included in Canadian manuals are similar to those in the HSM. However, it was identified that the HSM has CMFs for many other treatments not identified in Canadian manuals. Based on the rigorous inclusion process used by the HSM, these other CMFs can be assumed to be reliable and used for selecting safety treatments. However, it would be beneficial for the safety effects to be evaluated using the Empirical Bayes (EB) method to ensure the same change in collisions is achieved.

INTRODUCTION

The Highway Safety Manual (HSM) can have a significant impact on the success of Canada's Road Safety Vision successor plan for 2015 by enabling Canadian jurisdictions to benefit from the extensive research conducted during the compilation of the manual. This manual, which was published in 2010, contains a large compilation of Crash Modification Factors (CMFs)(AASHTO, 2010). CMFs are used as a method of representing the safety effect for a specific road safety treatment to determine the change in number of collisions that will occur as a result of the treatment. The majority of the CMFs in the HSM were collected from previous road safety treatment studies conducted at sites located in the U.S. Given that there is a limited number of CMFs published from evaluations of road safety treatments applied in in Canada, it would be beneficial to make use of the extensive collection of CMFs in the HSM, and use these for the implementation of road safety treatments in Canada.

An assessment of the Crash Modification Factors (CMFS) in the HSM as well as an assessment of the methodology used for their selection and inclusion into the HSM would assist in the determination of whether these CMFs can be readily adopted by Canadian jurisdictions. The main reason for doing such an assessment is mainly due to the nature of CMFs. A CMF developed from a Before and After Study will represent the change in number of collisions that occurred at the study areas as a result of the treatment, but could have varying effects in another situation if the conditions are different. This is why it is important that all external factors and phenomenon such as regression to the mean (RTM) are taken into account in the development of the CMF. This will increase the reliability of the CMF and increase the likelihood of achieving the same change in collisions if the treatment is implemented elsewhere.

Crash Modification Factors can therefore play a very important role in the success of Canada's Road Safety Vision successor plan for 2015. If used properly, these CMFs will act as an important tool to allow road safety practitioners to identify countermeasures to reduce the number of collisions at problematic locations. It is expected that the use of CMFs will increase with the recent release of the Highway Safety Manual and the 2009 launch of the CMF Clearinghouse website http://www.cmfclearinghouse.org(University of North Carolina Highway Safety Research Center, 2010), which has a database of CMFs. This paper documents the assessment that was undertaken for the Crash Modification factors in the Highway Safety Manual and for the methodologies used for inclusion of the CMFs in the HSM.

USE OF CRASH MODIFICATION FACTORS

Crash Modification Factors, as they are referred to in this paper, are also termed Collision Modification Factors or Accident Modification Factors (CMFs or AMFs), all of which function in exactly the same way. Crash Reduction Factors (CRFs) have a very similar functionality in that they represent the reduction in the number of collisions that is expected by a specific treatment. A CRF is converted to a CMF by the equation, CMF = 1 – CRF. Using a modification factor instead of a reduction factor allows the factor to indicate whether the treatment will produce an increase or decrease in the number of collisions. (A CMF greater that 1 indicates an increase, while a CMF less than 1 indicates a decrease, and unlike the case of crash reduction factors, the sign is always positive).

As an example of a CMF listed in the HSM's "Knowledge" document, conversion of stop controlled intersections in rural areas (with Annual Average Daily Traffic (AADT) volumes of 7185 to 17220) to single lane roundabouts has a CMF of 0.42 (NCHRP 17-27 Project Team, iTrans Consulting Inc., 2009) based on research by Persaud et al. (2001). This would imply that if an intersection has the characteristics identified by the CMF were to be converted to a single lane roundabout, and if it is estimated to experience 10.0 collisions per year without conversion, then it would be estimated to have 10 x 0.42 = 4.2 collisions per year after the conversion.

It is also identified by Lord and Bonnenson (2006) that CMFs can also be used to assist in the highway design process and not just in the development of countermeasures to treat existing road segments. This can be accomplished through the use of a safety performance function to estimate a base value of the expected number of collisions of the new facility and to then apply CMFs to evaluate the various alternative designs to determine which would produce the safest condition (Lord & Bonneson, 2006).

DEVELOPMENT OF CRASH MODIFICATION FACTORS

Collision Modification factors are typically developed through before-after studies of the road safety treatment. CMFs are also developed through cross-sectional studies; however, the difficulty with these types of studies is finding sites that are similar in all aspects with the exception of the treatment in question. For the before and after studies, there is a comparison of the specific site before and after the implementation of the treatment, and as such, the change in collisions can be attributed to the specific feature after accounting for changes not due to the feature. These before and after studies can be grouped into three main categories that were documented by Hauer (1997), which are:

1. **The simple (naïve) before and after study** - The simple before-and-after study, also referred to as the naïve before-and-after study, is a comparison in the number of crashes before and after treatment. This method assumes that the number of crashes before the treatment is a good estimate of the expected crashes that would occur without the treatment. It does not take into account any other factors that can affect this estimate such as changes in traffic volume and external causal factors. Sites are typically treated based on having a high accident count, which introduces a regression to the mean error whereby, without any treatment, the total number of collisions would have naturally declined in the after period (Hauer, 1997).

2. **The before and after study with comparison group** - The before-and-after study with comparison group method is similar to the simple before-and-after study. It uses a comparison group of untreated sites to compensate for the external causal factors that could affect the change in the number of collisions. It does this by assuming that the ratio of crashes between the before and after period of the untreated sites would have been the same for the treated sites. Therefore, any external changes that would have changed the number of collisions in the after period throughout the area would be accounted for. However, this method does not account for regression to the mean as it does not account for the natural reduction in crashes in the after period that would occur for the sites with abnormally high numbers of crashes (Hauer, 1997).

3. **The Empirical Bayes before and after study** - The Empirical Bayes (EB) method for before-and-after studies goes further by introducing an estimate for the mean crash frequency of similar sites that is used to adjust the crash record of the site for regression to the mean. The mean crash frequency of similar sites is usually estimated from a Safety Performance Function (SPF) calibrated from untreated "reference" site based on the AADT, and sometimes on other characteristics of the site. This SPF also accounts for traffic volume changes and those from other factors unrelated to the treatment. The result is a true estimate of crashes expected without the treatment, and ultimately, a true safety effect of the treatment (Hauer, 1997).

To date, the best way to properly conduct a before and after study to determine an accurate estimate of the safety effect is to use the EB method (Hauer, Harwood, & Council, 2002).

CRASH MODIFICATION FACTORS IN THE HSM

The Crash Modification Factors (CMFs) in the HSM are grouped into 5 main categories which are (NCHRP 17-27 Project Team, iTrans, 2007):

1. **Roadway Segments** – CMFS related to design, traffic control, and operational treatments on roadway segments.
2. **Intersections** – CMFs related to intersection types, access management characteristics near intersections, intersection design elements, and intersection traffic control and operational elements.
3. **Interchanges** – CMFs related to design, traffic control, and operational elements at interchanges and interchange ramp terminals.
4. **Special Facilities** – CMFs related to design, traffic control, and operational elements at various special facilities and geometric situations.
5. **Road Networks** – CMFs related to planning, design, operations, education, and enforcement-related decisions that are applied holistically to a road network.

The CMFs in these sections were compiled through a comprehensive review of safety information published within the last 50 years (NCHRP 17-27 Project Team, iTrans Consulting Inc., 2009). In order for the CMFs to have been included in the HSM, it was required that they pass a rigorous inclusion/exclusion process. This process is documented in the HSM knowledge base companion, where a CMF is considered to be reliable based on having a small standard error (NCHRP 17-27 Project Team, iTrans, 2007). Precision and accuracy are illustrated by the target in Figure 1. If the results from a safety treatment cluster at the same off target value they would be considered precise but not accurate, while if they scatter around the target then they are considered to be neither precise nor accurate. For a CMF to be included in the HSM it was required to have a standard error of less than 0.1, which would make that CMF reliable.

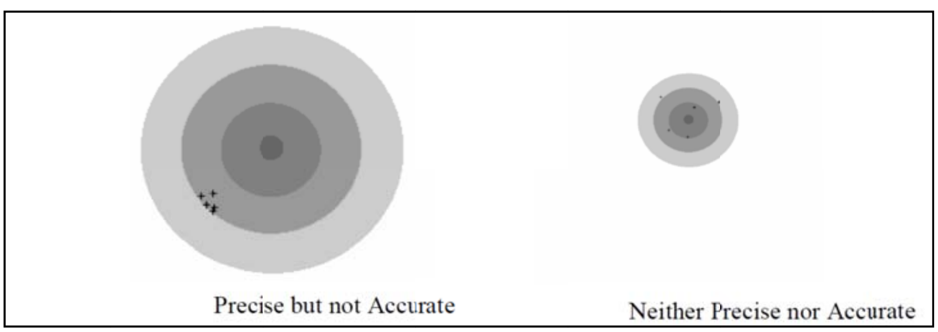

Figure 1: Illustration of precision and accuracy (NCHRP 17-27 Project Team, iTrans, 2007)

CORRECTION OF PUBLISHED CRASH MODIFICATION FACTORS

Crash Modification Factors that are developed from before-after evaluation studies without taking into account factors such as regression to the mean will overestimate the effect of a treatment. If a site is treated based on having an abnormally high number of crashes, as is commonly done, it is very likely that there will be an immediate reduction in the number of crashes in the following year regardless of whether or not a safety treatment was implemented. Even if a site with high accident counts is selected not because it has a high accident count but through some other selection process, while one may assume there is no longer selection bias, such a site may still become subject to the regression to the mean phenomenon, distorting the safety effect estimates in a simple before-after evaluation study (Hauer, 1997).

One part of the HSM review process was to apply a correction for CMFs that were suspected of having regression to the mean bias. This was done to increase the accuracy of those CMFs that did not account for RTM. Bahar (2009) authored a research circular on the methodologies for the development and inclusion of crash modification factors in the HSM. As part of this, the various methods for developing CMFs were described in order to explain how regression to the mean can affect the estimates of the safety effect that are produced through simple before-and-after studies. To account for this properly in a before and after study it is important the Empirical Bayes method be utilized and to be applied properly. A CMF produced using the EB method could still include regression to the mean bias if the method is not applied correctly. This can occur by using a Safety Performance Function (SPF) that includes the treatment sites in the calibration dataset as some researchers have done.

The method to correct affected CMFs for RTM is documented in the HSM's knowledge base companion (NCHRP 17-27 Project Team, iTrans, 2007). It is explained that if there is no regression to the mean bias, the CMF would simply be represented by A/B, which is the ratio of crashes in the after period to crashes in the before period. However, with regression to the mean bias, the crashes in the before period would be inflated and as such the CMF should be represented by A/(B – X), where X is the regression to the mean bias that needs to be subtracted from the number of before period collisions. Therefore, the difference between the biased and unbiased estimates of the AMF value is given by the equation (NCHRP 17-27 Project Team, iTrans, 2007):

$$CMF_{biased} - CMF_{unbiased} = A / B - A / (B-X)$$

Where:

A=After Crash Frequency

B=Before Crash Frequency

A⁄B=AMF biased

X=RTM bias assumed by the NCHRP 17-27 research team

Given that X is small compared to B the equation is simplified to:

$$CMFunbiased = CMFbiased \times (1 + X/B)$$

The X/B ratio identified by the project team range between 0.05 for a small RTM bias and 0.25 for a large RTM bias. A large RTM bias of 0.25 would be assumed if a few years of data were used and a very small proportion of the highest accident sites was selected for treatment. A small RTM of 0.05 would be assumed if a large proportion of all the sites was treated and many years of data were included in the development of the CMF.

In the HSM review process revealed some studies that did not account for regression to the mean. The correction factors for these were identified in the HSM knowledge base and are shown in Table 1. However, it is important to note that these were not included in the HSM as the standard errors were too large to be accepted.

Table 1: CMFs corrected to account for Regression to the Mean

Treatment	Unadjusted CMF	RTM Factor (X/B)	Adjusted CMF	Standard Error
Limited sight distance signs on road segments	1.02	0.05	1.07	0.67
Changeable curve speed warning signs on horizontal curves	1.03	0.10	1.13	1.19
	1.34	0.10	1.47	2.35
	0.89	0.10	0.98	1.38
Chevron signs on horizontal curves	0.29	0.25	0.36	0.48
converging chevron pattern markings on roadway segments	0.62	0.10	0.68	0.19

Our recent research, James (2010) sought to derive a more rational basis for the regression to the mean correction for Crash Modification Factors it investigate if the HSM CMFs require further adjustment for application in Canada. An empirical analysis of an existing collision history dataset and a simulated dataset was conducted to determine how the magnitude of regression to the mean depends on the following factors:

i) Number of years of before collision history used in the study
ii) The percentage of sites selected for treatment from the total population

iii) The mean number of collisions of the population that the sites for treatment selection were drawn from

iv) The standard deviation of collisions of the population that the sites for treatment selection were drawn from

The results indicate the directional relationships shown in Figure 2.

Figure 2: Relationship between the Regression to the Mean Magnitude and Independent Variables

A function was developed to quantify the impacts on RTM of these variables. This function, which is shown in below, could be used to estimate the RTM correction to results from a before-after study that did not account for this bias (James, 2010).

$$\text{RTM}\,\% = \left(0.486 - 0.132 \times \frac{\sigma}{\mu} - 0.0163 \times \mu \times Y_n - 0.269 \times \frac{p}{100}\right) \times 100$$

Where:

$\mu -$ *Mean number of accidents per year of the dataset*

$\sigma -$ *Standard Deviation of the number of accidents per year of the dataset*

$Y_n -$ *Number of years of target data selected*

$p -$ *Percentage of high accident sites selected from the entire dataset*

$$Corrected\ CMF = \frac{CMF}{(1 - RTM\ \%)}$$

Applying the function to a real dataset to determine the range of correction factors that should be used to correct a CMF for RTM, showed that correction factors ranging from 1.0 to 1.25 would be used (James, 2010). This verifies the HSM methodology for using X/B ratios (RTM bias to the before crash frequency ratio) of 0.05 for a small RTM bias and 0.25 for a large RTM bias.

COMPARISON OF CRASH MODIFICATION FACTORS

A comparison of the Crash Modification Factors (CMFs) in the Highway Safety Manual (HSM) to those currently listed in Canadian manuals was undertaken. It was not expected that a large number of CMFs would be found for the comparison given that there is a limited source of CMFs published in Canada (Forbes, 2003). The modification factors are referred to as CMFs in this paper; however, the HSM refers to these as AMFs. The Canadian manuals that were identified as having CMFs and selected for review included:

- **i)** **Collision Modification Factors for British Columbia** (Sayed & de Leur, 2008)
- **ii)** **Transport Canada Synthesis of Safety for Traffic Operations** (Belluz & Forbes, 2003)
- **iii)** **The Canadian Guide to In-service Road Safety Reviews** (Transportation Association of Canada, 2004) – These modification factors were represented as ranges of CRF which were converted to CMFs
- **iv)** **Geometric Design Guide for Canadian Roads** (Transportation Association of Canada, 1999)

These documents were reviewed to identify the quantity of road safety treatments listed in the documents that are also listed in the HSM. Once these were identified, the values of the CMFs or the CMF Function/Charts were compared to those in the HSM to determine whether they were close or the same. A CMF was listed as the same as long as the difference between the two was less than 0.1. The results of this comparison are shown in Table 2.

Table 2: Comparison of CMFs from different Canadian Sources

Manual	Total number of CMFs or CMF Functions/ Charts in HSM	Number of CMFs or CMF Functions/Charts for same treatments			
		i) BC CMFs (Same as HSM)	ii) TC Synthesis of Safety (Same as HSM)	iii) In-service Road Safety Review (Same as HSM)	iv) TAC Geometric Design Guide (Same as HSM)
Roadway Segments	107	54 (33)	0	0	3 (2)
Intersections	156	41 (30)	23 (14)	25 (12)	0
Interchanges	9	0	0	0	0
Special Facilities	7	5 (4)	0	0	0
Road Networks	6	6 (6)	0	0	0
Total	**285**	**106 (73)**	**23 (14)**	**25 (12)**	**3 (2)**

From the comparison of CMFS in the Canadian Manuals to those listed in the HSM it was found that there were some treatments that were listed in both. Of these, the majority of the CMFs had the same values. This shows that many of the CMFs represented in the HSM are already accepted for use in Canada and are now proven to have a high level of reliability. This was particularly evident with the British Columbia Collision Modification Factors manual which was published very recently (2008). However, for the most part, the HSM has significantly more CMFs for other treatments not listed in Canadian manuals as shown by the numbers in the table.

Lists of the CMFs listed in Canadian Manuals that are the same or similar to those in the HSM are shown in Table 3.

Lists of the CMFs that are in the Canadian manuals that have the same treatments as those listed in the HSM but with different CMF values or functions are listed in Table 4. While the values are different, the general trends for an increase or decrease in the number of crashes is the same. As such, with these CMFs where there are different values, it may be possible to use a combined average based on the reliability of each CMF, and after the treatment has been implemented the results could be verified to determine the actual reduction of crashes achieved by the treatment.

The remaining CMFs and CMF functions listed in the HSM could not be matched with any Canadian manuals and therefore have no basis for comparison. However, based on the rigorous inclusion/exclusion process those CMFs could be assumed to be reliable.

Table 3: CMFs listed in Canadian Manuals similar to those in the HSM

Treatments - Roadway Segment	**HSM**	**Canadian**	**Manuals**
Modify Lane Width	Chart & Function	Chart & Function	BC & TAC
Four to five lane conversion on urban freeway, 79,000 to 128,000 vpd, one direction for: All types, all severities	1.11	1.11	BC
Five to six lane conversion on urban freeway, 77,000 to 126,000 vpd, one direction for: All types, all severities	1.03	1.07	BC
Add or Widen Paved Shoulder	Chart & Function	Chart & Function	BC & TAC
Modify Shoulder Type	Table	Table	BC
Provide a median on urban multi-lane roads for: All types, injury	0.78	0.78	BC
Provide a median on urban multi-lane roads for: All types, PDO	1.09	1.09	BC
Change the Width of an Existing Median	Table	Function	BC
Flatten Sideslopes	Table	Function	BC
Install median guardrails on divided highways on multi-lane divided highways for: All types, fatal	0.57	0.57	BC
Install median guardrails on divided highways on multi-lane divided highways for: All types, injury	0.70	0.70	BC
Install median guardrails on divided highways on multi-lane divided highways for: All types, all severities	1.24	1.24	BC
Install crash cushions at permanent objects for: Fixed object, fatal	0.31	0.31	BC
Install crash cushions at permanent objects for: Fixed object, injury	0.31	0.31	BC
Install crash cushions at permanent objects for: Fixed object, PDO	0.54	0.54	BC
Reduce Roadside Hazard Rating	Function	Function	BC
Modify Horizontal Curve Radius and Length, and Provide Spiral Transitions	Chart & Function	Chart & Function	BC
Improve Superelevation of Horizontal Curves	Function	Function	BC
Increase vertical grade by 1% on rural two lane undivided roads for: All severities	1.02	Function	BC
Install normal edgelines (100 to 150 mm or 4 to 6 in) on roadway segments on rural two-lane undivided roads for: All types, Injury	0.97	0.97	BC
Install wide edgelines (200 mm or 8 in) on roadway segments on rural two-lane undivided roads for: All types, Injury	1.05	1.05	BC
Add centerlines on roadway segments on urban and rural two-lane undivided roads for: All types, Injury	0.99	0.99	BC
Install snowplowable raised pavement markers on roadway segments on rural 2-lane roadways with degree of curvature <= 3.5, AADT = 5001 to 15000 for: Nighttime	0.99	0.94	BC
Continuous milled-in shoulder rumble strips on all four shoulders with varying designs on rural multi-lane divided for: All types, all severities	0.84	0.86	BC
Install centerline rumble strips on rural two-lane roads, 5,000 to 22,000 veh/day for: All types, all severities	0.86	0.86	BC
Install speed humps on urban/ suburban residential two-lane, roads for: All types, injury	0.60	0.52	BC
Install speed humps on adjacent roads on urban/ suburban residential two-lane roads for: All types, injury	0.95	0.94	BC
Highway Illumination for: All types, Injury	0.72	0.79	BC
Highway Illumination for: All types, PDO	0.83	0.79	BC
Modify Access Point Density	Function	Function	BC
Reducing private driveways per km road from 30 to 16-30 on urban arterials for: All types, Injury	0.71	0.71	BC
Reducing private driveways per km road from 16-30 to 6-15 on urban arterials for: All types, Injury	0.69	0.69	BC
Reducing private driveways per km road from 6-15 to under 6 on urban arterials for: All types, Injury	0.75	Function	BC
Treatments - Special Facilities	**HSM**	**Canadian**	**Manuals**
Installing gates at crossings with flashing lights and sound signals	0.55	0.5	BC
Provide Two-Way Left-Turn Lane	Function & Chart	Function & Chart	BC
Provide a Passing Lane/Climbing Lane on Rural Roads	0.75	0.75	BC
Short Four-Lane Section on Rural Roads	0.65	0.65	BC

Treatments - Intersection	HSM	Canadian	Manuals
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with little minor road traffic (<15%) for: all types, injury severity	1.35	1.35	BC
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with some minor road traffic (15-30%) for: all types, injury severity	0.75	0.75	BC
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with heavy minor road traffic (>30%) for: all types, injury severity	0.67	0.67	BC
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with little minor road traffic (<15%) for: all types, PDO severity	1.15	1.15	BC
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with some minor road traffic (15-30%) for: all types, PDO severity	1.00	1.00	BC
Conversion of four-leg or cross intersections into two T-intersections on Urban for Intersections with heavy minor road traffic (>30%) for: all types, PDO severity	0.90	0.90	BC
Convert signalized intersection to roundabout on All settings, All lanes for: All types, All severities	0.52	0.35 - 0.65	TAC In-service
Convert two-way stop-controlled intersection to roundabout on Urban, Two-lane for: All types, All severities	0.88	0.89	BC
Convert two-way to all-way stop control on Urban intersections for MUTCD Warrants must be met for: Right angle, All severities	0.25	0.3 - 1.0 & 0.28	TAC In-service & TC Synthesis
Convert two-way to all-way stop control on Urban intersections for MUTCD Warrants must be met, Primarily Urban intersections for: Rear-end, All severities	0.82	0.8 - 0.85 & 0.78	TAC In-service & TC Synthesis
Convert two-way to all-way stop control on Urban intersections for MUTCD Warrants must be met, Primarily Urban intersections for: Pedestrian, All severities	0.57	0.58	TC Synthesis
Convert two-way to all-way stop control on Urban intersections for MUTCD Warrants must be met, Primarily Urban intersections for: All types, Injury	0.30	0.3 - 1.0 & 0.29	TAC In-service & TC Synthesis
Convert two-way to all-way stop control on Urban intersections for MUTCD Warrants must be met, Primarily Urban intersections for: All types, all severities	0.52	0.52	BC, TAC In-service & TC Synthesis
Remove an unwarranted signal (one-way streets) for Unwarranted signals, one-way streets in urban areas for: Right-Angle & Turning, All severities	0.76	0.5 - 1.0 & 0.78	TAC In-service & TC Synthesis
Remove an unwarranted signal (one-way streets) for Unwarranted signals, one-way streets in urban areas for: Rear-end, All severities	0.71	0.3 - 1.0 & 0.77	TAC In-service & TC Synthesis
Reduce Intersection Skew Angle on	Graph	Graph	BC
Installation of left-turn lane on single major road approach on Rural for Stop-controlled T-intersections, Major road 1,600 to 32,400 vpd, Minor road 50 to 11,800 vpd for: All types, all severities	0.56	0.56	BC
Installation of left-turn lane on single major road approach on Urban for Stop-controlled T-intersections, Major road 1,520 to 40,600 vpd, Minor road 200 to 8000 vpd for: All types, all severities	0.67	0.67	BC
Installation of left-turn lane on single major road approach on Rural for Signal-controlled T-intersections for: All types, all severities	0.85	0.85	BC
Installation of left-turn lane on single major road approach on Urban for Signal-controlled T-intersections for: All types, all severities	0.93	0.93	BC
Installation of left-turn lane on single major road approach on Rural for Stop-controlled four-leg/cross intersections, Major road 1,600 to 32,400 vpd, Minor road 50 to 11,800 vpd for: All types, all severities	0.72	0.72	TC Synthesis
Installation of left-turn lane on single major road approach on Urban for Stop-controlled four-leg/cross intersections, Major road 1,520 to 40,600 vpd, Minor road 200 to 8000 vpd for: All types, all severities	0.73	0.73	TC Synthesis
Installation of left-turn lane on single major road approach on Urban for Signal controlled four-leg/cross intersections, Major road 7,200 to 55,100 vpd, Minor road 550 to 2,600 vpd for: All types, all severities	0.90	0.9	TC Synthesis
Installation of left-turn lane on single major road approach on Urban for Stop-controlled four-leg/cross intersections, Major road 1,520 to 40,600 vpd, Minor road 200 to 8000 vpd for: All types, Fatal and Injury	0.71	0.73	BC

Treatments - Intersection	HSM	Canadian	Manuals
Installation of left-turn lanes on both major road approaches on Rural for Stop-controlled four-leg/cross intersections, Major road 1,600 to 32,400 vpd, Minor road 50 to 11,800 vpd for: All types, all severities	0.52	0.52	TC Synthesis
Add left-turn lanes to major road approaches at intersections on Urban for Stop-controlled four-leg/cross intersections, Major road 1,520 to 40,600 vpd, Minor road 200 to 8000 vpd for: All types, all severities	0.53	0.53	BC & TC Synthesis
Add left-turn lanes to major road approaches at intersections on Urban for Traffic signal controlled four-leg/cross intersections, Major road 7,200 to 55,100 vpd, Minor road 550 to 2,600 vpd for: All types, all severities	0.81	0.90	BC
Physical channelization of left-turn lane on major road on rural for T-intersections, mostly 2-lane roads, 5,000 to 15,000 veh/day for: All types, Injury	0.73	0.65 -0.9	TAC In-service
Installation of right-turn lane on single major road approach on urban and rural for Stop-controlled T- or Four-leg/cross intersections, major road 1,600 to 55,100 veh/day, minor road 25 to 26,000 veh/day for: All types, all severities	0.86	0.86	BC
Installation of right-turn lane on single major road approach on urban and rural for Traffic signal controlled T- or Four-leg/cross intersections, major road 1,600 to 55,100 veh/day, minor road 25 to 26,000 veh/day for: All types, all severities	0.96	0.96	BC & TC Synthesis
Installation of right-turn lane on both major road approaches on urban and rural for Traffic signal controlled T- or Four-leg/cross intersections, major road 1,600 to 55,100 veh/day, minor road 25 to 26,000 veh/day for: All types, all severities	0.92	0.96	BC & TC Synthesis
Widening median by 3 ft (1 m) on Rural for Four-leg unsignalized intersections for: Multiple-vehicle accidents, all severities	0.96	0.96	BC
Widening median by 3 ft (1 m) on Urban/ suburban for Four-leg unsignalized intersections for: Multiple-vehicle accidents, all severities	1.06	1.06	BC
Widening median by 3 ft (1 m) on Urban/ suburban for Three-leg unsignalized intersections for: Multiple-vehicle accidents, all severities	1.03	1.03	BC
Lighting in intersections for: All types, Nighttime, Injury accidents	0.624	0.72	BC & TAC In-service
Lighting in intersections for: Pedestrian accidents, Nighttime, Injury accidents	0.576	0.58	BC & TAC In-service
Retiming signal change intervals to ITE standards on 4-Leg Signalized Intersections for: All types and severities	0.92	0.92	BC
Retiming signal change intervals to ITE standards on 4-Leg Signalized Intersections for: Rear-end, all severities	1.12	1.12	BC
Retiming signal change intervals to ITE standards on 4-Leg Signalized Intersections for: Right angle, all severities	0.96	0.96	BC
Retiming signal change intervals to ITE standards on 4-Leg Signalized Intersections for: Pedestrian / Bicyclist, all severities	0.63	0.63	BC
Install red-light cameras at intersections in California, Maryland, North Carolina with Entering AADTs: Minor road: 12562 to 33679, Major road: 52625 to 109067 for: Right Angle, All Severities	0.75	0.80	BC
Install red-light cameras at intersections in California, Maryland, North Carolina with Entering AADTs: Minor road: 12562 to 33679, Major road: 52625 to 109067 for: Rear End, All Severities	1.15	1.10	BC
Flashing beacons at four leg stop controlled intersections on two lane roads; Standard and actuated beacons: Major road volume: 250 to 42,520 vpd; Minor road volume: 90 to 13,270 vpd, for: Rear end, All severities	0.921	0.85-0.9	TAC In-service
Flashing beacons at four leg stop controlled intersections on two lane roads; Standard and actuated beacons: Major road volume: 250 to 42,520 vpd; Minor road volume: 90 to 13,270 vpd, for: Angle	0.867	Up to 0.85	TAC In-service
Treatments - Road Networks	**HSM**	**Canadian**	**Manuals**
area-wide traffic calming on urban whole area for all types, injury	0.89	0.85	BC
area-wide traffic calming on urban local streets for all types, injury	0.82	0.74	BC
area-wide traffic calming on urban main streets for all types, injury	0.94	0.91	BC
area-wide traffic calming on urban whole area for all types, PDO	0.861	0.85	BC
area-wide traffic calming on urban local streets for all types, PDO	0.729	0.74	BC
area-wide traffic calming on urban main streets for all types, PDO	0.952	0.91	BC

Table 4: CMFs listed in Canadian Manuals that are different to those in the HSM

Treatment - Road Segments	HSM	Canadian	Manuals
Road diet (Convert 4-lane undivided road to 2-lanes plus turning lane) on urban four-lane undivided, 3700 to 26000 AADT	0.71	0.94	BC
Increase distance to roadside obstacle from around 1 m to around 5 m on rural freeways and two-lane highways	0.78	Function	BC
Increase distance to roadside obstacle from around 5 m to around 9 m on rural freeways and two-lane highways	0.56	Function	BC
one degree increase in horizontal curvature on urban and suburban arterials	1.04	Function	BC
one degree increase in horizontal curvature on urban and suburban arterials	1.06	Function	BC
one degree increase in horizontal curvature on urban and suburban arterials	1.05	Function	BC
Increase vertical grade by 1% on rural two lane undivided roads	1.04	Function	BC
Provide static combination horizontal alignment/ advisory speed signs	0.71	0.93	BC
Install changeable accident warning signs on freeways	0.56	0.8	BC
Install post-mounted delineators on rural two-lane undivided roads	1.04	0.92	BC
Install post-mounted delineators on rural two-lane undivided roads	1.05	0.92	BC
Prohibit on-street parking on urban major arterial (64-ft wide), AADT = 30,000	0.58	Function	BC
Prohibit on-street parking on urban major arterial (64-ft wide), AADT = 30,000	0.65	Function	BC
Prohibit on-street parking on urban major arterial (64-ft wide), AADT = 30,000	0.52	Function	BC
Convert from free to regulated on-street parking on urban arterial roads	0.94	Function	BC
Convert from free to regulated on-street parking on urban arterial roads	1.19	Function	BC
Implement time-limited on-street parking restrictions on urban arterial roads	0.89	Function	BC
Implement time-limited on-street parking restrictions on urban arterial roads	0.21	Function	BC
Convert angle parking to parallel parking	Function	Function	BC
Convert angle parking to parallel parking on urban local (residential) streets	0.65	Function	BC
Convert angle parking to parallel parking on urban mostly local (residential) streets	0.37	Function	BC
Treatments - Intersection	**HSM**	**Canadian**	**Manuals**
Convert signalized intersection to roundabout on Urban, All lanes for: All types, All severities	0.99	0.83	BC
Convert signalized intersection to roundabout on Suburban, Two lanes for: All types, All severities	0.33	0.21	TC Synthesis
Convert signalized intersection to roundabout on All settings, All lanes for: All types, Injury	0.22	0.3 - 0.7	In-Service
Convert two-way stop-controlled intersection to roundabout on All settings, All lanes for: All types, All severities	0.56	0.2 - 0.4	In-Service
Convert two-way stop-controlled intersection to roundabout on All settings, All lanes for: All types, Injury	0.18	1.2	In-Service
Convert two-way stop-controlled intersection to roundabout on Rural, Single-lane for: All types, All severities	0.29	0.73	BC
Convert two-way stop-controlled intersection to roundabout on Urban, Single-lane for: All types, All severities	0.61	0.76	BC
Remove an unwarranted signal (one-way streets) for Unwarranted signals, one-way streets in urban areas for: Pedestrian, All severities	0.82	1.24	TC Synthesis
Remove an unwarranted signal (one-way streets) for Unwarranted signals, one-way streets in urban areas for: All types, all severities	0.76	0.95	TC Synthesis
Convert stop-control to signal on Urban, Major Speed Limit at least 40 mph for 4-leg for: All crashes, all severities	0.95	0.65 - 0.8	In-Service
Convert stop-control to signal on Urban, Major Speed Limit at least 40 mph for 4-leg for: Right angle, all severities	0.33	0.4 - 0.6	In-Service
Convert stop-control to signal on Urban, Major Speed Limit at least 40 mph for 4-leg for: Rear end, all severities	2.43	0.3 - 0.8	In-Service
Add left-turn lanes to major road approaches at intersections on Rural for Signal-controlled four-leg/cross intersections for: All types, all severities	0.67	0.82	BC
Physical channelization of left-turn lane on major road on rural for Four-leg/cross intersections, mostly 2-lane roads , 5,000 to 15,000 veh/day for: All types, Injury	0.96	0.83	BC
Physical channelization of both major and minor roads on rural for Four-leg/cross intersections, mostly 2-lane roads , 5,000 to 15,000 veh/day for: All types, Injury	0.73	0.96	BC
Installation of right-turn lane on both major road approaches on urban and rural for Stop-controlled T- or Four-leg/cross intersections, major road 1,600 to 55,100 veh/day, minor road 25 to 26,000 veh/day for: All types, all severities	0.74	0.86	BC
Change permitted to protected/permitted or permitted/protected on Urban, Four-leg signalized with Major road 2,978 to 76,892 vpd, Minor road 6 to 45,474 vpd for: Left-turn injury	0.84	0.66	BC
Change from permitted or permitted-protected to protected on Urban, 3 and 4 leg signalized for: Total intersection crashes; all severities	0.99	0.83	BC
Flashing beacons at four leg stop controlled intersections on two lane roads; Standard and actuated beacons: Major road volume: 250 to 42,520 vpd; Minor road volume: 90 to 13,270 vpd, for: All types, All severities	0.949	0.5-0.7	In-Service
Permit Right-Turn-On-Red: South Carolina	1.13	1.8	In-Service
Treatments - Special Facilities	**HSM**	**Canadian**	**Manuals**
Upgrading signs to flashing lights and sound signals	0.5	0.67	BC

CONCLUSIONS AND RECOMMENDATIONS

It has been identified that there is a limited number of CMFs published based on studies conducted in Canada. Based on this, it is crucial that the number of CMFs be expanded to provide road safety practitioners with additional countermeasures to reduce the number of collisions on our roadways. From the comparison of the CMFs in the HSM with those that exist in Canadian manuals, it is shown that there is a large similarity between these. Based on this and the fact that the HSM research team had conducted a very rigorous inclusion/exclusion process for identifying CMFs that should be included in the HSM, we can assume that the CMFs that do not currently exist in Canadian manuals can provide reliable results when applied in Canada. However, given that there are geographic differences, it would be recommended that these new CMFs be applied carefully. While they can act as a good starting point for selection of a countermeasure for a specific location, it would be beneficial to use the Empirical Bayes methodology to conduct a before and after study of the treatment to determine whether the same results expected on the basis of the CMF are achieved.

The review of the regression to the mean correction employed by the HSM review process showed that this bias can significantly impact the results of a before-after study if not taken into account. As such, it is important that new before-after studies for determining the safety effect of a specific treatment be done accordingly to take into account all factors that could affect the accuracy and precision of the CMF. This would be achieved by undertaking the full EB method for before and after studies. As identified by the methodology in the HSM, using a strict review process would ensure a high level of reliability of newly published CMFs so that they can be used by Canadian jurisdictions. Adoption of the HSM's CMFs and methodology can have a significant impact on the success of Canada's Road Safety Vision successor plan for 2015 by enabling Canadian jurisdictions to benefit from the extensive research conducted during the compilation of the manual.

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