Collision Modification Factors For British Columbia

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NOTE for USERS

The Collision Modification Factors (CMFs) that are presented in this Manual are based on current and reliable information that was available at the time that this document was prepared. It is noted that some CMF values may vary in time and context.

To address this issue and to ensure that updated CMF information is incorporated into this CMF Manual, a CMF Review Committee has been formed, led by the Ministry of Transportation & Infrastructure, to periodically review the CMFs and to modify the values as required. In addition, the committee will consider new CMFs not currently in this Manual.

If the CMFs provided in this document disagree or are inconsistent with other information sources, the above mentioned Committee has the authority to determine the appropriate CMFs, which must be used.

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1.0 INTRODUCTION: HIGHWAY SAFETY IN BC

Highway safety is a very important consideration for the British Columbia Ministry of Transportation (BC MOT). Each year in BC, there are thousands of collisions that occur on provincial highways. However, as is shown in Exhibit 1.1, the frequency of collisions appear to be reducing over the 20 years of collision records contained in the Ministry's Highway Accident System (HAS). Changes to the collision reporting practices in 1991 and again in 1996 affected the long-term stability of collision data, particularly for the lower severity, property damage only (PDO) incidents, but the fatal collisions, which have not been significantly affected by changes to the collision reporting practices, also show a reduction over time.

Exhibit 1.1: Safety Record on BC Highway (1987 – 2006)

Year	Collision Frequency (1987 – 2006)			
	Fatal	Injury	P.D.O.	TOTAL
1987	310	7705	15445	23460
1988	302	8158	17034	25494
1989	280	8447	17653	26380
1990	335	8978	19208	28521
1991	263	8152	12275	20690
1992	257	8093	11932	20282
1993	252	7988	11563	19803
1994	263	8487	12443	21193
1995	257	8240	12033	20530
1996	186	6216	8309	14711
1997	172	5042	5194	10408
1998	186	4957	4834	9977
1999	200	4960	4576	9736
2000	187	4988	4995	10170
2001	197	5290	6276	11763
2002	235	5148	6597	11980
2003	208	5321	7086	12615
2004	229	5329	7382	12940
2005	221	5459	7902	13582
2006	224	5578	8248	14050

It should also be recognized that the amount of travel on BC Highways has increased considerably over the 20-year time frame from 1987 to 2006, while the number of collisions has reduced. This would suggest that the risk of a collision per kilometer of highway travel has decreased for BC drivers over time.

While there have been considerable improvements to provincial highways over the 20 years of collision records, it is unlikely that the reduction in collisions would be attributed solely to these improvements. More likely, there are several other factors that have contributed together with road improvements to achieve an improved level of safety. These other factors would include such things as improved vehicle design (e.g., collision-worthiness, improved braking and steering performance), educational campaigns that have improved driver behavior (e.g., greater use of seatbelts), and enhanced enforcement activities (e.g., targeting drivers that are alcohol impaired or driving at excessive speeds).

Even though it appears that the risk of a collision on a BC highway has reduced over time, there is still great opportunity to improve safety. In recent years, the BC MOT has been focused on improving highway safety by ensuring that safety is explicitly considered in highway design projects and through on-going rehabilitation of the provincial highway network. This report has been prepared to assist MOT staff in the evaluation and assessment of highway safety.

The current techniques to evaluate highway safety performance can be somewhat variable depending on the judgment of the analyst. Although judgment is often necessary in the evaluation of safety effects caused by road improvements, poor judgment can lead to questionable results, which produce safety effects that are either over-estimated or under estimated. As a result, there is a need to produce a framework that can be used by analysts in BC to evaluate and estimate the safety effects of highway improvements. This document, which provides a comprehensive list of collision modification factors (CMFs), is intended to assist in the evaluation of safety performance for BC Highways.

1.1 Purpose of the Document

The principle purpose of this document is to present the relationships between highway design / operational features and the resulting safety performance. These relationships should form the basis for the evaluation of safety for highway improvement projects in British Columbia.

The objective of this report is to develop a manual or reference document that will provide a set of collision modification factors for highway improvement projects in BC. The document will also provide information on how CMFs should be selected and applied, as well as how CMFs can be combined for a project.

To evaluate the safety associated with highway improvement projects, the overall safety effect of the improvements is based on the anticipated change (i.e., increase or decrease) in the frequency and/or severity of collisions. The change in safety performance is calculated using what is commonly known in the literature as collision modification factors (CMFs). A CMF is defined as follows:

> A CMF is simply a multiplicative factor used to reflect the expected change in safety performance associated with the corresponding change in highway design and/or the traffic control feature.

There is a substantial body of knowledge that describes the relationship between highway design and the corresponding impacts on the safety performance. However, not all of the information that is presented in the literature is reliable due to weaknesses and/or limitations in the study methodology. For example, there are many 'naïve' before-after research studies with results that are questionable due to the failure to consider 'regression to the mean' effects, and/or insufficient data. As well, the results from previous safety studies are often restricted to a specific set of circumstances that may not be applicable to the conditions in British Columbia. Therefore, both the quality and the applicability of the CMFs presented in the literature can lead to erroneous results for analysis in BC.

In general, there is a lack of uniformity and consistency of how collision modification factors are selected and applied for highway improvement projects in BC. This lack of uniformity and inconsistency in the selection of the CMFs can create significant discrepancies in the safety results that are generated as part of the evaluation of a project.

The intent of this document is to provide the BC Ministry of Transportation and Infrastructure with a comprehensive list of CMFs for the typical highway improvement projects in BC. Having a standard set of CMFs that reflect the BC specific conditions will ensure that the safety analysis in support of MOT projects is accurate as well as being more uniform and consistently applied.

1.2 Scope of the Assignment

There are hundreds of CMFs for different types of improvements for differing types of roads. However, this document provides guidance on CMFs that are relevant for the types of improvements that typically occur on BC highways. The selection of the CMFs included in this document is based on various discussions with MOT Staff and should be complete for typical safety analysis; however, there may be additional CMFs that can be included at a later date if required. Furthermore, there may be a need for periodic updating of the CMFs to reflect ongoing developments and research that examines the relationship between safety and design, and which is considered relevant to BC conditions.

The collision modification factors that are included in this document are listed by highway category as follows:

1) Two-Lane Highways
2) Multi-Lane Highways
3) Urban Streets
4) Rural Intersections
5) Urban Intersections
6) Pedestrian Facilities
7) Signs and Delineation
8) Miscellaneous Design Features

A great deal of effort was made to identify and investigate the various information sources that contain CMFs that are considered relevant to BC conditions. The various research papers, studies and reports that cite evidence of effectiveness for various CMFs were obtained and details of each study were recorded, such as topic of the information source (i.e., the CMF), the author, the date of publication, and so on. This information is included with each CMF, such that the safety analyst can use this reference to seek out more information.

For each paper, study, or information source that was obtained for each CMF, the evaluation team completed a review of the source, within the context of the BC MOT environment. The objective of the review was to accept or reject the findings of the information source, based on the following considerations:

- The research methodology used in the study;
- The research plan developed for the study;
- The quality and quantity of data used to support the study;
- The relevance of the study for the BC environment; and
- The interpretation of the research results.

For many CMFs that were investigated, there was a lack of consensus for the safety effect of a design feature or traffic control device. Furthermore, in some case, there was a lack of consensus as to whether the treatment is effective at all. The project evaluation team favored the findings from published research, which has been peer reviewed by a reputable source (e.g., the National Academy of Sciences documents) and recommends a CMF that should be considered and used by the BC MOT.

It is noted that although a systematic process for the evaluation of each information source was established and deployed for the literature review, some professional judgment was required for the recommendation of some CMFs, particularly if the studies were of equal quality and relevance but the result were different. The systematic process that will be used for the review is described in the following section (Section 1.3 Background).

1.3 Background

1.3.1 Definition: Collision Modification Factors

As presented earlier, a CMF is defined as follows:

> A CMF is simply a multiplicative factor used to reflect the expected change in safety performance associated with the corresponding change in highway design and/or the traffic control feature.

A CMF is expressed as a numerical value that can reflect the anticipated change in safety, computed as the ratio between the expected number of collisions with and without the design feature, as shown in equation 1. A CMF with a value of less than 1.0 corresponds to an expected reduction in collisions, a CMF with a value that is greater than 1.0 corresponds to an expected increase in collisions and a CMF equal to 1.0 has no effect on safety.

$$CMF = \frac{N_W}{N_{W/O}}$$ Equation 1

Where:

CMF = Collision modification factor;

N_W = Expected number of collisions with proposed change; and,

$N_{W/O}$ = Expected number of collisions without proposed change.

1.3.2 CMF Versus CRF

The development of CMFs has been motivated to generalize the concept of Collision Reduction Factors (CRFs) and to reduce confusion between CRFs and CMFs. A CRF fails to recognize the possibility that collisions can increase following a change in the roadway design or operation, whereas a CMF can account for the fact that a change in the roadway design or operation could result in either an increase or a decrease in collisions (or no effect, where the CMF = 1.0). For this report, CMFs will be presented rather than CRFs.

1.3.3 Forms for CMFs

There are many functional forms for CMFs. Some CMFs are presented as a single numeric value, while others can be determined with the aid of a function or graph, based on the characteristics of the design feature. Equation 2 below shows a CMF function used for a horizontal curve based on the elements of a curve. 1.2 shows a graphical form for a CMF from the Transportation Association of Canada (TAC).

$$CMF = \frac{1.55\ L_c + \frac{80.2}{R} - 0.012\ S}{1.55\ L_c} \qquad \text{Equation 2}$$

Where:

CMF = Collision modification factor for horizontal curve;

L_C/R = Length of curve / radius of curve; and

S = Presence of spirals.

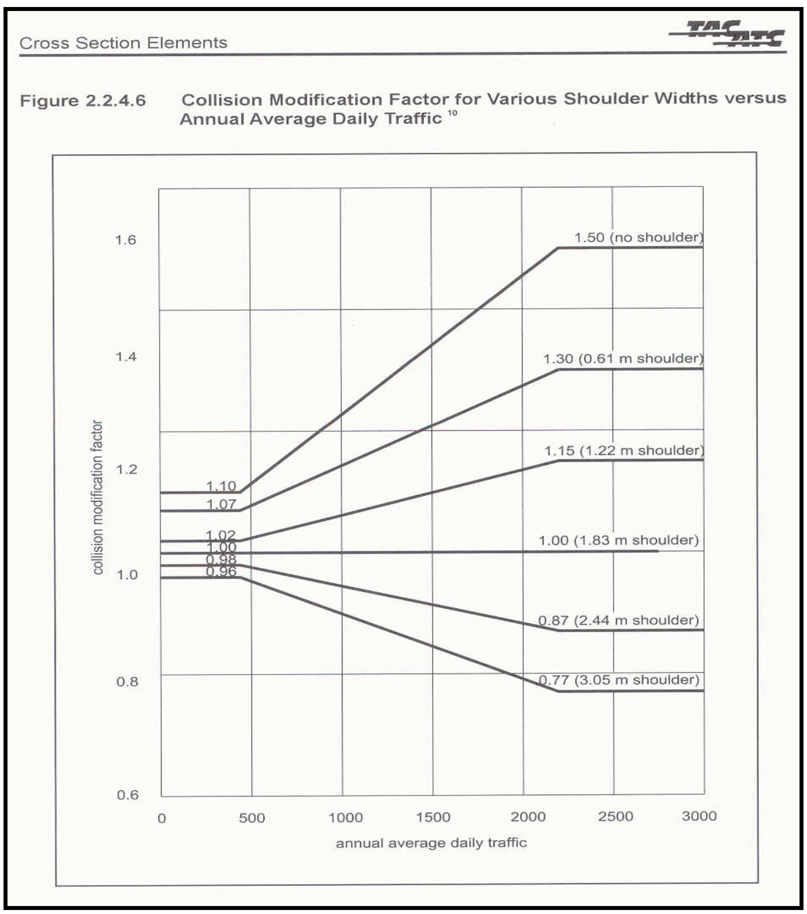


Exhibit 1.2: Example of a Graphical CMF (Source TAC)

1.3.4 Targets for CMFs

An important aspect of defining and applying CMFs is the identification of the collision population to which the CMF should be applied, referred to as the target of the CMF. For example, a CMF used for an increase in the outside shoulder width should be applied to off-road right collisions but it should not likely be applied to head-on type collisions.

For each CMF presented in this report, the target collision types will be identified. The target collisions can be the type of collisions (e.g., rear-end, off-road, etc.), the collision severity (e.g., fatal, injury, PDO), and so on, but in some cases, the CMF may apply to all collisions. Some of the more common proportions of collision are provided in a series of tables, based on the entire population of collisions from the Highway Accident System, using data from 1987 to 2006 inclusive, including 338,285 collisions. It is noted that it may be necessary to define other collision populations, rather than relying on the aggregate set of provincial proportions.

Exhibit 1.3: Distribution of Collision Severity

Collision Severity	**Percent**
Fatal Collisions	1.4
Injury Collisions	39.2
PDO Collisions	59.4

Exhibit 1.4: Distribution of Collision Type

Collision Type	**Percent**		**Collision Type**	**Percent**
Unknown	4.2		Right-turn Overtaking	0.2
Rear-End	23.5		Right-turn Side-swipe	0.1
Head-On	4.8		Left-turn Head On	1.3
Side-Swipe	4.1		Left-turn Rear-End	0.5
Backing	0.9		Left-Turn 90	3.8
Intersection 90	6.9		Off-Road Right	17.7
Overtaking	2.1		Off-Road Left	12.2
Right-turn Rear End	0.5		One-Way Street	0.4
Right-turn Head-On	0.2		Other	16.5

Exhibit 1.5: Distribution of Contributing Factors

Contributing Factor	Percent		Contributing Factor	Percent
Unknown	3.4		Improper Turning	1.0
Alcohol Involved	5.3		Unsafe Speed	8.0
Backing Unsafely	0.6		Avoiding Vehicle	1.1
Cutting In	1.0		Too Fast for Conditions	1.0
Driving w/o Due Care	10.0		Tire-Failure	0.7
Driver Inexperience	2.2		Road Condition	0.9
Fatigue	0.6		Obstruction/Debris	0.8
Fail to Yield ROW	5.0		Visibility Impaired	0.5
Fell Asleep	1.9		Weather	6.4
Following too Close	5.1		Road Maintenance	0.5
Improper Passing	0.8		Domestic Animal	0.6
Driving on Wrong Side	0.6		Wild Animal	10.0
Ignore Traffic Control	1.1		Driver Inattention	2.0

Exhibit 1.6: Distribution of Collision Second Events

Second Event	Percent		Second Event	Percent
Hit other vehicle	50.9		Light Pole	1.0
Motorcycle	0.9		Utility Pole	1.0
Pedestrian	1.2		Guard Rail / Barrier	4.0
Cyclist	0.8		Sign Post	0.8
Animal	10.1		Tree	0.5
Curbing	1.1		Snow-bank / Drift	0.7
Rock Face	0.6		Ditch	12.0
Rock / Debris	0.8		Over-Turned	1.6
Ran-Off Roadway	8.4		Other	1.3

Exhibit 1.7: Distribution of Vehicle Type Involvement

Vehicle Type	Percent		Vehicle Type	Percent
Passenger Car	67.1		Heavy Truck	1.4
Sports Utility	1.0		Combination Unit	0.5
Van	0.6		Combination TRK/TRL	2.4
Pick-Up Truck	20.3		Combination TRK/TRL/P	1.2
Motorcycle	1.4		Camper / Motor-home	1.4

Exhibit 1.8: Distribution of Road Surface Conditions

Road Surface	Percent
Dry	54.6
Wet	26.6
Snow	6.0
Slush	3.0
Ice	8.3

Exhibit 1.9: Distribution of Lighting Levels

Lighting Levels	Percent
Daylight	59.6
Dawn	2.6
Dusk	4.1
Dark – Full Illumination	4.8
Dark – No Illumination	17.0
Dark – Some Illumination	10.8

Exhibit 1.10: Distribution of Weather Conditions

Weather Conditions	Percent
Clear	44.8
Cloudy	27.6
Raining	16.6
Snowing	8.1
Fog	1.2

In the preceding tables, the distributions may not total 100%. Only collision types that exceeded 0.5% were included in the tables. The proportions shown in the tables can be used as default distributions (target values) when applying CMFs. Alternatively, the user can produce different set of collision proportions for the project being analyzed or use another set of proportions based on other criteria. For example, if a project under review is located in a northern region, it may be useful to have a set of collision proportions for the northern region since the collision proportions may be considerably different than in other regions. Section 1.6 will describe how a CMF for targeted collisions can be applied to total collisions.

1.4 Development of CMFs

There are three techniques to develop CMFs. The first technique uses an observational before - after analysis of locations where an improvement was implemented. The second technique uses cross-sectional analysis of locations with and without the improvement. The third technique is based on the use of a panel of safety experts to judge the most likely effect of a roadway improvement. The details of these techniques are presented in the following sections.

1.4.1 Before - After Studies

There are 3 typical methods that have been used in the development of collision modification factors using observational before-after studies. The methods include:

1) Simple Before - After Study;
2) Before - After Study with Comparison Group; and,
3) Before - After Study using Empirical Bayes Methodology.

1.4.1.1 Simple Before - After Studies

The simple before - after study, or sometimes referred to as a naïve before after study, quantifies the change in collisions at a specific location after an intervention has been undertaken. In this type of study, the expected number of collisions without the change ($N_{w/o}$) is estimated as the number of reported collisions **before** the change X_B (i.e., $N_{W/O} = X_B$). As such, the CMF is obtained using equation 3:

$$CMF = \frac{N_W}{N_{W/O}} = \frac{X_A}{X_B} \qquad \text{Equation 3}$$

Where:

- CMF = Collision modification factor
- N_W = Expected number of collision with proposed change
- $N_{W/O}$ = Expected number of collisions without proposed change
- X_A = Number of collisions **after** the proposed change
- X_B = Number of collisions **before** the proposed change

Hauer (1997), Griffin and Flowers (1997) and Shen et al. (2004) have shown that the use of the "simple before-after study" method to develop CMFs often leads to biased values that overstate the true effectiveness of an improvement. As such, in selecting and recommending CMFs for use in British Columbia, the studies that used simple before to after analysis were not viewed as 'trustworthy' as other studies that deployed more reliable evaluation methodologies.

A simple cause-and-effect relationship is very rare in road safety. Usually, there are several other factors that will operate simultaneously and may influence road safety performance. Therefore, a more reliable before – after evaluation process should ensure that a change in safety has been caused by the treatment and not by other "confounding factors". In road safety evaluation, there are normally three confounding factors that will impact the reliability of the result, which include history, maturation, and regression to the mean (RTM), as described below.

1) **History:** History refers to the possibility that factors other than the treatment being investigated caused all or part of the observed change in collisions (e.g., change in weather over time).
2) **Maturation:** Maturation refers to changes in long-tem collision trends. Comparing collisions before and after implementing a specific countermeasure may indicate a reduction attributed to the countermeasure. However, it is possible that the collision reduction could be attributed to a continuing decreasing trend (e.g., caused by improvements to vehicle safety / performance).
3) **Regression to the Mean (RTM):** RTM refers to the tendency of extreme events to be followed by less extreme values, even if no change has occurred in the underlying mechanism generating the process. Road improvement sites are often selected for treatment because of high collision frequency. This high collision frequency may regress to the mean value in the after-treatment period regardless of the effect of the treatment. This condition will lead to an overestimation of the treatment effect in terms of the collision reduction.

1.4.1.2 Before-After Studies with Comparison Groups

To account for the problems associated with history and maturation, the simple before - after study can be expanded to include the use of a comparison group of locations. Sites in the comparison group should be similar and in close proximity to the treated sites, although no treatment would have been applied. However, this method does not account for the effect caused by the regression-to-the-mean.

There are two commonly used methods to conduct before - after studies using a comparison group. The difference between the two methods, which are both based on the odds ratio, is that the first technique adjusts the after-to-before ratio for the treatment group through use of a correction factor computed from all sites in the comparison group, while in the second method, the treatment sites are matched with specific comparison sites. For both techniques, it is assumed that any change in the collision record in the comparison group would have also occurred in the treatment group had no treatment taken place. The statistical analysis techniques used for the first method is described by Griffin and Flowers (1997) and statistical techniques for the second method is described by Pendleton (1996).

1.4.1.3 Before-After Studies Using Empirical Bayes Methodology

The third method to develop CMFs uses the simple before - after method in conjunction with Collision Prediction Models (CPM) in order to estimate the expected collision frequency of a location both with and without the change. This method relies on having previous knowledge of collision history of the subject locations, as well as a collision prediction model that is applicable to the site under investigation.

The first step in developing a CMF for this type of study is to estimate the expected number of collisions without proposed change ($N_{W/O}$). This is estimated using a collision prediction model that is applicable for the type of facility under review. The CPM provides an estimate of the expected number of collisions at the location (N_P).

The second step involves using the collision history of the subject location to estimate the number of collision using the empirical Bayes technique. The technique is based on a weighted average of the value from the CPM and the reported collision count (X). The relationship is given by equations 4 and 5.

$$N_{(p|x)} = N_P w + \frac{X}{Y}(1 - w) \qquad \text{Equation 4}$$

$$w = \left(1 + \frac{KN_P Y}{L}\right)^{-1} \qquad \text{Equation 5}$$

Where:

- $N_{(p|x)}$ = Expected collisions given that X accidents were reported;
- N_p = Expected number of collisions at the subject location;
- X = Number of collisions reported at the subject location;
- Y = Number of years during which X accidents were reported;
- w = Weight given to $N_{p,}$ and,
- K = Dispersion parameter of the CPM.

The third step involves the estimation of the expected number of collisions that would have occurred without the change ($N_{w/o|x}$), given that *X* collisions were reported. This value is computed using equation 6:

$$N_{w/o|x} = N_{p|x} \frac{N_{(w/o|xA)}}{N_{(w/o|xB)}} \qquad \text{Equation 6}$$

Where:

- $N_{(p|x)}$ = Expected number of accidents without the change given that X accidents were reported;
- $N_{(w/o|x\,A)}$ = Expected number of accidents without the change based on the conditions present in the after period;
- $N_{(w/o|x\,B)}$ = Expected number of accidents without the change based on the conditions present in the before period.

The final step involves developing the CMF from equation 7 to obtain an unbiased estimate of the CMF associated with the changed condition:

$$CMF = \frac{x_a}{N_{w/o|x}} \qquad \text{Equation 7}$$

1.4.2 Cross Sectional Studies

An alternative approach to develop a CMF is through the use of cross-sectional studies. This type of study compares the expected collision frequency of a group of locations having a specific component of interest (N_w) to the expected collision frequency of a group of locations with similar characteristics, yet these locations lack the presence of this specific component ($N_{w/o}$). Any differences in collision frequency between the two groups can be attributed to the change in conditions. The ratio of the estimates is used to compute the CMF.

1.4.3 Expert Panel

Sometimes, a group of highly skilled highway safety and design experts are asked to provide their judgment to estimate the expected safety effect of a specific design component. Normally, the panel would conduct a critical review of the literature describing the safety effect of the geometric element or traffic control device of interest. The findings of the experts would be reviewed and debated, and once a consensus of opinion is reached, the expert panel is asked to provide the details of their results and the reasoning behind their decision for the recommendation for the CMF.

This approach is highly subjective and sometimes it is not entirely based on quantitative analysis of the data. Hence, a bias may be introduced by the experiences and preferences of the panel members. Nevertheless, this approach was implemented by Harwood et al. (2000) to estimate CMFs for rural highways. In the absence of collision data or in the presence of low quality data, such an approach to develop CMFs would be justifiable.

1.5 Combining CMFs

It is very common that a highway improvement project could involve changes to several design elements at the same time. Therefore, there is a need to be able to combine CMFs to reflect all of the various changes in the roadway. Equation 8 below is typically used to predict the combined effect of the individual changes / improvements.

$$CMF_C = CMF_1 \times CMF_2 \times ..... \times CMF_n \qquad \text{Equation 8}$$

Where:

CMF_c = Combined collision modification factor for all *n* changes

$CMF_{1/n}$ = The individual collision modification factors

It is noted that some CMFs should not be combined as the safety effect between elements may be overlapping. These potential CMF overlaps will be identified in the chapters that describe the CMFs.

1.6 CMFs for Target and Total Collisions

Many of the CMFs that will be presented in the following chapters of this document must be applied to a target type of collision, which is a subset of the total collisions. If the proportion of the target collision type is known, then the targeted CMF can be modified such that it can be applied to total collisions.

Equation 9 below can be used to generate a CMF that can be applied to all (total) collisions for a CMF that has been obtained for a targeted type of collision.

$$CMF_{TOTAL} = (CMF_{TARGET} - 1.0)\, P_{TARGET} + 1.0 \qquad \text{Equation 9}$$

Where:

CMF_{TOTAL} = Collision modification factor for total collisions;

CMF_{TARGET} = CMF for the target collisions (for any design element);

P_{TARGET} = Proportion of target collisions to total collisions.

An example is provided to illustrate how a CMF for a targeted collision type can be modified such that the CMF can be applied to the total collisions. Suppose that a CMF for the lane width of a two-lane highway was determined to be 1.300, but the CMF was only to be targeted at off-road right (17.7%), off-road left (12.2%) and head-on (4.8%) collisions. The CMF for total collisions could be obtained as follows:

CMF_{TARGET} = 1.300
P_{TARGET} = 0.347 (From Exhibit 1.3 (17.7% + 12.2% + 4.8%)

CMF_{TOTAL} = $(CMF_{TARGET} - 1.0)\ P_{TARGET} + 1.0$
= (1.30 – 1.0) 0.347 + 1.0
= 1.104

1.7 Organization of the Report

This first chapter has provided the purpose of the document, the scope of the assignment and some background material related to the use and development of collision modification factors.

There are 7 more chapters in this report. The next 6 chapters present the CMFs associated with each roadway type listed below. The final chapter presents miscellaneous CMFs, which are not associated with a specific roadway type. The chapters are as follows:

Chapter 2: Two-Lane Highways
Chapter 3: Multi-Lane Highways
Chapter 4: Urban Streets
Chapter 5: Rural Intersections
Chapter 6: Urban Intersections
Chapter 7: Pedestrian Facilities
Chapter 8: Miscellaneous Design Features

In some case, the CMFs will be similar between roadway types but the CMFs will be repeated in each chapter in the interest of completeness. It is also noted that the CMFs will differ between chapters.

1.8 References for Chapter 1

1. Hauer, E. Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety. Elsevier Science Ltd, 1997.

2. Griffin, L.I., and R.J. Flowers. A Discussion of Six Procedures for Evaluating Highway Safety Projects. Report No. FHWA-RD-99-040. Federal Highway Administration, Washington, D.C., December 1997.

3. Shen, J., A. Rodriguez, A. Gan, and P. Brady. "Development and Application of Crash Reduction Factors: A State-of-the-Practice Survey of State Departments of Transportation." Paper No. 04-3508. Presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2004.

4. Pendleton, O.J. Indirect Methods to Account for Exposure in Highway Safety Studies, Technical Report FHWA-RD-96-141, Federal Highway Administration, US Department of Transportation, Virginia, 1996.

5. Harwood, D.W., F.M. Council, E. Hauer, W.E. Hughes, and A. Vogt. Prediction of the Expected Safety Performance of Rural Two-Lane Highways. Report No. FHWA-RD-99-207. FHWA: Federal Highway Administration, Washington, D.C., 2000.

2.0 TWO-LANE HIGHWAYS

Two-lane highways are the most common type of highway within British Columbia, representing approximately 9,339 kilometers (or 86%) of the total length of numbered highways (10,853 kilometers, which excludes un-numbered and "Xn" classification routes). Many of the two-lane highways have a rural characteristic and many of these highways have low traffic volumes. Because of the prevalence of this type of facility in BC, collision modification factors specific to this road category are provided in this section of the report.

The CMFs for two-lane highways are divided into two categories:

1) Cross-Sectional Design Elements:

   Any design element that is related to the cross-section of the roadway, including both the travelled portion of the roadway as well as the roadside area.

2) Longitudinal Design Elements:

   Any design element that is related to the longitudinal features of the roadway.

2.1 Cross-Sectional Design Elements

A total of 12 different cross-sectional design elements are included in the list of CMFs for 2-Lane rural highways. Included are the following design elements, each of which are presented on the following pages:

1) Lane Width
2) Outside Shoulder Width
3) Outside Shoulder Surface
4) Flush Medians
5) Median Barriers
6) Roadside Design: Clear-Zone
7) Roadside Design: Side-Slope
8) Roadside Design: Utility Pole Density and Offset
9) Roadside Design: Roadside Barrier
10) Impact / Crash Attenuator
11) Shoulder Rumble Strips
12) Centreline Rumble Strips

2.1.1 Lane Width

Exhibit 2.1 is used to obtain a CMF for the lane width. The CMF is obtained by selecting the traffic volume (AADT) on the horizontal axis. A vertical line is then drawn from the traffic volume to intersect the line in the graph corresponding to the lane width. For lane widths not shown in Exhibit 2.1, the CMFs can be obtained by interpolating between the lines. If the lane widths for each travel direction differ, the CMF is determined for each direction and then averaged.

Target Collisions: Single vehicle off-road and head-on collisions
References: Geometric Design Guide for Canadian Roads
Transportation Association of Canada (TAC).

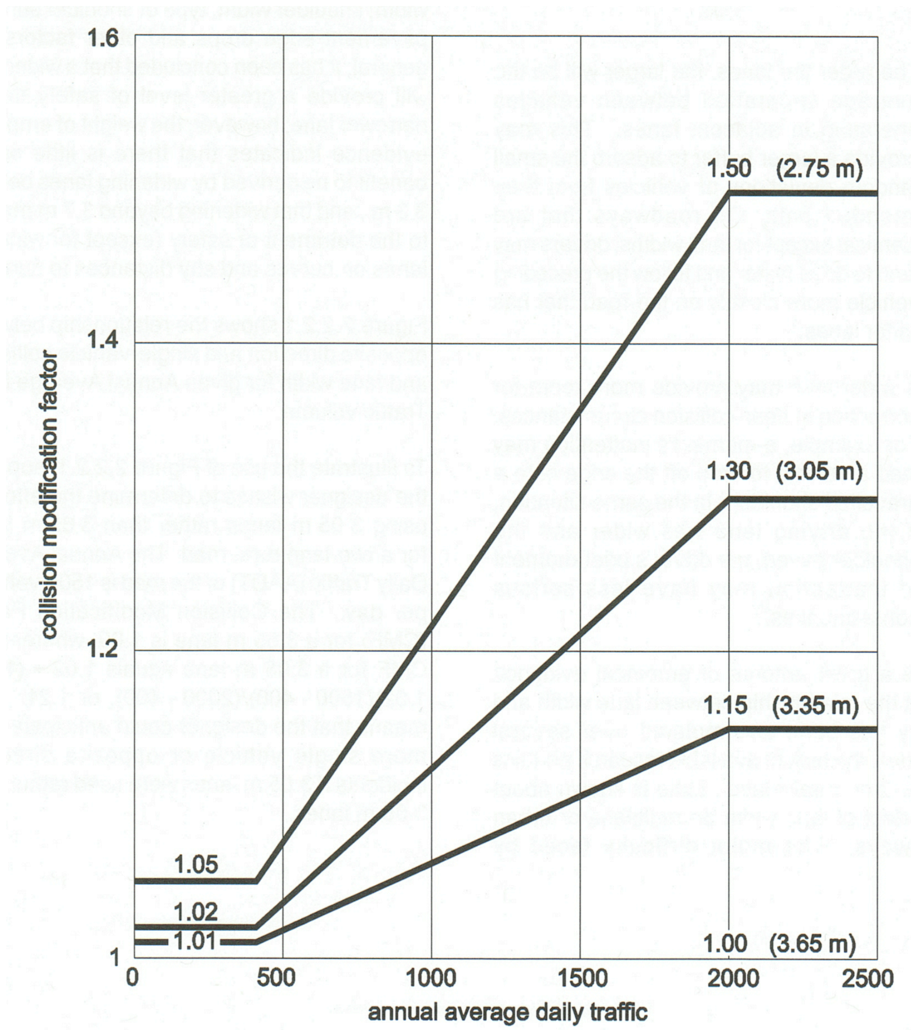


Exhibit 2.1: CMF for Lane Width

2.1.2 Outside Shoulder Width

Exhibit 2.2 is used to obtain a CMF for the outside shoulder width. To obtain the CMF, select the traffic volume (AADT) on the horizontal axis and then draw a vertical line to intersect the line in the graph corresponding to the shoulder width. For shoulder widths not shown in Exhibit 2.2, the CMFs can be obtained by interpolating between the lines. Outside shoulder width greater than 3.05 meters in width should be assigned the CMF equal the 3.05 meters. If the outside shoulder widths for each travel direction differ, the CMF is determined for each direction and then averaged.

Target Collisions: Single vehicle off-road right collisions

References: Geometric Design Guide for Canadian Roads Transportation Association of Canada (TAC).

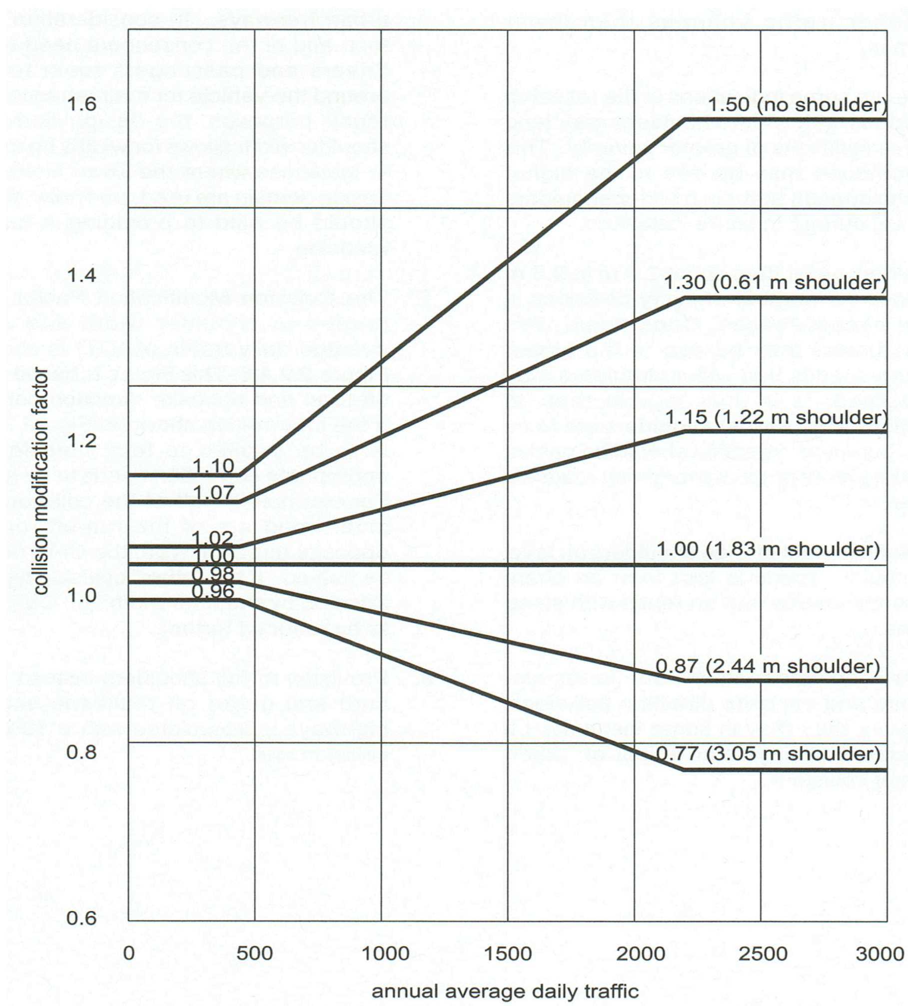


Exhibit 2.2: CMF for Shoulder Width

2.1.3 Outside Shoulder Surface

The safety effects of different outside shoulder surfaces are shown in Exhibit 2.3 below. The baseline condition is a paved shoulder, which has a CMF = 1.0, but for the other types of shoulder surfaces, there is a net loss in safety performance (i.e., the CMF is greater than 1.0). If the outside shoulder surfaces for each travel direction differ, then the CMF is determined for each direction and then averaged.

Target Collisions: Single vehicle off-road and head-on collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

Exhibit 2.3: CMFs for Shoulder Surface Type

Shoulder Type	Shoulder width (meter)						
	0.3	0.6	0.9	1.2	1.8	2.4	3.0
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.01	1.03	1.04	1.05	1.08	1.11	1.14

2.1.4 Median Width

It is somewhat unusual to have a median in place on a two-lane rural highway. However, in some locations in BC, a median may be provided, perhaps in anticipation of future widening or the potential need for a median barrier. The information source used to determine a CMF for a flush median comes from research by the Pennsylvania Department of Transportation (PennDOT) and from AASHTO. Using collision prediction models developed from research, the following expression can be used to determine the CMFs for flush medians.

$$CMF_{MW} = e^{(-0.0216(3.28 \times MW))}$$

Where:

MW = Flush median width in meters

Target Collisions: Off-Road Left and head-on collisions

References: Mason, J., Donnell, E., Harwood, D., Bauer, K., Sada, J., Pietrucha, M. (2001) "Median Safety Study (Interstates and Expressways)" Pennsylvania Transportation Institute, Pennsylvania State University, University Park, PA.

AASHTO - American Association of State Highway and Transportation Officials, Policy on Geometric Design of Highways and Streets, Washington, DC, 1994.

2.1.5 Median Barrier

It is somewhat unusual to have a median barrier in place on a two-lane, rural highway, although there are some locations where this condition exists (e.g., access control). As such, it is recommended that the CMFs derived from multi-lane highways be used in the event that median barrier is used on two-lane highways. The CMFs are dependant upon the collision severity level and reflect the fact that median barriers are very effective in reducing serious collisions (fatal and injury), but the presence of the median barrier will result in an increase in low severity incidents since the median barrier is considered a roadway hazard. The recommended CMFs for median barrier are as follows:

CMF_{MB}	= 0.57	Fatal collisions in the Target Group
	= 0.70	Injury collisions in the Target Group
	= 1.24	PDO collisions in the Target Group

The CMFs for median barrier does not explicitly distinguish between the types of median barrier although the information obtained in the literature review pertains primarily to median barrier that would normally exceed minimum performance testing specifications (e.g., NCHRP 350).

Target Collisions: Off-Road Left and head-on collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

2.1.6 Roadside Design: Clear-Zone

The relationship between the clear-zone and single vehicle off-road right collisions was evaluated to produce a CMF. Some modifications were made to better reflect BC specific conditions, in particular, the difficult terrain in many parts of BC.

The CMF for clear-zone, or often referred to as the horizontal clearance distance, is given in the equation below. The required clear-zone distance is dependant upon the design speed, which affects the lateral extent in which an errant vehicle will enter a roadside area. As such, the basis for the clear-zone CMF is based on the difference between width of clear-zone provided and the required (standard) clear-zone width.

$$CMF_{CZONE} = e^{-0.0137(3.28\,(W_{CZ} - S_{CZ}))}$$

Where:

CMF_{CZONE} = Collision modification factor for clear zone

W_{CZ} = Clear zone width provided (in meters)

S_{CZ} = Required (standard) clear zone width (in meters)

Target Collisions: Off-road right collisions

References: Miaou, S.P., Measuring the Goodness of Fit of Accident Prediction Models. Report No. FHWA-RD-96-040, FHWA, Washington, DC, 1996.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

2.1.7 Roadside Design: Side Slope

The relationship between the roadside embankment slope or side slope and single vehicle off-road right collisions were reviewed and evaluated to produce a CMF for BC.

The CMF for the side-slope is given in the equation below. The basis for the CMF for the side-slope is based on the difference between a traversable and recoverable side slope of 1:4 (Vertical to Horizontal) and the side-slope that is provided

$$CMF_{SS} = e^{0.692\,(1/S - 1/4)}$$

Where:

CMF_{SS} = Collision modification factor for side-slope

S = Horizontal distance (m) for 1 m change in elevation

Target Collisions: Off-road right collisions

References: Miaou, S.P., Measuring the Goodness of Fit of Accident Prediction Models. Report No. FHWA-RD-96-040, FHWA, Washington, DC, 1996.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

2.1.8 Roadside Design: Utility Pole Density and Offset

The relationship between the density and offset of utility poles within the roadside area and the likelihood of single vehicle off-road right collisions were reviewed. The CMF for utility pole density and offset was produced by research that developed a collision prediction model based on data from the United States.

The CMF for the utility pole density and offset can be obtained by using the equation below.

$$CMF_{UP} = \frac{(0.0000984\,ADT + 0.022 D_P)(3.28 W_O^{(-0.6)}) - 0.04}{0.0000128\,ADT + 0.075}$$

Where:

CMF_{UP}	= Collision modification factor for utility pole density
ADT	= Average daily traffic (vehicles per day)
D_P	= utility pole density (two-way total), poles per km
W_O	= Pole offset distance from the edge of pavement (m)

Target Collisions: Off-road right collisions

References: Zeeger, C.V., and M.R. Parker, Cost-Effectiveness of Countermeasures for Utility Pole Accidents, Report No. FHWA-RD-83-063, FHWA-RD-96-040, FHWA, Washington, DC, 1983.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

2.1.9 Roadside Design: Roadside Barrier

The recommended CMF for roadside barrier is based on roadside hazard rating system (RHR). The RHR uses a scale from 1 to 7 to represent different roadside areas, with a RHR = 1 being characterized by a safe roadside area and a RHR = 7 being characterized by a hazardous roadside area. Roadside barrier is normally placed when the roadside area cannot be made safer and thus, the roadside barrier prevents an errant vehicle from entering the hazardous roadside area. The CMF for roadside barrier is based on the presumption that the barrier is not being placed when a safe roadside area exists (free of hazards and a flat side-slope). The CMF for roadside barrier is obtained using the equations below, which is based on the selection of the RHR for the roadside area. This value should be selected based on the guidelines provided in Exhibit 2.4 and Exhibit 2.5.

The CMF for the roadside barrier should not be used in conjunction with other CMFs related to roadside design (clear-zone, side-slope or utility poles). In addition, the placement of roadside barrier is often very site specific and as such there are other tools that can be used to evaluate roadside safety, such as the Roadside Design Guide (AASHTO – 2006) and the Roadside Safety Analysis Program (RSAP) from NCHRP.

$$CMF_{RB} = \frac{e^{(-0.4197)}}{e^{(-0.6869+0.0668RHR)}}$$

Where:

CMF_{RB}	= Collision modification factor for roadside barriers
RHR	= Roadside Hazard Rating (Score 4 to 7)

Target Collisions: Off-Road right collisions

References: Zeeger, C. V., D.W. Reinfurt, J. Hummer, L. Herf, and W. Hunter, "Safety Effects of Cross-Section Design for Two-Lane Roads", Transportation Research Record 806, Transportation Research Board, 1981.

Exhibit 2.4: Guidance to Select RHR For Hazardous Roadside Areas

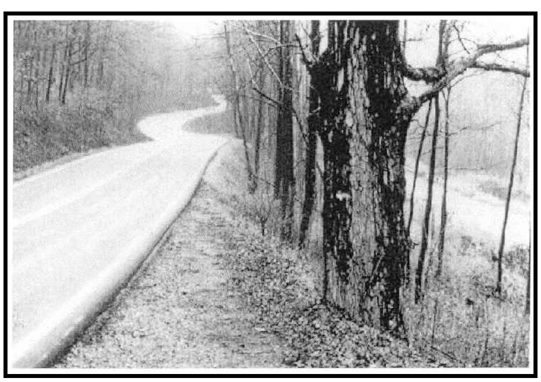
RHR Scores							
Side Slope	Clear Zone (meters)						
	> 12	12 - 10	10 - 8	8 - 6	6 - 4	4 - 2	< 2
>4.0:1	N/R	N/R	N/R	N/R	4	5	6
4.0:1	N/R	N/R	N/R	N/R	4	5	6
3.5:1	N/R	N/R	N/R	N/R	4	5	6
3.0:1	N/R	N/R	N/R	4	5	6	7
2.5:1	4	4	4	5	6	7	7
2.0:1	5	5	5	6	7	7	7
<2.0:1	6	6	6	7	7	7	7

N/R = Roadside barrier is not normally required since the roadside area is generally free of hazardous objects and the side slope is traversable.

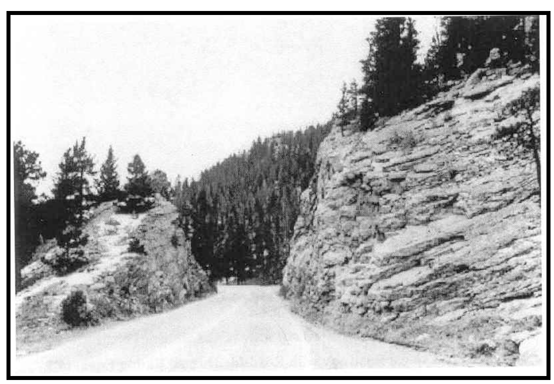
Exhibit 2.5: Illustrative Examples of RHR Scores

RHR = 4

RHR = 5



RHR = 6



RHR = 7

2.1.10 Install Impact / Crash Attenuators

Installing an impact or crash attenuator at fixed roadway or roadside features should reduce the severity of collisions between an errant vehicle and the fixed hazardous object on the roadway or in the roadside area.

The CMFs for impact attenuators are dependant on the collision severity level and reflect the fact that impact attenuators are design to reduce the severity on collisions (fatal and injury). The CMFs that are used in the safety evaluation of impact attenuators is as follows:

CMF_{IA} = 0.31 Fatal collisions in the Target Group
= 0.31 Injury collisions in the Target Group
= 0.54 PDO collisions in the Target Group

The CMFs for impact attenuators does not explicitly distinguish between the numerous types of impact attenuators that are available. As such, as long as the impact attenuator is an acceptable device for use on BC Highways, then the recommended CMFs can be applied.

Target Collisions: Off-Road right collisions for roadside installations
Off-road left collisions for median installations

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

2.1.11 Shoulder Rumble Strip

Shoulder rumble strips are a roadway safety devise that target off-road right collisions. The research that investigated the effectiveness of shoulder rumble strips is based on the experience on rural multi-lane highways, but it is suggested that the results could also be applied to two-lane highways. The CMF is applicable to the range of shoulder rumble strip designs (e.g., milled in, rolled in, raised, etc.) and for the placement of the rumble strip (e.g., continuous, intermittent). The CMF for shoulder rumble strips is listed below, and it is equally applicable for horizontal curves and for tangent sections.

CMF_{SRS} = 0.79

Target Collisions: Off-Road right collisions

References: Carrasco, O., McFadden, J, Chandhok, P., "Evaluation of the Effectiveness of Shoulder Rumble Strips on Rural Multi-Lane Divided Highways in Minnesota", 83rd Annual Transportation Research Board meeting, Washington DC, 2004.

Griffith, M.S., Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips, Transportation Research Record 1665, Transportation Research Board (TRB), Washington DC, pp 28-34(1999).

2.1.12 Centreline Rumble Strip

Median rumble strips are a road safety devise that target head-on and off-road left collisions. They may also be helpful in preventing risky passing maneuvers. The CMF for centreline rumble strips is listed below. The CMF is applicable to the range of centreline rumble strip designs (e.g., milled in, rolled in, raised) and placement of the rumble strip (e.g., continuous, intermittent). The CMFs are also applicable to horizontal curves, tangent sections, passing and no-passing lanes. There has been some suggestion that CRS may have a detrimental safety impact on motorcyclists, but quantitative information to support this assertion could not be found.

$CMF_{CRS} = 0.86$

Target Collisions: Off-Road left and head-on collisions

References: Persaud, B., Retting R, and Lyon, C, "Crash Reduction Following Installation of Centreline Rumble Strips on Rural Two-Lane Roads", Insurance Institute for Highway Safety, Arlington Virginia, 2003.

Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

2.2 Longitudinal Design Elements

A total of 7 different longitudinal design elements are included in the list of CMFs for two-lane Highways in British Columbia. Included are the following design elements, each of which are presented on the following pages:

1) Horizontal Alignment
2) Super-Elevation
3) Vertical Alignment
4) Design Consistency
5) Passing Lanes
6) Two-Way Left-Turn Lane (TWLTL)
7) Access Control

Similar to the format in the preceding section, a general description of the design element will be provided (if required), followed by the CMF that is recommended. The target collision types will also be identified and the information source is noted.

Some of the collision modification factors in this section should not be combined as the safety effect between elements may be overlapping (e.g., design consistency and horizontal alignment CMFs). These potential overlaps will be identified in the relevant sections that describe the longitudinal CMFs.

2.2.1 Horizontal Alignment

The horizontal alignment of a highway is known to be a contributing factor in the occurrence of collisions. Several elements of the geometry of the horizontal curve likely contribute to the safe navigation of the curve. The function below can be used to calculate the CMF for a horizontal curve, which has been modified to reflect metric units of measurement.

$$CMF_{HC} = \frac{0.962\ L_C + \dfrac{80.2}{3.28\ R} - 0.012\ S}{0.962\ L_C}$$

Where:

CMF_{HC}	= Collision modification factor for horizontal curve
L_C	= Horizontal curve length including spiral transitions (km)
R	= Radius of curvature (m)
S	= Spiral indicator: 1 if spirals used, or 0 if spirals absent

Target Collisions: Off-Road collisions

References:

Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

2.2.2 Super-Elevation

The super-elevation of a horizontal curve is determined through the design process and is normally built to the recommended design. In this case, the CMF is 1.0. However, the super-elevation of a highway can change over time due to the settlement and heaving of pavement structure.

The CMF for super-elevation is determined by taking into account the value of the maximum super-elevation (e max), which is set by the BC MOT at 6%. The CMF for super-elevation is based on the super-elevation deficiency (SD) (i.e., SD = difference between the actual super-elevation on the curve and the super-elevation that is required by AASHTO's Policy on Geometric Design AASHTO). When the actual super-elevation meets or exceeds the AASHTO requirement, then the CMF for super-elevation is 1.00. If the super-elevation deficiency (SD) is less than 1% deficient, then the CMF for super-elevation is still 1.00. However, should the super-elevation deficiency exceed 1%, then the following relationships can be used to determine the CMF for deficient super-elevation:

$CMF = 1.00$	Curves with $SD < 1.00\%$
$CMF = 1.00 + 6(SD - 1.00)$	Curves with $SD \geq 1.00\%$ and $< 2.00\%$
$CMF = 1.06 + 3(SD - 2.00)$	Curves with $SD \geq 2.00\%$

Target Collisions: All collisions

References: Zeeger, C., R. Steward, D. Reinfurt, F. Council, T. Miller, Newman, E. Hamilton, and W. Hunter, "Cost-Effective Geometric Improvements for the Safety Upgrading of Horizontal Curves", Report No. FHWA-R0-90-021, Federal Highway Administration, 1991.

Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

2.2.3 Vertical Alignment

The CMF for the vertical alignment is based on the roadway grade. The safety of a roadway is affected by the grade in several ways because the grade will affect the average speed of vehicles, the speed differential of vehicles on the grade, the required braking distances, and drainage. The CMF for grade can be determined using the equation below. It is noted that the grade variable is an absolute value, which implies that the CMF has the same value regardless of whether the grade is positive (uphill) or negative (downhill).

$$CMF_{GRADE} = e^{0.016\, P_G}$$

Where:

CMF_{GRADE} = Collision modification factor for roadway grade

P_G = Percent grade (absolute value) in %

Target Collisions: All collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

2.2.4 Design Consistency

Design consistency measures can be classified into four main categories: vehicle speed; vehicle stability; alignment indices; and driver workload. However, only the first 2 categories are used to obtain the CMF for design consistency.

<u>Vehicle Speed</u>

The change in vehicle operating speed is an indicator of inconsistency in geometric design. Since many collisions have been attributed to improper speed adaptation, the operating speed can also be a good indicator of the level design consistency. As such, two design consistency measures related to vehicle speed are used.

1) The difference between the operating speed and the design speed ($V85 - V_D$) is a good indicator of the consistent design at one location.
2) The speed reduction between two successive sections of road ($\Delta V85$) indicates an inconsistent design experienced by drivers when traveling from one section of road to the next.

<u>Vehicle Stability</u>

Vehicle stability is an important issue to ensure safe operation, as it directly influences road safety. A design consistency measure related to vehicle stability is related to the margin of safety on the difference between side friction assumed and side friction demanded.

<u>Consistency Evaluation Process</u>

The following steps are required to obtain a CMF for design consistency.

- Step 1: Apply an operating speed model (speed prediction).
- Step 2: Calculate consistency measures
- Step 3: Calculate the design consistency CMF

Step 1: Predicting Operating Speeds

Predicting the operating speed (V85) on the various segments of the highway alignment is a key step in consistency evaluation.

For horizontal curves, the operating speed (V85) is calculated as follows:

$$V_{85} = \mathrm{Exp}\,(4.561 - 0.000527\,CCR_S)$$

$$CCR_S = \frac{63{,}700\left(L_{cl1}/2R + L_{cr}/R + L_{cl2}/2R\right)}{L}$$

Where:

CCR_S	= curvature change rate (gon/km)(1 gon = 0.9°);
L_{cr}	= length of circular curve (m);
L_{cl1}, L_{cl2}	= length of spirals preceding & succeeding the curve (m);
R	= radius of curve (m); and
L	= total length of curve and spirals (m).

For tangents, operating speed (V85) is calculated as follows:
Determine whether a tangent is "independent" or "non-independent". "Non-independent" tangents are tangents that are too short to exceed the possible 85th-percentile speed differences (ΔV85) of 20 km/hr during the acceleration or deceleration maneuvers. In this case, the element sequence curve-to-curve will control the evaluation of the consistency measure (ΔV85).

On the other hand, an "independent" tangent is long enough to permit vehicles to exceed the possible 85th-percentile speed differences (ΔV85) of 20 km/h during the acceleration or deceleration maneuvers. In this case, the element sequence tangent-to-curve will control the evaluation of the consistency measure (ΔV85).

Exhibit 2.6 on the following page is used to determine whether a tangent "independent" or "non-independent".

"Non independent" tangents will have lengths equal to or shorter than the values in Exhibit 2.6. The value of ΔV85 is calculated between the two successive curves without considering the tangent in between. If the tangent length is greater than the values in Exhibit 2.6, it will be considered "independent" and the method described in section 1.4.3.2 of the TAC Geometric Design Guide for Canadian Roads should be used to estimate the speed on "independent" tangents. [1]

Exhibit 2.6: Limits for "Non-Independent" Tangent Length

V_{85} in curve (km/hr)	Tangent Length (m)
50	110
55	120
60	125
65	135
70	145
75	155
80	165
85	170
90	180
95	190
100	200

Step 2: Calculating Design Consistency Measures

Using the operating speed obtained from Step 1, the 2 design consistency measures related to vehicle speed are calculated. It should be noted that in determining ΔV85, the critical driving direction should be used.

DC_1 = difference between operating & design speed
= $V85 - V_D$

DC_2 = difference in the speed between successive road sections
= $\Delta V85$

[1] The 85th percentile desired speed on long tangent (V_f) is assumed to be 95.7 Km/hr.

The vehicle stability measure is defined as the difference between the side friction assumed and the side friction demanded ($\Delta f_R = f_R - f_{RD}$) and calculated as follows:

$$f_R = 0.22 - 1.79\times10^{-3}\ V_D + 0.56\times10^{-5}\ V_D^2$$

$$f_{RD} = V_{85}^2 / 127R - e$$

Where:

f_R = the side friction assumed;

f_{RD} = the side friction demanded;

R = radius of horizontal curve (m);

e = super elevation rate; and V_D = design speed.

Step 3: Calculate the CMF for design consistency

Using the three design consistency measures described above, calculate the design consistency collision modification factor as follows:

$$CMF = \exp\left[0.0049\ (V_{85} - V_d) + 0.0253\ \Delta V_{85} - 1.177\ \Delta f_R\right]$$

Target Collisions: All collisions

References: Sayed, T, Highway 99: Sea to Sky Highway Improvement Project: Collision Prediction Modeling (CPM) Instruction, Supplement 4 to Appendix 1F, BC MOT, (2005).

It is noted that the CMF for design consistency should not be used when the CMF for horizontal curve and super-elevation are applied. The CMF for horizontal curve and super-elevation are considered in the evaluation of design consistency.

2.2.5 Passing Lanes

The research that examined the relationship between two-lane highways with a passing lane and the collision frequency indicated that the safety performance was better on two lane highways that have passing lanes. CMF are available for two types of passing lanes:

1) Conventional passing lanes or climbing lanes that are provided in one direction on a two-lane highway, and
2) Short four-lane sections that are designed and built to provide passing opportunities in both directions on a two-lane roadway.

Guidelines that describe the design considerations and the justification for the passing lanes is provide in the American Association of State Highway and Transportation Officials, Policy on Geometric Design of Highways and Streets, Washington, DC, 2004.

The CMFs for the two types of passing lane is listed below. The CMFs are applied only to the section where the full length of the passing lane is provided and on passing lanes that have sufficient length to allow for safety and efficient passing.

$CMF_{3\text{-Lanes}} = 0.75$

$CMF_{4\text{-Lanes}} = 0.65$

Target Collisions: All collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

2.2.6 Two-Way Left-Turn Lane

A two-way left-turn lane (TWLTL) is a third lane that is located in the centre on a two-lane highway to assist in the turning maneuvers from driveways and access locations along the highway. In general, the effectiveness of the TWLTL increases as the density of the accesses and driveways increase on the highway. The CMF for a TWLTL on a two-lane highway can be determined by using the functions below. It is noted that the CMF for TWLTL should not be applied unless the driveway density is greater than 3 driveways per kilometer. If the driveway density is less than 3 driveways per kilometer, the CMF = 1.0.

$$CMF_{TWLTL} = 1.0 - 0.7\,(P_D)(P_{LT/D})$$

$$P_D = \frac{0.0047\ D_D + 0.0024\ D_D^2}{1.199 + 0.0047\ D_D + 0.0024\ D_D^2}$$

Where:

CMF_{TWLTL}	= Collision modification factor for a TWLTL
P_D	= Driveway/access related collisions as a proportion to total collisions
$P_{LT/D}$	= Left-turn collisions that are corrected by a TWLTL as a proportion of driveway related collisions ($P_{LT/D}$ = 0.5)
D_D	= Driveway density (driveways per kilometer)

Target Collisions: All collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

2.2.7 Access Control

Access control or access management is very important to the safety of a roadway and is designed to manage the frequency and magnitude of conflict points along a highway. Decreasing the density of the access points on a two-lane highway will cause an overall net reduction in the total collisions. The following formula can be used to calculate the CMF for access density.

$$CMF_{AC} = \frac{0.2 + D_D\ [0.05 - 0.005\ \ln(ADT)]}{0.2 + 3\ [0.05 - 0.005\ \ln(ADT)]}$$

Where:

CMF_{AC}	= Collision modification factor for access control
ADT	= Annual daily traffic volume (vehicles/day)
D_D	= Driveway density (driveways per kilometer)

Target Collisions: All collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

3.0 MULTI-LANE HIGHWAYS

Multi-lane highways in BC include all highways that have more than two lanes, such as expressways and freeways. Multi-lane highways are much less common than two-lane highways, with only 1,514 kilometers (or 14%) of the total length of numbered highways (10,853 kilometers). The majority of multi-lane highways are located in a rural environment (996 kilometers) but a significant amount is also located in urban areas (548 kilometers). Typically, the traffic volumes on multi-lane highways are higher than on two-lane highways and the operation is more complex due to increased lane changing and turning maneuvers that are more prevalent on multi-lane highways.

Similar to the CMFs that were presented for two-lane highways, the CMFs for multi-lane highways are divided into two categories:

1) Cross-Sectional Design Elements

   Any design element that is related to the cross-section of the roadway, including both the traveled portion of the roadway as well as the roadside area.

2) Longitudinal Design Elements

   Any design element that is related to the longitudinal features of the road.

It is noted that there may be some duplication with some of the CMFs that are presented in this chapter with the CMFs that were presented in other chapters. This duplication is intentional in the interest of completeness. It is also noted that the CMFs can be applied to changes to existing multi-lane highways or for newly constructed multi-lane highways to estimate the impact on safety.

3.1 Cross-Sectional Design Elements

A total of 14 different cross-sectional design elements are included in the list of CMFs for multi-lane highways. Included are the following design elements, each of which are presented on the following pages:

1) Lane Width
2) Outside Shoulder Width
3) Inside Shoulder Width
4) Shoulder Surface
5) Add Lanes by Narrowing Existing Lanes and Shoulders
6) Median Width
7) Median Barrier
8) Roadside Design: Clear-Zone
9) Roadside Design: Side-Slope
10) Roadside Design: Utility Pole Density and Offset
11) Roadside Design: Roadside Barrier
12) Install Impact / Crash Attenuator
13) Shoulder Rumble Strips
14) Centreline Rumble Strips

3.1.1 Lane Width

Many researchers have derived relationships between the lane width and the corresponding level of safety by using collision prediction models. It has determined that the safety effect of the lane width on a multi-lane highway has less impact than the safety effects on two-lane highways, as shown in Exhibit 3.1 below. The following function can be used to determine the CMF for lane width on a multi-lane highway.

$$CMF_{LW} = e^{-0.047\,(3.28\,W_L - 12)}$$

Where:

CMF_{LW} = Collision modification factor for lane width

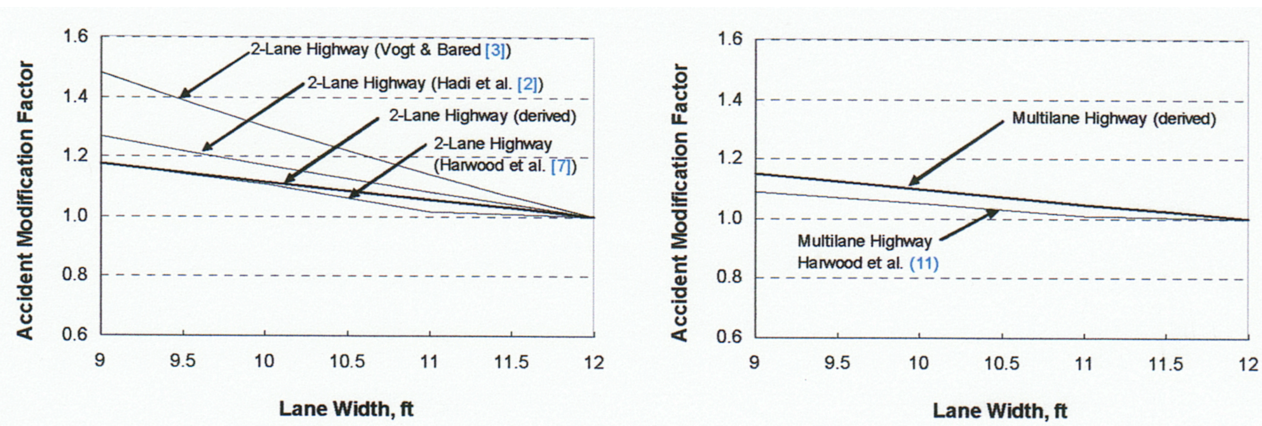
W_L = Lane width in meters

Target Collisions: Single vehicle off-road and head-on collisions

References: Harwood, D., E.R., Kohlman Rabbani, K.R., Richard, H.W. McGee, G.L. Gittings. NCHRP Report 486: System-wide Impacts of Safety & Traffic Operations Design Decisions for 3R Projects. TRB, Washington DC, 2003.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

Exhibit 3.1: Lane Width CMFs for Two-Lane and Multi-Lane Highways



a. Two-Lane Highways. *b. Multilane Highways.*

3.1.2 Outside Shoulder Width

The CMF for the outside shoulder width was derived in a similar manner to that of the lane width. The safety effect of the outside shoulder width on a multi-lane highway has less of an impact than on a two-lane highway, as shown in Exhibit 3.2. The following function can be used to determine the CMF for the outside shoulder width on a multi-lane highway.

$$CMF_{SW(O)} = e^{-0.021\,(3.28\,W_{S(O)} - 10)}$$

Where:

$CMF_{SW(O)}$ = Collision modification factor for shoulder width

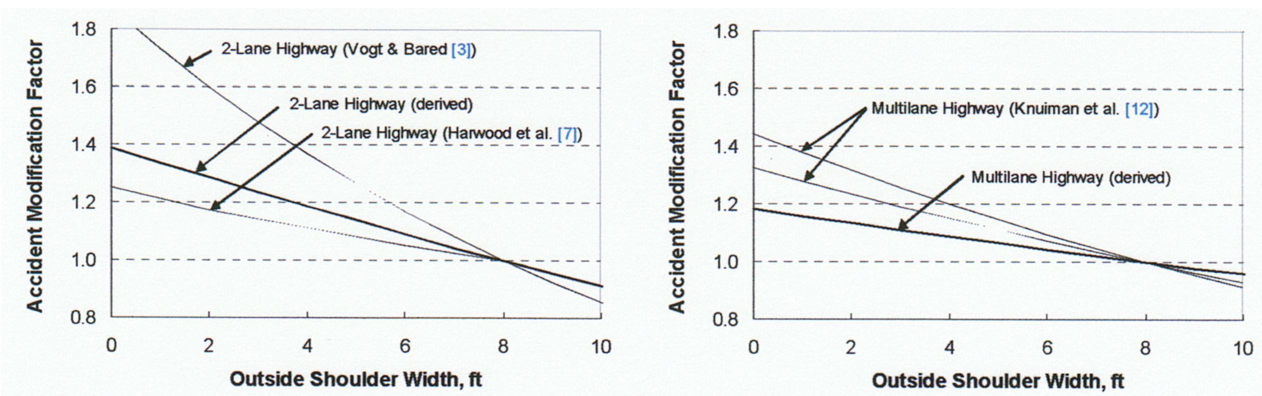
$W_{S(o)}$ = Outside shoulder width in meters

Target Collisions: Single vehicle off-road right collisions

References: Harwood, D., E.R., Kohlman Rabbani, K.R., Richard, H.W. McGee, G.L. Gittings. NCHRP Report 486: System-wide Impacts of Safety & Traffic Operations Design Decisions for 3R Projects. Transportation Research Board (TRB), Washington DC, 2003.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

Exhibit 3.2: Shoulder Width CMFs for Two-Lane and Multi-Lane Highways



a. Two-Lane Highways. *b. Multilane Highways.*

3.1.3 Inside Shoulder Width

Unlike most two-lane highways, many multi-lane highways will often have an inside shoulder, defined as the distance between the lane edge ('fast-lane') and the median barrier. The inside shoulder provides some physical separation between the travel lane and the median barrier and if wide enough, the inside shoulder can be used as a breakdown area for disabled vehicles traveling in the inside (fast) lane.

The following functions can be used to determine the CMF for an inside shoulder on a multi-lane highway. Note that there is a difference in the function depending on the number of lanes on the multi-lane highway.

$CMF_{SW(I)} = e^{-0.021\,(3.28\,W_{S(I)} - 4)}$ For highways with 4 lanes

$CMF_{SW(I)} = e^{-0.021\,(3.28\,W_{S(I)} - 10)}$ For highways with 6+ lanes

Where:

$CMF_{SW(I)}$ = Collision modification factor for inside shoulder width

$W_{S(I)}$ = Inside shoulder width in meters (measured from the lane edge to base of the median barrier)

Target Collisions: Single vehicle off-road left and head-on collisions

References: Hadi, M.A., J., Aruldhas, L.F., Chow, J.A., Waddleworth, "Estimating Safety Effects of Cross-Section for various Highway Types Using Negative Binomial Regression" Transportation Research Record (No. 1500), Washington DC, 1995, pp 169-177.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

3.1.4 Shoulder Surface

The safety effects of the different types of shoulder surfaces are shown in Exhibit 3.3 below. The baseline condition is a paved shoulder, which has a CMF = 1.0, but for the other types of shoulder surfaces, there is a net loss in safety performance (i.e., the CMF is greater than 1.0). If the shoulder surfaces for each travel direction differ, then the CMF is determined for each direction and then averaged.

Target Collisions: Single vehicle off-road and head-on collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

Exhibit 3.3: CMFs for Shoulder Surface Type

Shoulder Type	Shoulder width (meter)						
	0.3	0.6	0.9	1.2	1.8	2.4	3.0
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.01	1.03	1.04	1.05	1.08	1.11	1.14

3.1.5 Add Lanes by Narrowing Existing Lanes and Shoulders

Due to right-of way constraints, it is sometimes necessary to add capacity to a highway by narrowing the existing lanes and shoulders in order to accommodate an additional lane. The addition of a fifth lane to a four-lane lane highway or a sixth lane to a 5-lane cross section will have an adverse impact on the safety performance. This type of treatment is more common on urban multi-lane facilities, but there may be situations where it is used in a rural context.

The CMFs for adding through lanes by narrowing the existing travel lanes and shoulders are provide in Exhibit 3.4.

Exhibit 3.4: CMFs for Adding Through Lanes to Existing Multi-Lane Highways

Road Type	Treatment	Collision Severity	CMF
Multi-Lane Highways	4 to 5 lane conversion	All	1.11
	5 to 6 lane conversion	All	1.07

Target Collisions: All collisions

References: Bauer, K.M., Harwood, D., H., Hughes, W.E., Richard, K., “Safety Effects of Using Narrow Lanes and Shoulder-Use Lanes to Increase the Capacity of Urban Freeways” 83rd Transportation Research Board Annual Meeting, Washington DC, 2003.

3.1.6 Median Width

Wide medians on multi-lane highways are common and serve to separate opposing traffic, provide a recovery area for errant vehicles and provide an emergency stopping area. The information source used to determine a CMF for a median on multi-lane highways comes from data from the United States and was developed using collision prediction models. The following expressions can be used to determine the CMF for median width on a multi-lane highway. Note that the expressions are different for flush medians and for wide depressed medians.

$$CMF_{MW} = \frac{e^{\left(-0.046 \frac{W_M}{3.28}^{0.5}\right)}}{0.815}$$ For narrow, flush medians

$$CMF_{MW} = \frac{e^{\left(-0.050 \frac{W_M}{3.28}^{0.5}\right)}}{0.774}$$ For wide, depressed medians

Where:

CMF_{MW} = Collision modification factor for median width

W_M = Median width in meters

Target Collisions: Off-Road Left and head-on collisions

References: Knuiman, M.W., F.M., Council, D. Reinfurt, "Association of Median Width and Highway Accident Rates" Transportation Research Record 1401, Transportation Research Board, Washington, 1993, pp. 70 – 82.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

3.1.7 Median Barrier

The CMFs for median barrier on a multi-lane highway is dependant upon the collision severity level, which reflects the fact that median barriers are very effective in reducing serious collisions (fatal and injury), but the presence of the median barrier will result in more low severity incidents. This is because the median barrier can be considered a roadway hazard and will cause damage if struck by an errant vehicle. The CMFs for median barrier are as follows:

CMF_{MB} = 0.57 Fatal collisions in the Target Group
= 0.70 Injury collisions in the Target Group
= 1.24 PDO collisions in the Target Group

It is noted that the CMFs for median barrier does not explicitly distinguish between the types of median barrier.

Target Collisions: Off-Road Left and head-on collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

3.1.8 Roadside Design: Clear-Zone

In general, the literature that is related to the safety performance that is associated with roadside design is largely based on the evaluation of two-lane highways. As such, if a roadside design CMF that is based on multi-lane highways is not available, it is recommended that the CMFs that were presented for two-lane highways be used for multi-lane highway until new research is available that specifically evaluates roadsides on multi-lane highways.

The CMF for the clear-zone (horizontal clearance distance) is given in the equation below. The required clear-zone distance is dependant upon the design speed, which affects the lateral extent in which an errant vehicle will enter a roadside area. As such, the basis for the CMF for the clear-zone in British Columbia is based on the difference between width of clear-zone provided and the required (standard) clear-zone width.

$$CMF_{CZ} = (e^{-0.0137(3.28(W_{CZ} - S_{CZ}))})$$

Where:

CMF_{CZ} = Collision modification factor for clear zone
W_{CZ} = Clear zone with in meters
S_{CZ} = Required (standard) clear zone width in meters

Target Collisions: Off-road right collisions

References: Miaou, S.P., Measuring the Goodness of Fit of Accident Prediction Models. Report No. FHWA-RD-96-040, FHWA, Washington, DC, 1996.
Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

3.1.9 Roadside Design: Side-Slope

The CMF for the side-slope is given in the equation below. The basis for the CMF for the side-slope is based on the difference between a traversable and recoverable side slope of 1:4 (Vertical to Horizontal) and the side-slope that is provided

$$CMF_{SS} = (e^{0.692\,(1/S - 1/4)})$$

Where:

CMF_{SS}	= Collision modification factor for side-slope
S	= Horizontal distance (m) for 1 m change in elevation

Target Collisions: Off-road right collisions

References:

Miaou, S.P., Measuring the Goodness of Fit of Accident Prediction Models. Report No. FHWA-RD-96-040, FHWA, Washington, DC, 1996.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

3.1.10 Roadside Design: Utility Pole Density and Offset

The relationship between the density and offset of utility poles within the roadside areas and the likelihood of single vehicle off-road right collisions for multi-lane highways were reviewed and evaluated to produce a CMF.

The CMF for utility pole density and offset was produced by research that developed a collision prediction model based on data from the United States. The CMF for the utility pole density and offset can be obtained by using the equation below.

$$CMF_{UP} = \frac{(0.0000984\,ADT + 0.022D_P)(3.28W_O^{(-0.6)}) - 0.04}{0.0000128\,ADT + 0.075}$$

Where:

CMF_{UP}	= Collision modification factor for utility pole density
ADT	= Average daily traffic (vehicles per day)
D_P	= utility pole density (two-way total), poles per km
W_O	= Average pole offset from edge of pavement (m)

Target Collisions: Off-road right collisions

References: Zeeger, C.V., and M.R. Parker, Cost-Effectiveness of Countermeasures for Utility Pole Accidents, Report No. FHWA-RD-83-063, FHWA-RD-96-040, FHWA, Washington, DC, 1983.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

3.1.11 Roadside Design: Roadside Barrier

The recommended CMF for roadside barrier is based on roadside hazard rating system (RHR), which is described in detail in Section 2.1.9. Roadside barrier is normally placed when the roadside area cannot be made safer and thus, the roadside barrier prevents an errant vehicle from entering the hazardous roadside area. The CMF for roadside barrier is based on the presumption that the barrier is not being placed when a safe roadside area exists (free of hazards and a flat side-slope).

The CMF for the roadside barrier should not be used in conjunction with the other CMFs related to roadside design (clear-zone, side-slope or utility poles). In addition, the placement of roadside barrier is often very site specific and as such there are other tools that can be used to evaluate roadside safety, such as the Roadside Design Guide (AASHTO –2006) and the Roadside Safety Analysis Program (RSAP) from NCHRP.

The CMF for roadside barrier is obtained using the equation below. The CMF is based on the selection of the RHR for the roadside area. This value should be selected based on the guidelines provided in Exhibit 2.4 and Exhibit 2.5 in Section 2.1.9 (page 29).

$$CMF_{RB} = \frac{e^{(-0.4197)}}{e^{(-0.6869+0.0668RHR)}}$$

Where:

CMF_{RB}	= Collision modification factor for roadside barriers
RHR	= Roadside Hazard Rating (Score 4 to 7)

Target Collisions: Off-Road right collisions

References: Zeeger, C. V., D.W. Reinfurt, J. Hummer, L. Herf, and W. Hunter, "Safety Effects of Cross-Section Design for Two-Lane Roads", Transportation Research Record 806, Transportation Research Board, 1981.

3.1.12 Install Impact / Crash Attenuator

The CMFs for impact attenuators are dependant on the collision severity level and reflect the fact that impact attenuators are design to reduce the severity on collisions (fatal and injury). The CMFs that are used in the safety evaluation of impact attenuators is as follows:

CMF = 0.31 Fatal collisions in the Target Group
= 0.31 Injury collisions in the Target Group
= 0.54 PDO collisions in the Target Group

The CMFs for impact attenuators does not explicitly distinguish between the numerous types of impact attenuators that are available. As such, as long as the impact attenuator is an acceptable device for use on BC Highways, then the recommended CMFs can be applied.

Target Collisions:	Off-Road right collisions for roadside installations Off-road left collisions for median installations
References:	Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

3.1.13 Shoulder Rumble Strips

Shoulder rumble strips are a roadway safety devise that target off-road right collisions. The CMF are applicable to the range of shoulder rumble strip designs (e.g., milled in, rolled in, raised, etc.) and for the placement of the rumble strip (e.g., continuous, intermittent, etc.). The CMF for shoulder rumble strips is listed below, and it is equally applicable for horizontal curves and for tangent sections.

CMF_{SRS} = 0.86

Target Collisions: Off-Road right collisions

References: Carrasco, O., McFadden, J, Chandhok, P., "Evaluation of the Effectiveness of Shoulder Rumble Strips on Rural Multi-Lane Divided Highways in Minnesota", 83rd Annual Transportation Research Board meeting, Washington DC, 2004.

Griffith, M.S., Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips, Transportation Research Record 1665, Transportation Research Board (TRB), Washington DC, pp 28-34(1999).

3.1.14 Median / Centreline Rumble Strips

Median rumble strips are a road safety devise that target head-on and off-road left collisions. They may also be helpful in preventing risky passing maneuvers. The CMF for centreline rumble strips is listed below. The CMF is applicable to the range of centreline rumble strip designs (e.g., milled in, rolled in, raised) and placement of the rumble strip (e.g., continuous, intermittent). The CMFs are also applicable to horizontal curves, tangent sections, passing and no-passing lanes.

CMF_{CRS} = 0.90

Target Collisions: Off-Road left and head-on collisions

References: Persaud, B., Retting R, and Lyon, C, "Crash Reduction Following Installation of Centreline Rumble Strips on Rural Two-Lane Roads", Insurance Institute for Highway Safety, Arlington Virginia, 2003.

Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

3.2 Longitudinal Design Elements for Multi-Lane Highways

Four different longitudinal design elements are included in the list of CMFs for multi-lane highways in British Columbia. Included are the following design elements, each of which are presented on the following pages:

1) Horizontal Alignment
2) Super-Elevation
3) Vertical Alignment
4) Access Control

There are fewer CMFs for multi-lane highway as compared to the CMFs that were presented for two-lane highways. This is because several of the CMFs do not apply to a multi-lane highway, such as passing lanes or two-way left-urn lanes (TWLTL).

3.2.1 Horizontal Alignment

Road safety engineering literature does not have sufficient information to reliably estimate the safety effects of horizontal alignment for multi-lane highways. Some very early research by Raff (1953) did yield a CMF for horizontal curves on freeways, but it was not current or reliable to be recommended. This research suggested that the CMF for horizontal curves on multi-lane highways is higher than on 2-lane highway (Exhibit 3.5). Until new research is available, it is recommended that the CMF for horizontal curves for two-lane highways be used for multi-lane highways.

$$CMF_{HC} = \frac{0.962\ L_c + \frac{80.2}{3.28\ R} - 0.012\ S}{0.962\ L_c}$$

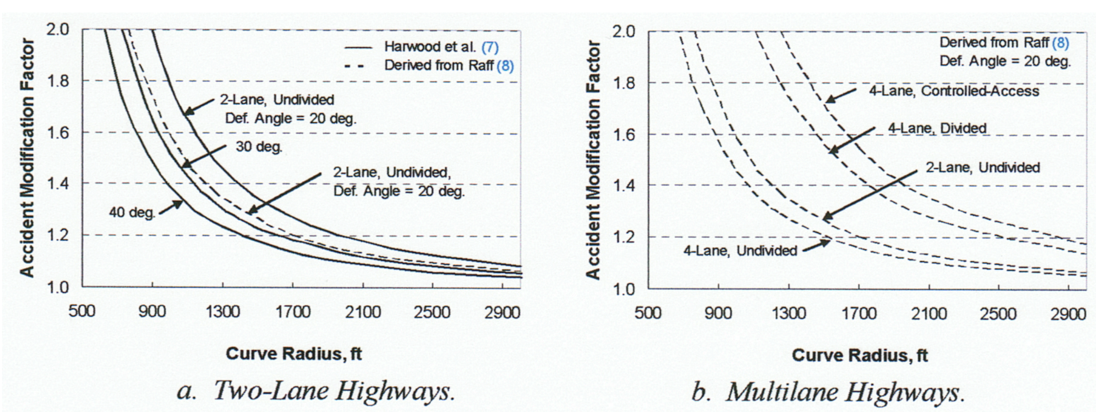
Where:

CMF_{HC}	= Collision modification factor for horizontal curve
L_C	= Horizontal curve length including spiral transitions (km)
R	= Radius of curvature (m)
S	= Spiral indicator: 1 if spirals used, or 0 if spirals absent

Target Collisions: Off-road collisions

References: Raff, M., "Interstate Highway Accident Study" Highway Research Board Bulletin 74, Washington DC, 1953.
Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

Exhibit 3.5: Horizontal Curve CMFs on two-Lane and Multi-Lane Highways



a. Two-Lane Highways. *b. Multilane Highways.*

3.2.2 Super-Elevation

The CMF for super-elevation is based on the super-elevation deficiency, defined as SD. The value of SD is the difference between the actual super-elevation on the curve and the super-elevation that is required by AASHTO – A Policy on Geometric Design of Highways and Streets. When the actual super-elevation meets or exceeds the AASHTO requirement, then the CMF for super-elevation is 1.00. If the super-elevation deficiency (SD) is less than 1% deficient, then the CMF for super-elevation is still 1.00. However, should the super-elevation deficiency exceed 1%, then the following relationships can be used to determine the CMF for super-elevation:

$CMF = 1.00$	Curves with $SD < 1.00\%$
$CMF = 1.00 + 6(SD - 1.00)$	Curves with $SD \geq 1.00\%$ and $< 2.00\%$
$CMF = 1.06 + 3(SD - 2.00)$	Curves with $SD \geq 2.00\%$

Target Collisions: All collisions

References: Zeeger, C., R. Steward, D. Reinfurt, F. Council, T. Miller, Newman, E. Hamilton, and W. Hunter, "Cost-Effective Geometric Improvements for the Safety Upgrading of Horizontal Curves", Report No. FHWA-R0-90-021, Federal Highway Administration, 1991.

Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

3.2.3 Vertical Alignment

The CMF for the vertical alignment for multi-lane highways is based on the grade of the roadway. The safety of a roadway is affected by the grade in several ways because the grade will affect the average speed of vehicles, the speed differential of vehicles on the grade, the required braking distances, and drainage. The CMF for grade can be determined using the equation below. It is noted that the grade variable is an absolute value, which implies that the CMF has the same value regardless of whether the grade is positive (uphill) or negative (downhill).

$$CMF_G = e^{0.019 P_G}$$

Where:

CMF_G = Collision modification factor for roadway grade

P_G = Percent grade (absolute value) in %

Target Collisions: All collisions

References: Milton, J. and F., Mannering, "The Relationship Between Highway Geometrics, Traffic Related Elements, and Motor Vehicle Accidents", Report No. WA-RD 403.1. Washington State Transportation Centre, University of Washington, Seattle, March 1996.

3.2.4 Access Control

Reliable information that is specific to the safety effects of access control on multi-lane highways was not found in the road safety engineering literature. However, information that pertains to suburban arterials was found and the corresponding CMFs are recommended for multi-lane highways. The research indicated that a decrease in the density of access points along a suburban arterial would cause a net decrease in all types of collisions.

The safety effect that can be expected with a reduction in the level of access is shown in Exhibit 3.6 below.

Exhibit 3.6: Access Control on Multi-Lane Highways

Treatment	Collisions Severity	CMF
Reduce Assess Locations from > 30 per kilometer to 16 to 30 per kilometer	Injury	0.71
Reduce Assess Locations from 16 - 30 per kilometer to 6 to 15 per kilometer	Injury	0.69
Reduce Assess Locations from 6 - 15 per kilometer to less than 6 per kilometer	Injury	0.75

Target Collisions: Injury collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

4.0 URBAN STREETS

Although the majority of the roadways within the jurisdiction of the BC Ministry of Transportation and Infrastructure are located within a rural environment, there is approximately 908 kilometers that are classified as being within an urban environment, which represents 8.3% of the total provincial highway system. However, in terms of the number of collisions, there were 104,595 collisions that occurred on urban highways from the total of 273,674 collisions between 1987 and 2006 (inclusive). This means that although the length of urban highway is relatively small (8.3%), the collision frequency is considerable at 38.2%. As such, it was considered important to include CMFs for urban streets

The list of CMFs that are included for urban streets is listed below and the details of each CMF are provided in the following pages. It is noted that the CMFs that are presented in this chapter were generated from typical urban conditions; however, it is recognized that some BC MOT highways that are classified as "urban" may be considered "sub-urban" or "inter-urban", but regardless the CMFs should be considered applicable.

1) Lane Width
2) Shoulder Width
3) Provide a Median
4) Median Width
5) Raised Medians
6) Un-Curbed Cross-Section
7) TWLTL Median
8) Roadside Design: Utility Pole Density and Offset
9) Installation of Impact / Crash Attenuators
10) Horizontal Alignment
11) Access Control
12) Traffic Calming
13) Speed Humps
14) Road Dieting
15) On-Street Parking

4.1 Lane Width

The engineering research has indicated that the safety effect of lane width for urban streets is less than for highways. The CMF for lane width on urban streets was derived by examining the relationships between the lane width and safety performance using collision prediction models. The following function can be used to determine the CMF for lane width on a multi-lane highway.

$$CMF_{LW} = e^{-0.040\,(3.28\,W_L\,-\,12)}$$

Where:

CMF_{LW}	= Collision modification factor for lane width
W_L	= Lane width in meters

Target Collisions: Single vehicle off-road and head-on collisions

References: Hadi, M.A., J., Aruldhas, L.F., Chow, J.A., Waddleworth, "Estimating Safety Effects of Cross-Section for various Highway Types Using Negative Binomial Regression" Transportation Research Record (No. 1500), Washington DC, 1995, pp 169-177.

Harwood, D.W., NCHRP Report Number 282: "Multi-lane Design Alternatives for Improving Sub-Urban Highways" TRB Transportation Research Board, Washington, DC., 1986.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

4.2 Shoulder Width

Lower classification urban streets (e.g., residential streets) typically do not have defined / demarcated shoulders. However, some of the more major urban streets (e.g., major arterials) could have some clearly defined shoulder. The CMF for a shoulder on an urban street is derived in a similar manner to that of the lane width. It is noted that the safety effect of the shoulder width on an urban street has less of an impact than the shoulder on two-lane or multi-lane highways. The following function can be used to determine the CMF for the shoulder width on an urban street.

$$CMF_{SW} = e^{-0.014\,(3.28\,W_S - 1.5)}$$

Where:

CMF_{SW}	= Collision modification factor for shoulder width
W_S	= Shoulder width in meters

Target Collisions: Single vehicle off-road and head-on collisions

References:

Hadi, M.A., J., Aruldhas, L.F., Chow, J.A., Waddleworth, "Estimating Safety Effects of Cross-Section for various Highway Types Using Negative Binomial Regression" Transportation Research Record (No. 1500), Washington DC, 1995, pp 169-177.

Harwood, D.W., NCHRP Report Number 282: "Multi-lane Design Alternatives for Improving Sub-Urban Highways" TRB Transportation Research Board, Washington, DC., 1986.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

4.3 Provide a Median

Although somewhat uncommon on urban roads in North America, the provision of a median on an urban arterial road can be quite effective in reducing collisions. The safety benefits are likely generated because of the reduction in the turning maneuvers from the various access points on the urban road due to the physical restriction created by the median.

The CMFs associated with the provision of a median on an urban road is shown in Exhibit 4.1.

Exhibit 4.1: Providing a Median on Urban Roads

Treatment	**Road Type**	**Target Collisions**	**CMF**
Provide a Raised Median	Urban Multi-Lane	Fatal and Injury	0.78
	Urban Multi-Lane	PDO	1.09

Target Collisions: Fatal / Injury and PDO collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

4.4 Median Width

Wide medians on urban roadways are somewhat uncommon because of limited right of way, however wide medians can sometimes be used on urban parkways and major arterial streets. The information source used to determine the CMFs for a median on urban street is based on data from 4 and 6 lane divided arterial streets and was developed using collision prediction models. The following expression can be used to determine the CMF for median width on an urban street.

$$CMF_{MW} = \frac{e^{\left(-0.041\ \frac{W_M}{3.28}^{0.5}\right)}}{0.879} \qquad \text{For urban medians}$$

Where:

CMF_{MW} = Collision modification factor for median width

W_M = Median width in meters

Target Collisions: Off-Road Left and head-on collisions

References: Hadi, M.A., J., Aruldhas, L.F., Chow, J.A., Waddleworth, "Estimating Safety Effects of Cross-Section for various Highway Types Using Negative Binomial Regression" Transportation Research Record (No. 1500), Washington DC, 1995, pp 169-177.

Bowman, B.L., R.L., Vecellio, P.T., McCoy, "Vehicle and Pedestrian Accident Models for Median Locations", Journal of Transportation Engineering, Vol. 121, NO.6, American Society of Civil Engineers, Washington DC, Nov/Dec 1994, pp. 531-537.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

4.5 Raised Medians / Curbing

Providing raised median / median curbing on urban roadways can be very effective in reducing the number of collisions. The safety benefits may accrue as a result of the reduced turning maneuvers from access points on the urban road as a result of the physical restriction created by the raised median / curbing.

The CMF for the provision of a raised median on an urban road is provided below in Exhibit 4.2.

Exhibit 4.2: CMF for Raised Medians on Urban Roads

Treatment	**Road Type**	**Target Collisions**	**CMF**
Provide a Raised Median	Urban Two-Lane	All	0.61

Target Collisions: All collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

4.6 TWLTL Median

A centre two-way left-turn lane (TWLTL) is an effective facility to separate turning vehicles from the through lanes on a roadway, as well as providing a refuge for vehicles entering the through lanes from access locations on along a road. The safety effects of a TWLTL have been studied by many researchers, in both urban and rural environments. To determine the CMF for the use of a TWLTL on an urban street, the following equations can be used.

$$CMF_{TWLTL} = (CMF_{TARGET} - 1.0)\, P_{TARGET} + 1.0$$

$$P_{TARGET} = 1 - e^{-0.008\,(0.621)\,D_{D,\,B/O}\,(N_L + 1)}$$

Where:

CMF_{TWLTL} = CMF for a TWLTL in an urban street
CMF_{TARGET} = CMF for collisions affected by a TWLTL (=0.70)
P_{TARGET} = Target collisions are a proportion of total collisions
$D_{D,\,B/O}$ = Business / Office driveway density (two-way, per km)
N_L = Number of through lanes

Target Collisions: All collisions

References:

Bonneson, J., and P.T. McCoy, NCHRP Report Number 395: “Capacity and Operational Effects of Midblock Left-Turn Lanes”, Transportation Research Board (TRB), Washington, DC, 1997.

Thakkar, J.S., “Study of the Effects of Left-Turn Lanes on Traffic Accidents” transportation Research Record 960, Transportation Research Board (TRB), Washington, DC, 1984, pp. 27 – 33.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

4.7 Horizontal Alignment

There is limited information on the safety effect of horizontal curves on urban streets. One study that applies to un-divided urban streets used a collision prediction model to derive the CMF for a curve on an urban road. The equation below can be used to calculate the CMF for curve radius.

$$CMF_{CR} = 2.30\left(e^{-2298/3.28R} + \frac{343.8}{3.28\ R}\right)\left[1 - P_{OFF-ROAD}\right] + 0.781\left(e^{320.9/3.28R}\right)P_{OFF-ROAD}$$

Where:

CMF_{CR}	= Collision modification factor for curve radius
R	= Radius of the curve (m)
$P_{OFF\text{-}ROAD}$	= Proportion of the collisions that occur off the roadway

Target Collisions: All collisions

References: Hauer, E., F.M. Council, Y. Mohammedshah, "Safety Model for Urban Four-Lane Un-Divided Road Segments" Transportation Research Records 1897, Transportation Research Board, Washington DC, 2004.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

4.8 Access Control

There is considerable information related to the level of access and safety on urban streets. Several design parameters have an impact on collision frequency including the median type, the adjacent land use and the access density. Using three different sources where the results compared favorably, an expression for a CMF for driveway density on an urban roadway was obtained. The expression is shown below.

$$CMF_{DD} = e^{0.008(0.621\, D_{D,\, B/O} - 50)}$$

Where:

CMF_{DD}	= Collision modification factor for access control
$D_{D,\, B/O}$	= Business / Office driveway density (two-way, per km)
$P_{OFF\text{-}ROAD}$	= Proportion of the collisions that occur off the roadway

Target Collisions: All collisions

References:

Bonneson, J., and P.T. McCoy, NCHRP Report Number 395: "Capacity and Operational Effects of Midblock Left-Turn Lanes", Transportation Research Board (TRB), Washington, DC, 1997.

Harwood, D.W., NCHRP Report Number 282: "Multi-lane Design Alternatives for Improving Sub-Urban Highways" TRB Transportation Research Board, Washington, DC., 1986.

Sawalha, Z and T. Sayed, "Evaluating Safety of Urban Arterial Roadways", Journal Transportation Engineering, American Society of Civil Engineers, Reston, Virginia, March/April 2001, pp 151-158.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

4.9 Traffic Calming

Traffic calming can be a very effective treatment to improve the safety and operation on urban roads. Traffic calming measures are most often applied to two-lane urban roadways (particularly to residential roads) that have operating speeds less than 60 km/hr. There are several traffic-calming measures such as, but not limited to, the following:

- Narrowing driving lanes
- Installing chokers or curb bulbs
- Providing raised crosswalks
- Installing traverse rumble strips

The CMFs in Exhibit 4.3 can be used to evaluate the safety impact of traffic calming, using some engineering judgment on the effectiveness and extent of the traffic calming measures (i.e., significant traffic calming measures should be employed to use the CMFs reported in Exhibit 4.3).

Exhibit 4.3: Traffic Calming on Urban Roads

Treatment	**Road Type**	**Target Collisions**	**CMF**
Provide Traffic Calming	Entire Area (Main + Local streets)	All	0.85
	Local Roads Only	All	0.74
	Main Street Only	All	0.91

Target Collisions: All collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

4.10 Speed Humps

Speed humps are normally used to control vehicle speed and are most often applied on residential streets and school zones or other areas where vehicle-operating speeds are a concern. The safety effect of installing speed humps for treated roads (where speed humps are deployed) and for adjacent untreated roads are provided in Exhibit 4.4 below.

Exhibit 4.4: Speed Humps on Urban Roads

Treatment	**Road**	**Target Collisions**	**CMF**
Provide Speed Humps	Roads With Speed Humps	Injury	0.52
	Adjacent Roads w/o Speed Humps	Injury	0.94

Target Collisions: Injury collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

4.11 Road Dieting

The term "road diet" normally refers to a roadway where the number of through lanes is reduced. For example, a four-lane roadway is reduced to 3 lanes (2 lanes + a TWLTL) or to 2 lanes. The additional roadway space is then converted to bike lanes, sidewalks, on-street parking, wider lanes or other elements.

The CMF for the safety effect of a road diet that consists of reducing a four-lane road urban arterial to a 3 lane urban road (2 lanes + a TWLTL) is shown in Exhibit 4.5.

Exhibit 4.5: Road Diets on Urban Roads

Treatment	**Road**	**Target Collisions**	**CMF**
Road Diet (4 to 3 lane)	Urban Arterial	All	0.94

Target Collisions: All collisions

References: Huang, H.F., Stewart, J.R., Zeeger, C. V., "Evaluation of Lane Reduction "Road Diet" Measures on Crashes and Injuries" Transportation Research Record Number 1784, Washington DC, Transportation Research Board (TRB), National Research Council, (2002), pp. 80-90.

4.12 On-Street Parking

Parking is a necessity on many urban roadways. However, the presence of parking is known to have a detrimental impact on the safety performance of a roadway. Several researchers have examined the safety effects of parking, including the presence of parking and the type of parking (parallel versus angle). Several studies were considered and combined to produce a CMF that describes the safety impacts that are associated with parking on urban roads. The following equations can be used to calculate the CMF for parking on urban roads.

$$CMF_{PARK} = 1 + P_{PARK} (B_{PARK} - 1.0)$$

$$B_{PARK} = (1.10 + 0.365 (I_{U2}) + 0.0609 P_{B/O}) [(f_{AP/PP} - 1.0) P_{AP} + 1.0]$$

Where:

CMF_{PARK}	= Collision modification factor for presence of parking
P_{PARK}	= Proportion of road with parallel or angle parking
B_{PARK}	= Proportion of road with business parking
I_{U2}	= Cross-section (use 1 for 2-lanes, 0 otherwise)
$P_{B/O}$	= Proportion of parking with adjacent business use
$f_{AP/PP}$	= Ratio of crashes for angle to parallel (Default = 2.34)
P_{AP}	= Proportion of angle parking

Target Collisions: All collisions

References:

Bonneson, J., and P.T. McCoy, NCHRP Report Number 395: "Capacity and Operational Effects of Mid-block Left-Turn Lanes", Transportation Research Board (TRB), Washington, DC, 1997.

Box, P.C., "Angle Parking Issues Revisited", ITE Journal, Institute of Transportation Engineers, Washington DC, March 2002, pp. 36-47.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.0 RURAL INTERSECTIONS

In the 20 years of collision data (1987 - 2006), there were 103,115 collisions that occurred at intersections on provincial highways, representing 30.5% of the total collisions (338,279 total collisions). Of these, 39,065 collisions (or 38%) occurred on highways are classified as "rural" in character.

The risk of a collision at an intersection is generally higher than on a road segment because of 1) the complexity of the driving tasks required at an intersection, 2) turning movements / route choices that may be required and 3) the increase in the traffic conflict points between vehicles and other road users (e.g., pedestrians). Collisions at rural intersections are typically more severe than the collisions at urban intersection because vehicle speeds are typically higher at rural intersections.

There are several design alternatives that address safety issues at rural intersections, which will be presented in this chapter, as listed below.

1) Intersection Skew Angle
2) Convert 4-Leg Intersection to two Staggered T-Intersections
3) Convert Signalized Intersection to a Modern Roundabout
4) Convert Stop Controlled Intersection to a Modern Roundabout
5) Provide Left-Turn Lanes at Signalized Intersections
6) Provide Left-Turn Lanes at Stop-controlled Intersections
7) Exclude Left-Turn Lanes at Signalized Intersections
8) Provide Channelization for Left-Turn Lanes
9) Provide Right Turn Lanes at Signalized Intersections
10) Provide Right Turn Lanes at Stop Controlled Intersections
11) Sight Distance
12) Median Width
13) Shoulder Width
14) Access Control
15) Convert 2-Way Stop Control to 4-Way Stop Control
16) Provide Protected (Lead) Left-Turn Phase
17) Improve Signal Timing / Clearance Interval
18) Install Red-light Cameras

5.1 Intersection Skew Angle

The angle between the major road and the minor roads at an intersection is referred to as the skew angle. Intersections with a skew angle that is closer to perpendicular is typically safer than intersections that are highly skewed due to the fact that motorists will have to turn their head and neck to view vehicles that approach the intersection from the intersecting roadway.

Several researchers have studied the effect of skew angle at intersections and the results for the CMFs are presented below.

CMF_{SIGNAL}	$= 1.0$	For 3 or 4 leg intersections
$CMF_{No\ Signal}$	$= e^{0.040 INT_{SKEW}}$	For 3 leg stop-control intersections
$CMF_{No\ Signal}$	$= e^{0.054 INT_{SKEW}}$	For 4 leg stop-control intersections

Where:

CMF_{SIGNAL}	= CMF for skew angle at signalized intersections
$CMF_{NO\ SIGNAL}$	= CMF for skew angle at stop controlled intersections
INT_{SKEW}	= ABS(Skew angle (degrees) – 90) x 50%

Target Collisions: All collisions

References:

Vogt, A., "Crash Models - Rural Intersections: Four Lane by Two Lane Stop Controlled and Two-Lane by Two-Lane Signalized" Report No. FHWA-RD-99-128 Federal Highway Administration, Washington, DC, 1997.

Harwood, D., F. Council, E. Hauer, W. Hughes, A. Vogt., "Prediction of the Expected Safety Performance of Rural Two-Lane Highways". Report No. FHWA-RD-99-207. FHWA, Washington, D.C., 2000.

Washington, S., B. Persaud, C. Lyon, J. Oh, Validation of Accident Models for Intersections, Report no. FHWA-RD-03-037, Washington, DC, July 2005.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.2 Convert 4-Leg Intersection to two Staggered T-Intersections

Due to the number of conflict points at intersections, there can be some safety benefit in converting a 4-leg two-way stop-controlled intersection into a pair of 3-leg intersections. The benefit of this conversion will be dependant upon the proportion of the traffic volumes on the major and minor roadways.

Although the research for this CMF is based on an urban environment, it is recommended that it be used for a rural environment as well, until more applicable research becomes available.

The CMFs that can be used to evaluate the safety performance when a 4-leg intersection is converted to a pair of staggered 3-leg intersections is provided in Exhibit 5.1 below.

Exhibit 5.1: Convert 4-Leg Intersection to 3-Leg Intersection

Treatment	Intersection Type	Traffic Conditions	Target Collisions	CMF
Convert 4-Leg Intersection to a pair of 3-Leg Intersections	Urban 4-Leg Stop-control	Minor Road Traffic >30% Total Traffic	Injury PDO	0.67 0.90
	Urban 4-Leg Stop-control	Minor Road Traffic 15- 30% Total Traffic	Injury PDO	0.75 1.00
	Urban 4-Leg Stop-control	Minor Road Traffic <15% Total Traffic	Injury PDO	1.35 1.15

Target Collisions: Injury and PDO collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

5.3 Convert Signalized Intersection to a Modern Roundabout

The reduction of collisions that occur as a result of converting a signalized intersection into a modern roundabout is due to the fact that vehicles speeds are reduced with a roundabout and a reduction in the amount of traffic conflicts. Because of the known safety benefits associated with modern roundabouts, they are becoming considerably more common in North America.

The CMFs that can be used when considering a modern roundabout in place of a signalized intersection are shown in Exhibit 5.2.

Exhibit 5.2: Convert Signalized Intersection to Roundabout

Treatment	Intersection Type	Target Collisions	CMF
Convert Rural Signalized Intersection to Roundabout	Single-Lane	All	0.67
	Multi-Lane	All	0.77

Target Collisions: All collisions

References: Rodegerdts, L.A., Blogg, M, Wemple, E, Myers, E, Kyte, M, Dixon, M, List, G., Flannery, A., Troutbect, R., Brilon, W, Wu, N., Persaud, B, Lyon, C., Harkey, D., and Carter, E, NCHRP Report 572: Applying roundabouts in the United States, Washington DC, Transportation Research Board, National Research Council, 2007.

5.4 Convert Stop-controlled Intersection to a Modern Roundabout

The reduction of collisions that occur as a result of converting a stop controlled intersection into a modern roundabout is due to the fact that vehicles speeds are reduced with a roundabout and a reduction in the amount and type of conflicting traffic. Because of the known safety benefits associated with modern roundabouts, they are becoming considerably more common in North America.

The CMFs that can be used when considering a modern roundabout in place of a stop-controlled intersection are shown in Exhibit 5.3.

Exhibit 5.3: Convert Stop-Control Intersection to Roundabout

Treatment	Intersection Type	Target Collisions	CMF
Convert Rural Stop-controlled Intersection to a Roundabout	Single-Lane	All	0.73
	Multi-Lane	All	0.88

Target Collisions: All and Injury collisions

References: Rodegerdts, L.A., Blogg, M, Wemple, E, Myers, E, Kyte, M, Dixon, M, List, G., Flannery, A., Troutbect, R., Brilon, W, Wu, N., Persaud, B, Lyon, C., Harkey, D., and Carter, E, NCHRP Report 572: Applying roundabouts in the United States, Washington DC, Transportation Research Board, National Research Council, 2007.

5.5 Provide Left-Turn Lanes at Signalized Intersections

Safety benefits can be realized at intersections when left-turning vehicles are removed from the through traffic stream by providing a left-turn lane. The safety benefits accrue by reducing the conflicts between the left turning vehicle and the opposing through traffic, which in a rural setting can be a very severe conflict because of vehicle operating speeds. The safety benefits can be further increased if the left-turn vehicles have protected movement (i.e., this movement has its dedicated signal phase) rather than a permissive movement.

The safety effect of adding left-turn lanes for rural signalized intersections is provided in Exhibit 5.4, which is based on before –after analysis.

Exhibit 5.4: Add Left-turn lane at Rural Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Add Left-turn Lanes at Rural Signalized Intersections	3-Leg Signalized (One Approach)	All	0.85
	4-Leg Signalized (Two Approaches)	All	0.82
	4-Leg Signalized (Four Approaches)	All	0.67

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, L. Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

5.6 Provide Left-Turn Lanes at Stop-Controlled Intersections

Regardless of whether an intersection is signalized or stop-controlled, safety benefits can be realized when left-turning vehicles are removed from the through traffic stream by providing a left-turn lane. The safety benefits occur by reducing traffic conflicts between the left turning vehicles and the opposing through traffic.

The safety effectiveness (shown as CMFs) of adding left-turn lanes for rural stop-controlled intersections are provided in Exhibit 5.5.

Exhibit 5.5: Add Left-turn lane at Rural Stop Controlled Intersections

Treatment	Intersection Type	Target Collisions	CMF
Add Left-Turn Lane at Rural Stop Controlled Intersections	3-Leg Signalized (One Approach)	All	0.56
	4-Leg Signalized (Two Approaches)	All	0.72
	4-Leg Signalized (Four Approaches)	All	0.52

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Hauer, E. Kohlman Rabbani, L. Elefteriadou, "Safety Effect of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

5.7 Exclude Left-Turn Lanes at Signalized Intersections.

Many signalized intersections are typically designed with left-turn lanes, which could be considered the 'baseline' condition for a rural signalized intersection. However, there can be circumstances where the provision of a left-turn lane is difficult (e.g., right of way constraints or property costs) and a designer may consider excluding a left-turn lane. This will cause a net decrease in the safety performance at the intersection.

The safety effect of excluding left-turn lanes at signalized intersections in a rural environment is provided in Exhibit 5.6.

Exhibit 5.6: Exclude Left-turn lane at Rural Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Exclude Left-turn Lanes at Rural Signalized Intersections	3-Leg Signalized (One Approach)	All	1.14
	4-Leg Signalized (Two Approaches)	All	1.17
	4-Leg Signalized (Four Approaches)	All	1.32

Target Collisions: All and Injury collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Hauer, L. Elefteriadou, "Safety Effect of Intersection Left Turn and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

5.8 Provide Channelization for Left-Turn Lanes

Channelization is the separation of conflicting traffic movements into definitive travel paths and is achieved by providing traffic islands, raised curbing or pavement markings. Providing physically channelized left-turn lanes at rural intersections will reduce the number of collisions at the intersection.

The safety effect of providing channelization at rural intersections is shown below in Exhibit 5.7

Exhibit 5.7: Provide Channelization for Rural Intersections

Treatment	Intersection Type	Target Collisions	CMF
Provide Left-Turn Channelization For Rural Intersections	4-Leg Intersection All 4 Approaches	Injury	0.96
	4-Leg Intersection Major Approaches Only	Injury	0.83
	3-Leg Intersection All 3 Approaches	Injury	0.73
	3-Leg Intersection Major Approaches Only	Injury	1.18

Target Collisions: Injury collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004) (Page 293).

5.9 Provide Right Turn Lanes at Signalized Intersection

Similar to left-turn lanes, right-turn lanes can provide safety benefits at an intersection by separating the through traffic from the right-turning traffic. The safety benefits arise from the reduction in conflicts between the right turning vehicle and the following through traffic.

The safety effectiveness and the CMFs associated with providing right-turn lanes for rural signalized intersections are provided below in Exhibit 5.8.

Exhibit 5.8: Provide Right-turn lane at Rural Signalized Intersections

Treatment	Intersection Type	Target Collisions	CMF
Add Right-turn Lanes at Rural Signalized Intersections	3-Leg Signalized (One Approach)	All	0.96
	4-Leg Signalized (Two Approach)	All	0.96
	4-Leg Signalized (Four Approaches)	All	0.92

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, and L Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.10 Provide Right-Turn Lanes at Stop-Controlled Intersections

Similar to right-turn lanes at signalized intersections, a right-turn lane at a stop-controlled intersection can provide safety benefits by separating the through traffic from the right-turning traffic. Safety benefits will accrue from the reduction in conflicts between the right turning vehicle and the following through traffic.

The safety effectiveness and the CMFs associated with providing right-turn lanes for rural stop-controlled intersections are provided in Exhibit 5.9.

Exhibit 5.9: Provide Right-turn lane at Rural Stop Control Intersection

Treatment	Intersection Type	Target Collisions	CMF
Add Left-turn Lanes at Rural Signalized Intersections	3-Leg Signalized (One Approach)	All	0.86
	4-Leg Signalized (Two Approach)	All	0.86
	4-Leg Signalized (Four Approaches)	All	0.74

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, and L Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.11 Sight Distance At Intersections

The development of a collision modification factor for sight-distance at intersections was based on the outcome from an expert panel. The basis for the CMF compares the amount of sight-distance that is available at the intersection to the amount of sight distance that is required, as specified by AASHTO - A Policy on Geometric Design of Highways and Streets (Washington, DC, 2004).

The following CMFs related to the sight-distance at an intersection can be used.

CMF_{SIGNAL}	= 1.00	Rural signalized intersections
$CMF_{NO\ SIGNAL}$	= 1.05	Sight distance restricted in 1 quadrant
$CMF_{NO\ SIGNAL}$	= 1.10	Sight distance restricted in 2 quadrants
$CMF_{NO\ SIGNAL}$	= 1.15	Sight distance restricted in 3 quadrants
$CMF_{NO\ SIGNAL}$	= 1.20	Sight distance restricted in 4 quadrants

Target Collisions: All collisions

References: Harwood, D., Council, F., Hauer, E., Hughes, W., Vogt, "Prediction of Expected Safety Performance of Rural Two-Lane Highways", FHWA-RD-99-207, FHWA (2000).

5.12 Median Width (Stop-Control Intersections)

At intersections, the principle function of a median is to separate the opposing traffic, allow space for left-turning and U-turning vehicles (if allowed), to minimize headlight glare and to provide width for future lanes. Some safety benefit can be realized with an increase in the width of a median at an intersection. Several researchers have studied the relationship between the median width and safety performance at stop-controlled intersections.

The CMF for median width at rural intersections can be determined by using the equation below.

$$CMF_{MW} = e^{-0.012\,(3.28\,W_M - 16.0)}$$

Where:

CMF_{MW} = CMF for median width stop-controlled intersections

W_M = Median width in meters

Target Collisions: All collisions

References: Vogt, A., “Crash Models - Rural Intersections: Four Lane by Two Lane Stop Controlled and Two-Lane by Two-Lane Signalized” Report No. FHWA-RD-99-128 Federal Highway Administration, Washington, DC, 1997

Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, and L Elefteriadou, “ Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Harwood, D, M. Pietrucha, K. Fitzpatrick, M. Woolridge, “Design of Intersections on Divided Highway” TRB Circular E-C003, International Symposium on Highway Geometric Design”, TRB, Washington DC, 1998.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.13 Shoulder Width

Geometric design standards for shoulders at intersections are generally based on the intersection setting, the amount of traffic and the right-of way constraints. Some research has been completed that involved the development of collision prediction models that related the outside shoulder width (and other factors) to the collision frequency at rural stop-controlled intersections.

The CMF that can be used to evaluate the safety effect of the shoulder width at a rural stop-controlled intersection is provided below.

$$CMF_{SW} = e^{-0.030\,(3.28\,W_S - 8.0)}$$

Where:

CMF_{SW} = CMF - shoulder width stop-controlled intersections

W_S = Shoulder width in meters

Target Collisions: All collisions

References: Bauer, K, and D. Harwood, “Statistical Models of At-Grade Intersections – Addendum” Report FHWA-RD-99-094, Federal Highway Administration, Washington DC, March 2000.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.14 Access Control at Stop-Controlled Intersections

Excessive accesses in close proximity to an intersection can have adverse impact on the safety performance of the intersection. Several researchers have examined the effect of an access on collision frequency and have found that in general, as the number of accesses increase, there is a corresponding increase in collisions.

The CMF for access control at rural intersections can be determined by using the equation below. It is noted that driveways that should be included in the determination of the CMF include driveways on both sides of the road and on both the major and minor roadways.

$$CMF_{AC} = e^{0.056\,D_N}$$

Where:

CMF_{AC} = CMF for access at stop-controlled intersection

D_N = Number of driveways within 80 m of intersection

Target Collisions: All collisions

References:

Vogt, A., "Crash Models - Rural Intersections: Four Lane by Two Lane Stop Controlled and Two-Lane by Two-Lane Signalized" Report No. FHWA-RD-99-128 Federal Highway Administration, Washington, DC, 1997.

Harwood, D., F. Council, E. Hauer, W. Hughes, A. Vogt., "Prediction of the Expected Safety Performance of Rural Two-Lane Highways". Report No. FHWA-RD-99-207. FHWA, Washington, D.C., 2000.

Washington, S., B. Persaud, C. Lyon, J. Oh, Validation of Accident Models for Intersections, Report no. FHWA-RD-03-037, Washington, DC, July 2005.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

5.15 Convert 2-Way Stop Control to 4-Way Stop Control

Safety benefits can be obtained when a two-way stop-controlled rural intersection is converted to a four-way stop controlled intersection when the established MUTCD warrants are met.

The safety effectiveness associated with the change in traffic control for 2-way stop control to 4-way (all-way) stop control for rural intersections is provided in Exhibit 5.10.

Exhibit 5.10: Change from 2-Way to 4-Way (All-Way) Stop Control at Rural Intersections

Treatment	Intersection Type	Target Collisions	CMF
Convert 2-Way Stop to 4-Way Stop at Rural Intersections	Rural	All	0.52

Target Collisions: All collisions

References: Harwood, D., F. Council, E. Hauer, W. Hughes, A. Vogt., "Prediction of the Expected Safety Performance of Rural Two-Lane Highways". Report No. FHWA-RD-99-207. FHWA, Washington, D.C., 2000.

5.16 Provide Protected (Lead) Left-Turn Phase

The provision of protected traffic movements is beneficial to safety as it separates and eliminates conflicting traffic. Protected left-turn phases at a traffic signal can improve safety by eliminating the severe conflicts caused by the opposing traffic flow. In a rural environment, the protected left-turn phases are very beneficial since the speed of the opposing traffic is typically higher than in an urban setting.

The safety effectiveness associated with the introduction of a protected (lead) left-turn phase is given below in Exhibit 5.11. It is noted that the CMFs listed below were developed based on an urban condition, but it is recommended that it should also be applied to rural intersections.

Exhibit 5.11: Protected Left-Turn Phase at Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Protected Left-Turn Phase at Signalized Intersections	Rural	Left-Turn Injury	0.83
Protected / Permitted Phase with a Left-Turn Bay at High-Speed Intersections	Rural	Left-Turn	0.66

Target Collisions: Left-Turn injury collisions

References: Lyon, C., Haq, A., Persaud, B., and Kodama, S., "the Development of Safety Performance Functions for Signalized Intersections in a large Urban Area and the Application to Evaluation Left-Turn Priority Treatment", 2005, Annual TRB Meeting.

Maze, T.H., Henderson, J.L., and Sankar, R., Impacts on Safety of Left-Turn Treatment at High-Speed Signalized Intersections, Iowa State University, 1994.

Sayed, T, et al.,, Safety Aspects of Traffic Signal Design, University of British Columbia, 1999.

Improve Signal Timing and Clearance Interval

The clearance interval at a signalized intersection is defined as the amount of amber and all-red time within the signal phase. Researchers have determined that the level of safety at a signalized intersection can be improved if the signal timing and the clearance interval adhere to the Institute of Transportation Engineers (ITE) report "Proposed Recommended Practice for Determining Vehicle Change Intervals (1985)".

The CMFs that are associated with improved traffic signal timing and the clearance interval are provided in Exhibit 5.12. It is noted that the safety benefit can only be realized if the traffic signal timing are inadequate.

Exhibit 5.12: Improve Signal Timing and Clearance Interval

Treatment	Intersection Type	Target Collisions	CMF
Improve Signal Timing and Clearance Interval	4-Leg Signalized	ALL	0.92
	4-Leg Signalized	Rear-End	1.12
	4-Leg Signalized	Right-Angle	0.96
	4-Leg Signalized	Pedestrian and Cyclist	0.63

Target Collisions: Refer to Exhibit

References: Retting, R., Chapline, J., and Williams, A., "Changes in Crash Risk Following Re-Timing of Traffic Signal Change Intervals", Accident Analysis and Prevention, Vol. 34, No. 2, Oxford, NY, Perganmom Press, 2002, pp. 215-220.

5.17 Install Red-light Cameras

The findings of studies that investigated the safety effects resulting from red-light camera programs indicated that the red-light cameras produce a reduction in total collisions and a more significant reduction in left-turn 90 collisions. The results of these studies generally suggest that the more severe, angle-type collisions are significantly reduced, but there is a slight increase in the less severe, rear-end type collisions.

The effectiveness associated with the introduction of red-light cameras are provided below in Exhibit 5.13. It is noted that the CMFs listed below were developed based on an urban condition, but it is recommended that it should also be applied to rural intersections.

Exhibit 5.13: Installation of Red Light Cameras

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Installation of Red Light Cameras	Signalized - Rural	Total	0.90
	Signalized - Rural	Left-Turn 90	0.80
	Signalized - Rural	Rear-End	1.10

Target Collisions: Refer to Exhibit

References:

Sayed, T., de Leur, P. (2006), "Evaluation of Edmonton's Intersection Safety Camera Program", Transportation Research Board Annual Conference 2007, Washington, In print for the *Transportation Research Record*.

Persaud, B., Council, F., Lyon, C., Eccles, K and Griffith, M, "A Multi-Jurisdictional Safety Evaluation of Red Light Cameras", 84th Transportation Research Board Meeting, Washington DC, 2005, pp. 1-14.

6.0 URBAN INTERSECTIONS

There are more intersection collisions that occur on highways classified as "urban" as compared to rural highway. Based on the 20 years of collision data in the MOT's Highway Accident System (HAS) (from 1987 to 2006), there were 51,194 collisions (or 49.6%) that occurred at urban intersection from the total of 103,115 intersection collisions on BC highways. Although the frequency of intersection collisions is higher on urban highways, the severity of collisions at urban intersections is less than at rural intersections (Accident Severity Ratio (ASR) = 5.27 for urban versus 6.32 for rural).

The risk of a collision at an intersection is generally higher than on a road segment because of 1) the complexity of the driving tasks required at an intersection, 2) turning movements / route choices that may be required and 3) the increase in the traffic conflict points between vehicles and other road users (e.g., pedestrians).

There are several design alternatives that specifically address the safety at urban intersections, which are presented in this chapter and listed below.

1) Convert 4-leg into 2 Staggered T Intersections
2) Convert Signal to Roundabout
3) Convert Stop Control to Roundabout
4) Left-Turn Lanes at Signalized Intersections
5) Exclude Left-Turn Lanes at Signalized Intersections
6) Left-Turn Lanes at Stop-Control Intersections
7) Exclude Left-Turn Lanes at Stop-Control Intersections
8) Right-Turn Lanes at Signalized Intersections
9) Right-Turn Lanes at Stop Control Intersections
10) Lane Width
11) Shoulder Width (Stop Control)
12) Median Presence (Stop Control)
13) Median Width (Stop-Control)
14) Convert 2-Way Stop to 4-Way Stop
15) Provide protected (Lead) Left-Turn Phase
16) Improve Signal Timing / Clearance Interval
17) Install Red-Light Cameras

6.1 Convert 4-Leg Intersection into Two Staggered T-Intersections

Due to the number of conflict points at intersections, there can be some safety benefit in converting a 4-leg two-way stop-controlled intersection into a pair of 3-leg intersections. The benefit of this conversion will be dependant upon the proportion of the traffic volumes on the major and minor roadways. The research for this CMF is directly applicable to urban intersections.

The CMFs that can be used to evaluate the safety performance when a 4-leg intersection is converted to a pair of staggered 3-leg intersections are provided in Exhibit 6.1 below.

Exhibit 6.1: Convert 4-Leg Intersection to 3-Leg Intersection

Treatment	Intersection Type	Traffic Conditions	Target Collisions	CMF
Convert 4-Leg Intersections Into Two 3-Leg Intersections	Urban 4-Leg Stop-Controlled	Minor Road Traffic >30% Total Traffic	Injury PDO	0.67 0.90
	Urban 4-Leg Stop-Controlled	Minor Road Traffic 15- 30% Total Traffic	Injury PDO	0.75 1.00
	Urban 4-Leg Stop-Controlled	Minor Road Traffic <15% Total Traffic	Injury PDO	1.35 1.15

Target Collisions: Injury and PDO collisions

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

6.2 Convert Signalized Intersection to a Roundabout

The reduction of collisions that occur as a result of converting a signalized intersection into a modern roundabout is due to the fact that vehicles speeds are reduced with a roundabout and a reduction in the amount of traffic conflicts. Because of the known safety benefits associated with modern roundabouts, they are becoming considerably more common in North America.

The CMFs that can be used when considering a modern roundabout in place of a signalized intersection for an urban intersection are shown in Exhibit 6.2.

Exhibit 6.2: Convert Urban Signalized Intersection to a Roundabout

Treatment	Intersection Type	Target Collisions	CMF
Convert Urban Signalized Intersection to Roundabout	Single-Lane	All	0.71
	Multi-Lane	All	0.83

Target Collisions: All collisions

References: Rodegerdts, L.A., Blogg, M, Wemple, E, Myers, E, Kyte, M, Dixon, M, List, G., Flannery, A., Troutbect, R., Brilon, W, Wu, N., Persaud, B, Lyon, C., Harkey, D., and Carter, E, NCHRP Report 572: Applying roundabouts in the United States, Washington DC, Transportation Research Board, National Research Council, 2007.

6.3 Convert Stop Control Intersection to a Roundabout

The reduction of collisions that occur as a result of converting an urban stop controlled intersection into a modern roundabout is due to the fact that speeds are reduced with a roundabout and conflicting traffics are reduced. Because of the known safety benefits associated with modern roundabouts, they are becoming considerably more common in North America.

The CMFs that can be used when considering a modern roundabout in place of a stop-controlled intersection at an urban intersection are shown in Exhibit 6.3.

Exhibit 6.3: Convert Urban Stop-Controlled Intersection to Roundabout

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Convert Urban Stop-Controlled Intersection to Roundabout	Urban One-Lane	All	0.76
	Urban Two-Lane	All	0.89

Target Collisions: All collisions

References: Rodegerdts, L.A., Blogg, M, Wemple, E, Myers, E, Kyte, M, Dixon, M, List, G., Flannery, A., Troutbect, R., Brilon, W, Wu, N., Persaud, B, Lyon, C., Harkey, D., and Carter, E, NCHRP Report 572: Applying roundabouts in the United States, Washington DC, Transportation Research Board, National Research Council, 2007.

6.4 Provide Left-Turn Lanes at Signalized Intersections

Safety benefits can be realized at intersections when left-turning vehicles are removed from the through traffic stream by providing a left-turn lane. The safety benefits accrue by reducing the conflicts between the left turning vehicle and the opposing through traffic. Safety benefits can be further increased if the left-turn vehicles have protected movement (i.e., this movement has its dedicated signal phase) rather than a permissive movement.

The safety effect of adding left-turn lanes for urban signalized intersections are provided in Exhibit 6.4.

Exhibit 6.4: Add Left-turn lane at Urban Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Add Left-turn Lanes at Urban Signalized Intersections	3-Leg Signalized (One Approach)	All	0.93
	4-Leg Signalized (Two Approaches)	All	0.90
	4-Leg Signalized (Four Approaches)	All	0.81

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, L. Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

6.5 Exclude Left-Turn Lanes at Signalized Intersections

High volume urban, signalized intersections will normally be designed with left-turn lanes to accommodate the left-turn traffic demand (if it exists). However, there can be circumstances where the provision of a left-turn lane is difficult (e.g., right of way constraints or property costs) and a designer may consider excluding a left-turn lane at a location that would otherwise have a left-turn lane. This could cause a net decrease in the safety performance at the intersection.

The safety effects of excluding left-turn lanes at signalized intersections in an urban environment are provided in Exhibit 6.5.

Exhibit 6.5: Exclude Left-turn lane at Urban Signalized Intersections

Treatment	Intersection Type	Target Collisions	CMF
Exclude Left-turn Lanes at Urban Signalized Intersections	3-Leg Signalized (One Approach)	All	1.08
	4-Leg Signalized (Two Approaches)	All	1.11
	4-Leg Signalized (Four Approaches)	All	1.23

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Hauer, L. Elefteriadou, "Safety Effect of Intersection Left Turn and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

6.6 Provide Left-Turn Lanes at Stop-Control Intersections

Regardless of whether an intersection is signalized or is stop-controlled, safety benefits can be realized when left-turning vehicles are removed from the through traffic stream by providing a left-turn lane. The safety benefits occur by reducing traffic conflicts between the left turning vehicles and the opposing through traffic.

The safety effectiveness (shown as CMFs) of adding left-turn lanes for urban stop-controlled intersections are provided in Exhibit 6.6.

Exhibit 6.6: Add Left-turn lane at Urban Stop Controlled Intersections

Treatment	Intersection Type	Target Collisions	CMF
Add Left-Turn Lane at Urban Stop Controlled Intersections	3-Leg Signalized (One Approach)	All	0.67
	4-Leg Signalized (One Approach)	All	0.73
	4-Leg Signalized (Both Approaches)	All	0.53

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Hauer, E. Kohlman Rabbani, L. Elefteriadou, "Safety Effect of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

6.7 Exclude Left-Turn Lanes at Stop-Control Intersections

Excluding left-turn lanes from a stop-controlled urban intersection will have an adverse impact on the safety performance. However, there can be circumstances where the provision of a left-turn lane is difficult (e.g., right of way constraints or property costs) and a designer may consider excluding a left-turn lane at a location that would otherwise have a left-turn lane.

The CMFs for excluding left-turn lanes at stop-controlled intersections in an urban environment are provided in Exhibit 6.7.

Exhibit 6.7: Exclude Left-turn Lane at Urban Stop-Controlled Intersections

Treatment	Intersection Type	Target Collisions	CMF
Exclude Left-turn Lanes at Urban Stop-Controlled Intersections	3-Leg Signalized (One Approach)	All	1.49
	4-Leg Signalized (Two Approaches)	All	1.37
	4-Leg Signalized (Four Approaches)	All	1.88

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Hauer, L. Elefteriadou, "Safety Effect of Intersection Left Turn and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for the FHWA and Texas DOT (2005).

6.8 Right-Turn Lanes at Signalized Intersections

Similar to left-turn lanes, right-turn lanes can provide safety benefits at an intersection by separating the through traffic from the right-turning traffic. The safety benefits arise from the reduction in conflicts between the right turning vehicle and the following through traffic.

The safety effectiveness and the CMFs associated with providing right-turn lanes for urban signalized intersections are provided below in Exhibit 6.8.

Exhibit 6.8: Provide Right-turn lane at Urban Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Add Left-turn Lanes at Urban Signalized Intersections	3-Leg Signalized (One Approach)	All	0.96
	4-Leg Signalized (Two Approaches)	All	0.96
	4-Leg Signalized (Four Approaches)	All	0.92

Target Collisions: All collisions

References: Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, and L Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.9 Right-Turn Lanes at Stop Control Intersections

Similar to right-turn lanes at signalized intersections, a right-turn lane at a stop-controlled intersection can provide safety benefits by separating the through traffic from the right-turning traffic. Safety benefits will accrue from the reduction in conflicts between the right turning vehicle and the following through traffic.

The safety effectiveness and the CMFs associated with providing right-turn lanes at urban stop-controlled intersections are provided in Exhibit 6.9.

Exhibit 6.9: Provide Right-turn lane at Urban Stop Control Intersections

Treatment	Intersection Type	Target Collisions	CMF
Add Left-turn Lanes at Urban Signalized Intersections	3-Leg Signalized (One Approach)	All	0.86
	4-Leg Signalized (One Approach)	All	0.86
	4-Leg Signalized (Both Approaches)	All	0.74

Target Collisions: All collisions

References:

Harwood, D., K. Bauer, I. Potts, D. Torpic, K. Richard, E. Kohlman Rabbani, E. Hauer, and L Elefteriadou, " Safety Effectiveness of Intersection Left and Right Turn Lanes, Report No. FHWA-RD-02-089, FHWA, Washington DC, July 2002.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.10 Lane Width

Many researchers have derived relationships between the lane width and safety using collision prediction models. The research has determined that the safety at an urban intersection is dependant upon the lane width. The following functions can be used to determine the CMF for lane width at urban intersections.

$CMF_{LW} = e^{-0.053\,(3.28\,W_L - 12)}$ Signalized intersections

$CMF_{LW} = e^{-0.057\,(3.28\,W_L - 12)}$ Stop-controlled intersections

Where:

CMF_{LW} = Collision modification factor for lane width
W_L = Lane width in meters

Target Collisions: Single vehicle off-road and head-on collisions

References: Bauer, K, and D. Harwood, "Statistical Models of At-Grade Intersections – Addendum" Report FHWA-RD-99-094, Federal Highway Administration, Washington DC, March 2000.
Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.11 Shoulder Width (Stop-Control Intersection)

Geometric design standards for shoulders at intersections are generally based on the intersection setting, the amount of traffic and the right-of way constraints. Some research has been completed that involved the development of collision prediction models that related the outside shoulder width (and other factors) to the collision frequency at urban stop-controlled intersections.

The CMF that can be used to evaluate the safety effect of the shoulder width at an urban stop-controlled intersection is provided below.

$$CMF_{SW} = e^{-0.020\,(3.28\,W_S - 1.5)}$$

Where:

CMF_{SW} = CMF - shoulder width stop-controlled intersections

W_S = Shoulder width in meters

Target Collisions: All collisions

References: Bauer, K, and D. Harwood, "Statistical Models of At-Grade Intersections – Addendum" Report FHWA-RD-99-094, Federal Highway Administration, Washington DC, March 2000.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.12 Median Presence (Stop Control)

In general, the presence of a median at an urban intersection will have a positive impact on the safety performance at the intersection. Research was conducted that included the examination of the safety effect of the presence of a median at urban intersections, although it is noted that this research was based on 3-Leg intersections.

The CMF for the presence of a median at an urban intersection is listed below. The CMFs can be applied to either 3-Leg or a 4-Leg intersections (until research for 4-leg intersections become available) and the CMF is based on the presence of a median on the major roadway only.

CMF_{MP} = 1.00 Un-divided Urban Intersection (No Median)

CMF_{MP} = 0.83 Divided Urban Intersection

Target Collisions: All collisions

References: Bauer, K, & D. Harwood, "Statistical Models of At-Grade Intersections – Addendum" Report FHWA-RD-99-094, Federal Highway Administration (FHWA), Washington DC, March 2000.

Bonneson, J, Zimmerman, K, Fitzpatrick, K, "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.13 Median Width (Stop-Control)

Medians at urban intersections serve to separate opposing traffic, allow space for left-turning and U-turning vehicles (if allowed), and prevents un-intended crossing of the roadway in close proximity to the intersection. Researchers have determined that some safety benefit can be realized with an increase in the width of a median at an urban intersection.

The CMFs for median width at urban intersections can be determined by using the following:

$CMF_{MW} = e^{0.0076 (3.28 W_M - 16.0)}$ 3-Leg intersection $W_M > 5.0$ m

$CMF_{MW} = e^{0.0160 (3.28 W_M - 16.0)}$ 4-Leg intersection $W_M > 5.0$ m

$CMF_{MW} = 1.00$ 3 or 4 leg Intersection $W_M < 5.0$ m

Where:

CMF_{MW} = CMF for median width stop-controlled intersections
W_M = Median width in meters

It is noted that the presence of a median and the median width CMFs should be applied together to evaluate changes in the median near an urban stop-controlled intersection. The following equation can be used to combine CMFs, which was described further in Section 1.5 of this report.

$$CMF_{MEDIAN} = CMF_{MP} \times CMF_{MW}$$

Target Collisions: All collisions

References: Harwood, D, M. Pietrucha, K. Fitzpatrick, M. Woolridge, “Design of Intersections on Divided Highway” TRB Circular E-C003, International Symposium on Highway Geometric Design”, TRB, Washington DC, 1998.
Bonneson, J, Zimmerman, K, Fitzpatrick, K, “Roadway Safety Design Synthesis”, Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).

6.14 Convert 2-Way Stop to 4-Way Stop

The safety at an urban stop-controlled intersection can be improved by converting the two-way stop-control to four-way stop control, when the established MUTCD warrants are met. The safety effectiveness associated with the change in traffic control for 2-way stop control to 4-way (all-way) stop control for urban intersections is provided in Exhibit 6.10.

Exhibit 6.10: Change from 2-Way to 4-Way Stop Control at Urban Intersections

Treatment	Intersection Type	Target Collisions	CMF
Convert 2-Way Stop to 4-Way Stop at Urban Intersections	Urban	All	0.82

Target Collisions: All collisions

References: Lovell, J. and Hauer, E., "The Safety Effect of Conversion to 4-Way/All way Stop Control" Transportation Research Record 1068, Washington DC, Transportation Research Board, National Research Council (1986), pp 103 – 107.

6.15 Provide Protected (Lead) / Permissive Left-Turn Phase

The provision of protected traffic movements is beneficial to safety as it allows for the separation of conflicting traffic. A protected left-turn phase at a signalized urban intersection will improve safety by eliminating the severe conflict between left-turning traffic and opposing through traffic.

The safety effectiveness associated with the introduction of a protected (lead) left-turn phase at an urban signalized intersection is given below in Exhibit 6.11.

Exhibit 6.11: Protected Left-Turn Phase at Urban Signalized Intersections

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Protected Left-Turn Phase at Signalized Intersections	Urban	Left-Turn Injury	0.83
Protected / Permitted Phase with a Left-Turn Bay at High-Speed Intersections	High-Speed	Left-Turn	0.66

Target Collisions: Left-Turn injury collisions

References:

Lyon, C., Haq, A., Persaud, B., and Kodama, S., "the Development of Safety Performance Functions for Signalized Intersections in a large Urban Area and the Application to Evaluation Left-Turn Priority Treatment", 2005, Annual TRB Meeting.

Maze, T.H., Henderson, J.L., and Sankar, R., Impacts on Safety of Left-Turn Treatment at High-Speed Signalized Intersections, Iowa State University, 1994.

Sayed, T, Lovegrove, G., Quintero, M., and Vahidi, H., Safety Aspects of Traffic Signal Design, University of British Columbia, 1999.

6.16 Improve Signal Timing / Clearance Interval

The clearance interval at a signalized intersection is defined as the amount of amber and all-red time within the signal phase. Researchers have determined that the level of safety at a signalized intersection can be improved if the signal timing and the clearance interval adhere to the Institute of Transportation Engineers (ITE) report "Proposed Recommended Practice for Determining Vehicle Change Intervals (1985)".

The CMFs that are associated with improved traffic signal timing and the clearance interval are provided in Exhibit 6.12. It is noted that the safety benefit can only be realized if the traffic signal timing are inadequate.

Exhibit 6.12: CMFs: Improve Signal Timing and Clearance Interval

Treatment	Intersection Type	Target Collisions	CMF
Improve Signal Timing and Clearance Interval	4-Leg Signalized	All	0.92
	4-Leg Signalized	Rear-End	1.12
	4-Leg Signalized	Right-Angle	1.06
	4-Leg Signalized	Pedestrian and Cyclist	0.63

Target Collisions: Refer to Exhibit

References: Retting, R., Chapline, J., and Williams, A., "Changes in Crash Risk Following Re-Timing of Traffic Signal Change Intervals", Accident Analysis and Prevention, Vol. 34, No. 2, Oxford, NY, Pergamom Press, 2002, pp. 215-220.

6.17 Install Red-Light Cameras

Several studies have investigated the safety impacts resulting from red-light camera programs. These studies indicate that red-light cameras can produce a reduction in total collisions and a more significant reduction in severe collisions. The results suggest that the more severe, angle-type collisions are significantly reduced, while there is an increase in the less severe, rear-end type collisions.

The effectiveness associated with the introduction of red-light cameras is provided below in Exhibit 6.13. It is noted that the CMFs listed below were developed based on urban conditions.

Exhibit 6.13: Installation of Red Light Cameras

Treatment	**Intersection Type**	**Target Collisions**	**CMF**
Installation of Red Light Cameras	Signalized – Urban	Total	0.90
	Signalized – Urban	Left-Turn 90	0.80
	Signalized – Urban	Rear-End	1.10

Target Collisions: Refer to Exhibit

References: Sayed, T., de Leur, P. (2006), "Evaluation of Edmonton's Intersection Safety Camera Program", Transportation Research Board Annual Conference 2007, Washington, In print for the *Transportation Research Record*.

Persaud, B., Council, F., Lyon, C., Eccles, K and Griffith, M, "A Multi-Jurisdictional Safety Evaluation of Red Light Cameras", 84th Transportation Research Board Meeting, Washington DC, 2005, pp. 1-14.

7.0 PEDESTRIAN

Unfortunately, the road safety engineering literature lacks reliable studies and information concerning the safety effects of pedestrian treatments. There is a lot of information that discusses the various pedestrian facilities and the guidelines / warrants for when and how these pedestrian facilities should be implemented. However, quantitative analysis of the effect of pedestrian facilities and the corresponding safety performance do not exist with sufficient certainty. This is likely due to the fact that pedestrian collisions are relatively few, within the context of the entire collision population. For example, Table 1.5 indicated that only 1.2% of collisions were pedestrian related. It is noted however, that pedestrian collisions are typically very severe.

Since quality information concerning the safety effectiveness of various pedestrian facility is not available, some general collision modification factors are provided. The source of the information and the robustness of the methodology that was used to obtain the CMFs are not known. As such, the analyst should used caution and judgment in applying these CMFs for pedestrians.

For the CMFs for pedestrian facilities, a range is provided for the CMF values, which allows the user to use judgment in selecting the CMF. A "LOW" effectiveness value and a "HIGH" effectiveness value are provided for each pedestrian facility item. The target collision type and the source are also identified. The information source is from The Canadian Guide to In-Service Road Safety Reviews, by the Transportation Association of Canada (TAC), (January 2004), which appears to be based largely on the textbook entitled, Safer Roads: A Guide to Road Safety Engineering, by K.W. Ogden.

As more definitive research becomes available that quantifies the safety effect of pedestrian facilities, it should be included in any updates to this document.

7.1 Provide Pedestrian Indicators / Signals at Signalized Intersections

CMF_{LOW}	= 0.80
CMF_{HIGH}	= 0.70
Target:	Pedestrian Collisions
Source:	The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.2 Pedestrian Refuge

CMF_{LOW}	= 0.80
CMF_{HIGH}	= 0.40
Target:	Pedestrian Collisions
Source:	The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.3 Pedestrian Fencing

CMF_{LOW}	= 0.70
CMF_{HIGH}	= 0.50
Target:	Pedestrian Collisions
Source:	The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.4 Provided Marked Pedestrian Crosswalk

CMF_{LOW}	= 0.90
CMF_{HIGH}	= 0.50
Target:	Pedestrian Collisions
Source:	The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.5 Provide Curb Extensions

CMF_{LOW} = 0.70
CMF_{HIGH} = 0.50
Target: Pedestrian Collisions
Source: The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.6 Pedestrian Signals

CMF_{LOW} = 0.90
CMF_{HIGH} = 0.30
Target: Pedestrian Collisions
Source: The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.7 Pedestrian Grade Separation

CMF_{LOW} = 0.30
CMF_{HIGH} = 0.10
Target: Pedestrian Collisions
Source: The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

7.8 Provide Street Lighting

CMF_{LOW} = 0.30
CMF_{HIGH} = 0.10
Target: Pedestrian Collisions
Source: The Canadian Guide to In-Service Road Safety Reviews, Transportation Association of Canada (TAC), January 2004.

8.0 SIGNING AND DELINEATION

8.1 Improved Signage

Signs on provincial highways in British Columbia are generally grouped into several categories, including:

1) Regulatory Signs (Black on White)
2) Warning Signs (Black on Yellow)
3) Guide Signs (White on Green)
4) Information Signs (White on Blue)
5) Construction Zone Signs (Black on Orange)
6) Temporary Signs (Black on Orange)

There are design standards and guidance in place for the selection and application of signs, which generally follow the Manual of Uniform Traffic Control Devices (MUTCD). The Ministry's Senior Traffic Engineer and the Regional Traffic Engineers provide the authority for the selection and application of the various road signs.

Many highway signs are designed to provide information to the motorist such that the motorist can modify their driving behavior to respond to the demands of the road. Often, the requirement to modify driving behavior is in the interest of highway safety.

Unfortunately, the definitive and reliable research on the effectiveness of highway signs is somewhat limited in road safety engineering literature. Information on what is known about the type and application of signs is presented on the following pages. In addition (and in the interest of completeness), some additional CMFs for signs are presented where reliable information may be limited. CMFs signs include:

1) Signs to Conform to MUTCD
2) Install Warning Signs
3) Improve Sign Conspicuity and Reflectivity
4) Changeable / Dynamic Warning Signs

8.1.1 Conform to MUTCD

The purpose of the MUTCD is to try to ensure that roadway signing is consistently applied between jurisdictions, recognizing that there will be some local differences in the required signing. Consistent road signing facilitates driver expectation, which ultimately will have a benefit to the safety of the roadway.

Research has indicated that replacing older and non-compliant signs with new signs that conform to the specifications provided in the MUTCD manual will improve safety. The effectiveness of improving the signs is provided in Exhibit 8.1 below. It is noted that the CMF listed below are based on research from urban conditions, but it is recommended that the CMFs should also be applied to rural conditions.

Exhibit 8.1: Improve Signs to Conform to MUTCD Standards

Treatment	Road Type	Target Collisions	CMF
Improve Signs to Conform to MUTCD Standards	All	All	0.95

Target Collisions: All collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).
Manual of Uniform Traffic Control Devices for Streets and Highways (MUTCD), Washington DC, FHWA Federal Highway Administration, 2003.

8.1.2 Install Warning Signs

Common types of warning signs used on BC highway include horizontal alignment warning signs and advisory speed signs, as shown below. Compared to no curve or speed warning signs, the provision of this type of signing can be beneficial in reducing the frequency of collisions on all road types.

The effectiveness of installing curve and speed warning signs is provided in Exhibit 8.2 below.

Exhibit 8.2: Install Curve and Speed Warning Signs

Treatment	Road Type	Target Collisions	CMF
Install Curve And Speed Warning Signs	All	All	0.93

Target Collisions: All collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.1.3 Improve Sign Conspicuity / Reflectivity

Unfortunately, reliable information that quantifies the safety effectiveness of the conspicuity and reflectivity of signs is limited. However, it is common belief that a sign that is more highly visible should be recognized easier by a motorist and thus, should provide some safety benefit.

The CMFs presented in Exhibit 8.3 are recommended to evaluate the safety effect of improvements to sign conspicuity and reflectivity.

Exhibit 8.3: Improve Sign Conspicuity and Reflectivity

Treatment	**Road Type**	**Target Collisions**	**CMF**
Larger Signs	All	All	0.95
Higher Reflectivity	All	Night	0.90
Illuminated Signs	All	Night	0.85

Target Collisions: All and Night collisions.

References: Various information sources were reviewed but CMFs are estimated based on judgment and experience.

8.1.4 Changeable / Dynamic Warning Signs

Changeable or dynamic highway signs are becoming more common in British Columbia. These signs are considered to be more effective than static roadway signs because the information provide on the dynamic sign is normally more relevant to the driving task. Often, the information on a changeable / dynamic road signs can provide information that could impact safety, such as:

1) Congestion or Collision Ahead
2) Road Surface Conditions
3) Excessive Speed on the Approach to a Curve or Grade
4) Road Closures

Research has attempted to quantify the safety impacts of changeable or dynamic warning signs. The effectiveness of this type of warning sign is provided in Exhibit 8.4 below.

Exhibit 8.4: Install Changeable / Dynamic Warning Signs

Treatment	Road Type	Target Collisions	CMF
Install Changeable or Dynamic Warning Signs	All	All	0.80

Target Collisions: All collisions (for target of the sign message).

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.2 Delineation / Pavement Markings

Roadway delineation is a very important road feature that offers some communication between the roadway and the road user by providing guidance to the driver. Like signage, delineation is designed to provide information to the motorist such that the motorist can modify their driving behavior to respond to the demands of the road and very often, the requirement to modify driving behavior is in the interest of highway safety. It is noted that delineation may also be used to supplement other traffic control devises.

There are standards and guidance in place for the use of delineation devices, which generally follow the Manual of Uniform Traffic Control Devices (MUTCD). Similar to signs, the Ministry's Senior Traffic Engineer and the Regional Traffic Engineers provide the authority for the selection and application of the various delineation devices.

Unfortunately, the definitive and reliable research on the effectiveness of highway delineation is limited. Information on what is known about the type and application of delineation is presented on the following pages. In addition (and in the interest of completeness), some additional CMFs for delineation are presented where reliable information may be limited. The CMFs for delineation include:

1) Post-Mounted Delineators
2) Install Standard Edge-line Markings
3) Install Wide Edge-line Markings
4) Install Centreline Markings
5) Highly Reflective Pavement Marking
6) Raised Pavement Mounted Delineators / Cat-Eyes
7) Recessed Pavement Marking / Delineators
8) Flashing Beacons

8.2.1 Post-Mounted Delineators

Post-mounted delineators are normally installed in the roadside area and in close proximity to the edgeline. The delineation is used as guidance by motorists to navigate a roadway under difficult visibility conditions (e.g., dark, rain, snow, etc.). The research that quantifies the safety effect of post-mounted delineators is based on two-lane rural highways, but it is recommended that the CMF also be used for other types of roads where post-mounted delineation is used.

Exhibit 8.5: Install Post-Mounted Delineators

Treatment	Road Type	Target Collisions	CMF
Install Post-Mounted Delineators	Rural	All	0.92

Target Collisions: All collisions.

References: Bahar, G., Masliah, M, Wolff, R., Park, P., The Desktop Reference for Crash Reduction Factors, Report Number FHWA-SA-07-015, US Department of Transportation, Federal Highway Administration, September, 2007.

8.2.2 Install Standard Edge-line Markings

Roadway edgelines are used to demarcate the travel portion of the roadway and are intended to assist motorists in the safe navigation of the roadway and to avoid entering the roadside area. They are particularly effective under difficult visibility conditions. The research that quantifies the safety effect of installing edgelines is based on data from two-lane rural highways, but it is recommended that the CMF presented below also be used for other types of roads where standard edgeline markings are proposed.

The effectiveness of standard edgeline markings is provided in Exhibit 8.6 below.

Exhibit 8.6: Install Standard Edgeline Markings

Treatment	Road Type	Target Collisions	CMF
Install Standard Edge-line Markings	All	Injury	0.97

Target Collisions: Injury collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.2.3 Install Wide Edgeline Markings

The MUTCD indicates that wider edgelines can be used to provide greater emphasis on the demarcation of the travel portion of the road. Standard edgelines are typically 100 to 150 mm in width, whereas wide edgelines can be 200 mm in width. It is noted that the research that quantifies the safety effect of installing wide edgelines is based on data from two-lane rural highways, but it is recommended that the CMF presented below also be used for other types of roads where wide edgelines are proposed.

Exhibit 8.7: Install Wide Edgeline Markings

Treatment	Road Type	Target Collisions	CMF
Install Wide Edge-line Markings	All	Injury	1.05

Target Collisions: Injury collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.2.4 Install Centreline Markings

Similar to edgelines, a centreline is used to demarcate the travel lane and is intended to assist motorists in the safe navigation of the roadway and to avoid crossing into opposing traffic. Centrelines are most effective under difficult visibility conditions. The research that quantifies the safety effect of installing edgelines is based on data from two-lane rural highways, but the information should also be used for other roads where centreline markings are proposed. It is noted that the CMF for centreline markings should only be used on roadway that previously did not have a centreline.

Exhibit 8.8: Install Centreline Markings

Treatment	Road Type	Target Collisions	CMF
Install Centreline Markings	All	Injury	0.99

Target Collisions: Injury collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.2.5 Highly Reflective Pavement Marking

There are products available that can improve the quality and durability of standard pavement markings. These markings will provide additional safety benefits over standard pavement marking due of the increased level of reflectivity / visibility of the marking, as well as the durability of the marking (i.e. the usefulness of the pavement marking is maintained over a longer time period).

The effectiveness of highly reflective pavement markings are provided in Exhibit 8.9 below.

Exhibit 8.9: Install Highly Reflective Pavement Markings

Treatment	Road Type	Target Collisions	CMF
Install Highly Reflective Pavement Markings	All	Night	1.00
	All	Poor Weather	1.00

Target Collisions: Night and Poor Weather collisions.

References: NCHRP Web-Only Document 92: Pavement Marking Materials and Makers: Real World Relationship Between Retro-Reflectivity and Safety Over time, NCHRP Project 17-28, Bahar, G., Masliah, M, Erwin, T, Tan E, and Hauer, E. April 2006.

8.2.6 Raised Pavement-Mounted Delineators / Cat-Eyes

Surface mounted delineators are used by many jurisdictions to delineate a roadway. Delineators (or often referred to as "cat-eyes") are affixed to the lane lines in order to help guide motorists under difficult visibility conditions. It is noted that surface mounted delineators also can provide an audible warning when a motorist leaves their travel lane.

The effectiveness of surface mounted delineators is provided in Exhibit 8.10 below.

Exhibit 8.10: Install Surface Mounted Delineators

Treatment	Road Type	Target Collisions	CMF
Install Surface Mounted Delineators	All	Night or Poor Weather	0.92

Target Collisions: Night and Poor Weather collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

8.2.7 Recessed or Snowplowable Pavement Marking / Delineators

In regions where the highways require snowplowing, raised pavement mounted delineators are typically not installed because the blades of the snowplows will remove the surface mounted delineators. In these areas, it is more common to install recessed reflectors or snowplowable reflectors to delineate the roadway.

The effectiveness of recessed or snowplowable roadway delineators is provided in Exhibit 8.11 below.

Exhibit 8.11: Install Recessed or Snowplowable Reflectors

Treatment	**Road Type**	**Target Collisions**	**CMF**
Install Recessed Or Snowplowable Reflectors	Rural	Night	0.94

Target Collisions: Night collisions.

References: Bahar, G., Masliah, M, Wolff, R., Park, P., The Desktop Reference for Crash Reduction Factors, Report Number FHWA-SA-07-015, US Department of Transportation, Federal Highway Administration, September, 2007.

8.2.8 Flashing Beacons

Flashing beacons are a delineation device that can be used to alert motorists of a roadway feature that may require extra care or attention. For example in BC, a flashing beacon might be to delineate the presence of an intersection that is located on a remote, rural highway where there is a high potential for conflicts between the main line traffic and the side road traffic. The MOT's Traffic Engineers are normally consulted before a flashing beacon would be installed.

The effectiveness of a flashing beacon at improving safety is provided in Exhibit 8.12 below.

Exhibit 8.12: Install Flashing Beacon

Treatment	**Road Type**	**Target Collisions**	**CMF**
Install Flashing Beacon	All	Night or Poor Weather	0.80
	All	All	0.90

Target Collisions: Night, poor weather or All collisions.

References: Various information sources were reviewed but not considered reliable and/or applicable and as such, the CMFs in the table are estimated based on judgment and experience.

9.0 MISCELLANEOUS DESIGN FEATURES

There are some other design features that can be used on any type of highway (rather than being associated with a certain type of highway) and will be included in this final section of the report. For several of the design features that are included in this section of the report, the effectiveness of the design feature is targeted at a specific collision type, which might be more specific than the types of collisions listed in earlier sections (e.g., wildlife fencing will target wildlife related collisions).

The list of design features that are presented in this section of the report include:

1) Illumination
2) Road Surface Treatments
3) Traverse Rumble Strips
4) Wildlife Collision Mitigation
5) Tunnels
6) Intelligent Transportation Systems (ITS)
7) Railway Crossings
8) Bridge Narrowing

9.1 Illumination

Illumination (or roadway lighting) can be provided on all types of highway facilities, including rural highways, multilane highways, rural intersections and urban intersections. Research has indicated that there are safety benefits of providing roadway lighting at locations where illumination has previously not been installed.

The effectiveness associated with the implementation of road lighting on roads previously without lighting is listed in Exhibit 9.1 below, for the various roadway applications.

Exhibit 9.1: Install Roadway Lighting

Treatment	Road Type	Target Collisions	CMF
Install Roadway Lighting	Highways	Night	0.79
	Urban Intersections	Night	0.72
		Pedestrian Night	0.58

Target Collisions: Refer to Exhibit.

References:

Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

Griffith, M., "Comparison of Safety of Lighting Options on Urban Freeways" Public Roads, Vol. 58, No. 2, McLean Va., FHWA, 1994, pp. 8-15.

Preston, H., and Schoenecker, T., " Safety Impacts of Street Lighting at Rural Intersections", 1999, Minnesota Department of Transportation, 1999.

Elvik, R., "Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure" Transportation Research Record 1485, TRB, 1995, pp. 112-123.

9.2 Road Surface Treatments

There are many types of treatments that can be used to improve the surface quality for a highway, including the application of chemical de-icing, using high-friction pavements and using grooved pavements to assist in drainage. The road safety engineering literature is somewhat limited in the details of the specific effects of the various treatments, but a general CMF for improvements to road surface treatments is provided as guidance. Some judgment may be required to select a CMF to reflect the success of a road safety treatment relative to a roadway without any road surface improvements.

The effectiveness of general road surface treatments is provided in Exhibit 9.3. Some subjectivity and judgment should be used in applying the CMFs in Exhibit 9.3, because of the variability in the success of road surface treatments.

Exhibit 9.3: Improve Road Surface Conditions

Treatment	**Road Type**	**Target Collisions**	**CMF**
Anti-Icing	All	All	0.87
Improved Drainage	All	All	0.92

Target Collisions: All collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

9.3 Traverse Rumble Strips

Traverse rumble strips are a type of rumble strip that are installed across the traveled portion of a roadway in order to alert motorists of a potential road hazard. Traverse rumble strips have several applications in BC, such as in advance of tollbooths, ferry terminals or rail-road crossings, and at times, they are in advance of a required stop on minor access roads and intersections that connect to main highways.

The CMF for traverse rumble strips is provided in Exhibit 9.4 and the CMFs should be applied only to proportion of traffic that is affected by the traverse rumble strip.

Exhibit 9.4: Traverse Rumble Strips

Treatment	Road Type	Target Collisions	CMF
Traverse Rumble Strips	All	Injury	0.67
	All	PDO	0.75

Target Collisions: Injury and PDO collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

9.4 Wildlife Collision Mitigation

Collisions involving wild animals are a significant problem in the province of British Columbia. There have been a total of 33,780 collisions involving wild animals on BC highways in 20 years of collision records (1987 – 2006 inclusive), which equates to 1 in 10 collisions involves a wild animal. Further, these statistics are for the police report collisions, but it is known that a significantly higher number of wild animal collisions occur but are not reported by the police. It should also be recognized, that in more remote parts of the province, that collisions involving wild animals can approach 50% (i.e., 1 in 2 collisions involves a wild animal).

Several researchers have attempted to examine the safety effects of the various measures to reduce wildlife collisions. A summary of the effects is listed in Exhibit 9.5 below.

Exhibit 9.5: Wildlife Collision Mitigation

Treatment	Road Type	Target Collisions	CMF
Wildlife Fencing	All	Wildlife Collisions	0.05
Predator Scents	All	Wildlife Collisions	0.90
Roadside Clearing	All	Wildlife Collisions	0.85

Target Collisions: Wildlife related collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

Sielecki, L., "Wildlife Exclusion Systems for Accident Mitigation on BC Highways", Proceedings from the IX International Mammalogical Congress: Wild Animals and Traffic Accidents, Sapporo Japan, August 2005.

9.5 Tunnels

In the mountainous terrain in British Columbia, it sometimes becomes prudent to consider the use of tunnels to shorten the road length, reduce excavation and to avoid constructing bridges. Much of the research that examined the safety performance associated with tunnels is from Norway, which likely compares favorably to BC in terms of weather and operating conditions.

The safety effects of a tunnel are broken down by the area of the tunnel, as shown below in Exhibit 9.6.

Exhibit 9.6: Tunnels and Safety

Treatment	**Road Type**	**Target Collisions**	**CMF**
Tunnel Portals	All	All	1.62
Central Zone	All	All	0.64

Target Collisions: Injury and PDO collisions.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).
de Leur, P., "Safety Review of Tunnel Design Options for the Kicking Horse Canyon Project (KHCP)", for the BC Ministry of Transportation.

9.6 Intelligent Transportation Systems

Various intelligent transportation systems (ITS) are becoming common for many road authorities. The types of ITS systems vary considerably, but most are implemented in an attempt to improve the operation of a facility and/or to increase the capacity of the facility. At this time, there is a lack of definitive research that quantifies the safety effect of many of the ITS systems that are available, but it is expected that new research will be available in the near future to improve the safety estimates for ITS initiatives.

CMF estimates for various types of ITS initiatives are provided Exhibit 9.7, but it is noted that judgment should be used when applying the CMFs.

Exhibit 9.7: ITS and Safety

Treatment	**Road Type**	**Target Collisions**	**CMF**
Signal Coordination	All	Intersection	0.85
Freeway Ramp Metering	All	Ramp	0.80
Weather Information Systems	All	All	0.95
Camera Systems	All	All	0.95

Target Collisions: Refer to Exhibit.

References: Various information sources were reviewed but CMFs are estimated based on judgment and experience.

9.7 Railway Crossings

Accommodating the safety requirements for the interaction between highways and railways must be carefully considered. There are several different treatments that can be implemented to reduce the safety risk of at-grade railway crossings, including automatic barrier systems, flashing signals, audible warnings, warning signs among others.

Considerable research on rail-crossing safety has been conducted in North America. The safety effects of a various railway crossing are summarized in Exhibit 9.8 below.

Exhibit 9.8: Railway Crossings

Treatment	**Road Type**	**Target Collisions**	**CMF**
Warning Signs	All	Trains	0.75
Flashing Lights / Audible Warnings	All	Trains	0.67
Barricades, Lights, Sounds	All	Trains	0.50

Target Collisions: Collisions involving trains.

References: Elvik, Rune and Vaa, T., The Handbook of Road Safety Measures", Oxford, United Kingdom, Elsevier, (2004).

9.8 Bridge Narrowing

Aggregate collision statistics often show an increase in collision frequency on bridges, which may be due in part to the narrowing of the road surface over the bridge structure. The narrowing of a road over a bridge structure can cause an increase in the amount of driver friction, which ultimately can cause a net deterioration in the safety performance. The following equation can be used to calculate the safety effect caused by a narrowing of a bridge structure. It is noted that the CMF pertains to rural two-lanes highways.

$$CMF_{BW} = e^{-0.135\,(3.28\,W_B - 12.0)}$$

Where:

CMF_{BW} = Bridge width Collision modification factor

W_B = Relative bridge width (= bridge width – the approach traveled-way width) in meters.

Target Collisions: Single vehicle collisions with bridge.

References: Turner, D., S., "Prediction of Bridge Accident Rates", Journal of Transportation Engineering, Vol. 110, No.1, American Society of Civil Engineers, Washington DC, January 1984, pp. 45-54.

Bonneson, J., Zimmerman, K., Fitzpatrick, K., "Roadway Safety Design Synthesis", Texas Transportation Institute, Report 0-4703-P1, for FHWA and Texas DOT (2005).