City of Hamilton

Red Hill Valley Parkway Detailed Safety Analysis

FINAL DRAFT

October 2015

B000558

City of Hamilton

Red Hill Valley Parkway Detailed Safety Analysis

FINAL DRAFT

October 2015

B000558

PREPARED BY:

Giovani Bottesini, P.Eng., M.Eng.

Khaled Hawash, B.Sc. Eng.

REVIEWED BY:

Maurice Masliah, Ph.D.

VERIFIED BY:

Brian Malone, P. Eng., PTOE

Table of Contents

B000558

List of Figures

List of Tables

Appendices

1. Introduction and Background

The planning and design of the Red Hill Valley Parkway (RHVP) has a long history in Hamilton. In December of 1982, the original Environmental Assessment (EA) documents were filed by the former Region of Hamilton-Wentworth that outlined the need, scope and timing for the expansion of the Regional road network. The EA identified that a roadway connecting Highway 403 in Ancaster to the QEW in east Hamilton was required. The original design for the roadway was completed in 1985, and the EA was approved by the Province in 1987. A subsequent Preliminary Design Report for the RHVP was completed in January of 1990.

~~Construction of the Valley portion of the Parkway was begun in the early 1990s. Some aspects of funding, but not approvals, were halted and the project restarted in the mid-2000's. Construction of the Lincoln Alexander Parkway portion of the roadway went ahead and was completed in 1997, extending from Highway 403 to Dartnall Road.~~

~~In the early 1990's, the City entered into discussions with the Provincial government on how to further reduce impacts to the environment within the Valley section of the road. As a result of these discussions, in 1996, the City requested from the Province that they be allowed to undertake changes to the original designs and undertake a new EA. The Province approved this request in 1997 and work on the design changes and the new EA were begun and the City undertook an Impact Assessment and Design Process (IADP).~~

~~In 1999 the project was subject to panel hearing under the Canadian Environmental Assessment Act (CEAA). Construction in the Valley was placed on hold until 2002 when issues were resolved. In 2003 the design changes and the IADP were completed and construction on the Parkway~~ recommenced. In 2007, the Red Hill Valley Parkway was opened to traffic and has been in operation since, forming part of a continuous connection from Highway 403 and the QEW in conjunction with the Lincoln Alexander Parkway. The road serves both intra-city traffic and inter-city traffic since it forms a connection between Niagara Region and South West Ontario.

Traffic volumes on the road are high, and, although Average Daily Traffic (ADT) has increased from approximately 46,000 vehicles in 2008, it has been oscillating between 55,000 and 59,000 from 2009 to 2014. Traffic conditions on ~~the~~ RHVP can become congested as the road reaches capacity, particularly during peak hours.

There were 474 collisions on the RHVP mainline between January 1, 2008 and July 23, 2015, an average of 62.5 collisions per year. There were 131 median related collisions, involving vehicles hitting guide rails/concrete barriers, resting on the grass median, or crossing over to the opposite direction during this time period, median related collisions were 28% of total collisions and include 1 fatal collision (2 fatalities) and 56 non-fatal injury collisions.

B000558

2. Study Purpose

The purpose of this study is to review the safety and operational performance along the entire length of the RHVP (from the QEW interchange to the Dartnall Road interchange), and to identify measures that could potentially improve performance and reduce the number and/or the severity of collisions. In 2013, CIMA Canada Inc. (CIMA) conducted a safety review of the section of the RHVP between the Dartnall Road and Greenhill Avenue interchanges, providing a series of recommendations to improve safety.

This study has an extended area of review in comparison with the 2013 study, and particular focus has been paid to collisions related to the median and median crossover, as well as the potential need for illumination. The study completed the following tasks:

- Investigate the role of road-related factors in collisions;
- Complete a road safety assessment and field investigation;
- Evaluate of the need for and type of potential countermeasures, including median barrier system(s) and illumination; and
- Complete a benefit / cost analysis for all viable countermeasures.

The scope of the study does not allow for consideration of any major changes in the geometric design of the road including elements related to interchange spacing.

3. Study Area

The study area segment of the RHVP extends for 8.1 km, mostly in the north-south direction from approximately 500 m west of the Dartnall Road interchange in the south to the railway overpass approximately 500 m north of Barton Street in the north. The study area includes six full access interchanges of various design types. **Figure 1** illustrates the study area.

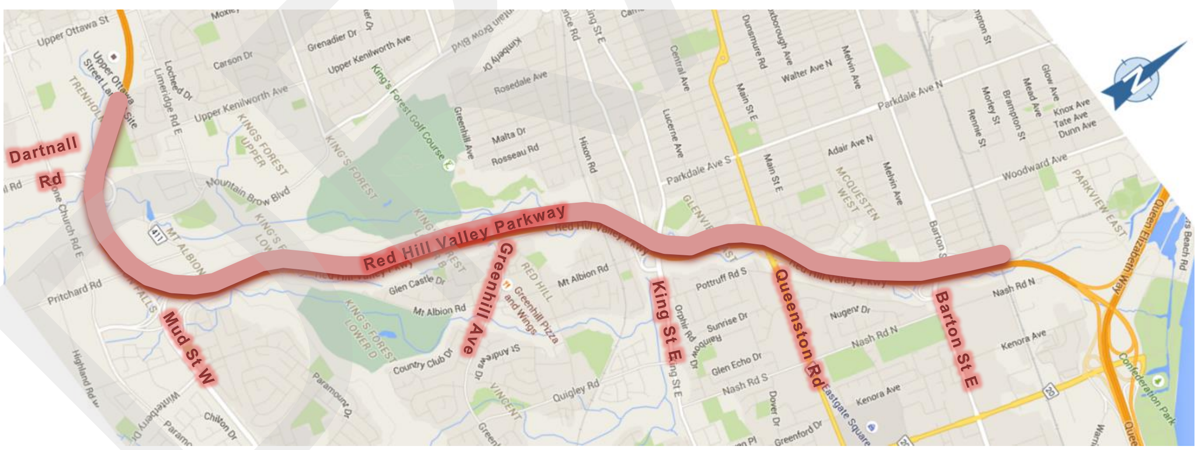

Figure 1: Study area

The RHVP is a 4-lane divided parkway between its north end and Greenhill Avenue, and a 5-lane divided parkway between Greenhill Avenue and its south end. In this section, there is an additional southbound lane due to the existing uphill grade. Controlled access is provided through interchanges with on and off ramps. The posted speed of the road is 90 km/h, and the design speed is assumed to be 110 km/h.

The divider between directions is a ~~raised~~ grassy median for most of the length of the RHVP. The exception is a section starting close to the Mud Street West interchange and continuing north, 1,100 m, towards Greenhill Avenue where a concrete barrier divides the road. Occasionally, steel beam guide rails are present primarily to protect ~~motorists from~~ fixed object hazards such as overhead signs and bridge structures located within the median. The median is buffered from the travel lanes by a paved shoulder. ~~The median is flush, and there is no curb and gutter~~.

~~The roadway is not continually illuminated~~. Partial illumination is available at exit and entrance ramps.

Based on traffic counts provided by the City for a permanent count station located near Queenston Road, two-way Average Daily Traffic (ADT) for the RHVP ranges approximately between 55,000 and 60,000 (**Table 1**). ~~Due to limited data available to determine Average Annual Daily Traffic (AADT), these volumes are daily averages over 1-week periods in the months of May or October. These months were selected by the City based on consistency of available data over the years.~~

Table 1: RHVP average daily traffic

Year	Week	ADT
2008	October 20 – 26	45,749
2009	October 19 – 26	55,833
2010	October 18 – 25	59,123
2011	May 1 – 8	55,406
2012	May 20 – 26	57,812
2013	Data not available	
2014	May 21 – 27	58,444
2015	Data available only for Winter and Summer	

4. Review of Collisions

Collision data was reviewed to gain an in-depth understanding of the safety issues within the study area. CIMA reviewed the results of the collision analysis provided by the City, which was conducted for the period from January 1, 2008 (following opening of the RHVP) to July 23, 2015 (latest data available). CIMA conducted the review of collision characteristics in two parts. The first considered all types of collisions within the study area, which is detailed in Section 4.1. The second part considered only those collisions that are related to medians and is detailed in Section 4.2.

4.1 Review of Collision Characteristics Considering All Collisions

The study area experienced a total of 474 collisions during the period from January 1, 2008 to July 23, 2015. The data, broken down by collision severity, is summarized in **Figure 2**. There were 4 fatal collisions (resulting in 5 fatalities), 205 injury collisions, and 265 Property Damage Only (PDO) collisions.

B000558

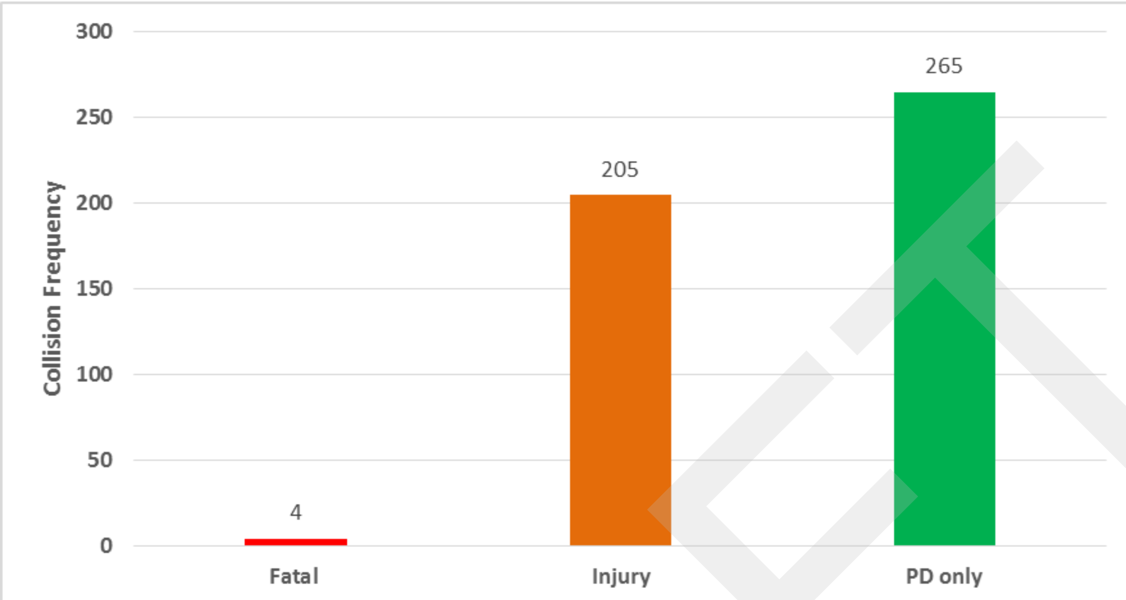

Figure 2: Collision severity

4.1.1 Light, Environment and Road Surface Conditions

Figure 3 through **Figure 5** summarizes the collisions in the study area, broken down by light, environment and road surface condition.

The majority of collisions occurred under daylight/daylight artificial conditions, with a total of 300 out of 474 collisions (63.3%), with the remaining 174 (36.7%) collisions occurring during non-daylight conditions, which include dark/dark artificial, dusk/dusk artificial, and dawn/dawn artificial. When compared to the Provincial average of 30.7%[1] and the City of Hamilton average of 36.3%[2], and based on a Chi-Square statistical test, the proportion of collisions under non-daylight condition is significantly higher, however the range of this distribution can be considered normal. Details about the statistical test can be found in **Appendix A**, and a discussion regarding the need for illumination in the study area can be found in **Section 6 – Illumination Review**.

B000558

[1] Ontario Road Safety Annual Report (ORSAR), Ontario Ministry of Transportation, 2012.
[2] 2008-2010 Traffic Safety Status Report, City of Hamilton, 2010.

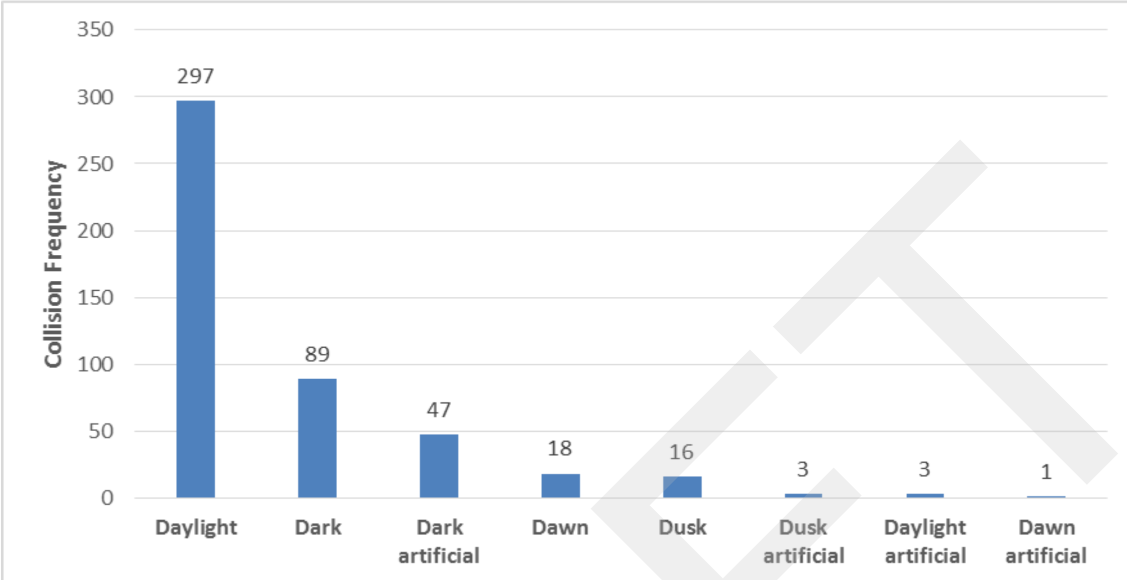

Figure 3: Collisions by light condition

With respect to environment condition, 275 out of 474 collisions (58.0%) occurred with clear weather; 160 (33.7%) with rainy weather, and the remaining collisions with other weather conditions, including snow, drifting snow, freezing rain, strong wind, and fog/mist/smoke/dust. Compared to the Provincial average of 10.9%[3] and the overall City of Hamilton average of 13.4%[4], and based on a Chi-Square statistical test, the proportion of collisions under rainy weather is significantly higher. Details about the statistical test can be found in **Appendix A**.

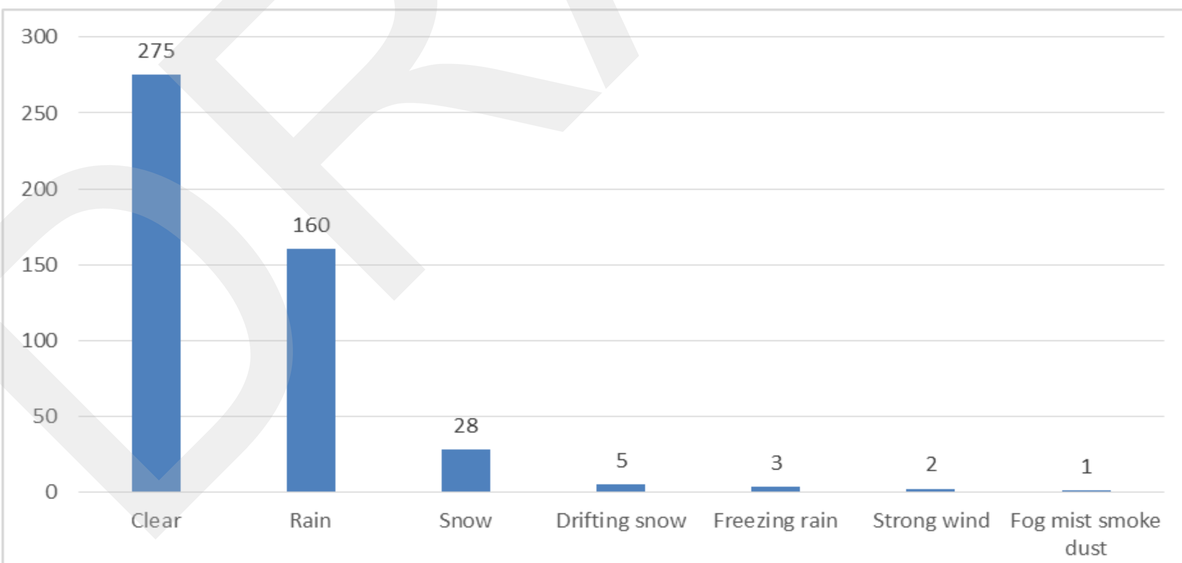

Figure 4: Collisions by environment condition

[3] Ontario Road Safety Annual Report (ORSAR), Ontario Ministry of Transportation, 2012.
[4] 2008-2010 Traffic Safety Status Report, City of Hamilton, 2010.

Wet surface collisions make up the majority of collisions in the study area, with 50.4% (239 out of 474), followed by dry surface with 43.9% (208 out of 474). When compared to the Provincial average of 17.6% and the City of Hamilton average of 22%, and based on a Chi-Square statistical test, the proportion of collisions under wet road surface is significantly higher. Details about the statistical test can be found in **Appendix A**.

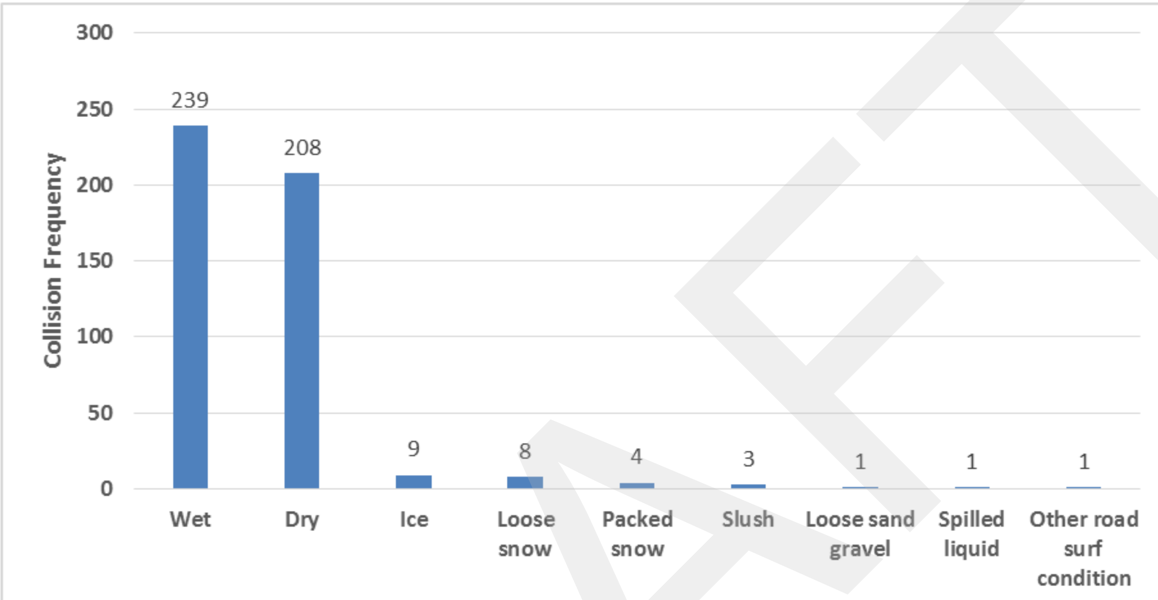

Figure 5: Collisions by road surface condition

4.1.2 Collision Impact Type

Figure 6 summarizes collisions by impact type and by roadway surface condition.[5] Single motor vehicle collisions (SMV) collisions are the most prevalent collision type with 208 incidents of a total of 474 collisions (44%). Rear end and sideswipe collisions with 116 (24%) and 108 (23%) incidents, respectively, were the next most common collision types.

Out of the 208 SMV collisions, 117 (56.3%) occurred under wet surface conditions, as well as 45 out of 116 rear end collisions (38.8%) and 56 out of 108 sideswipe collisions (51.9%).

B000558

[5] Due to the high proportion of wet surface collisions, as discussed in Section 4.1.1, all remaining sections of the collision review will be combined with wet surface collisions.

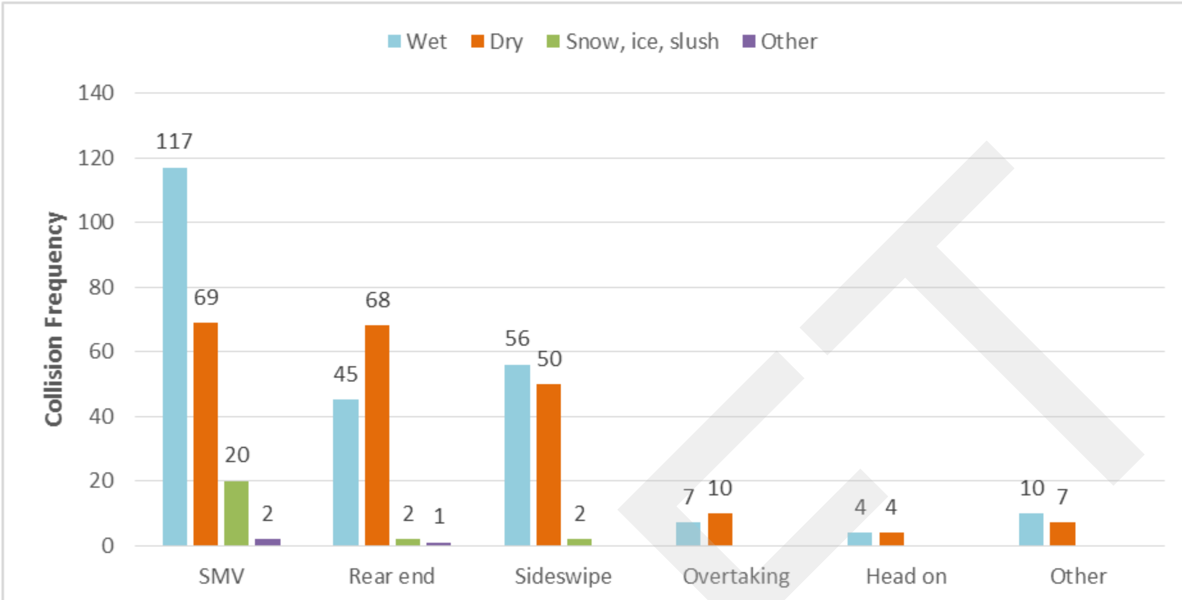

Figure 6: Collisions by impact type and roadway surface condition

4.1.3 Apparent Driver Action

Figure 7 summarizes the collisions in the study area according to the apparent driver action, including total collisions and wet surface collisions. The most frequent apparent driver action reported is "lost control", with 165 out of 474 collisions (34.8%), followed by "driving properly" (23.4%), "speed too fast" (12.4%), "following too close" (10.1%), and "improper lane change" (9.9%).

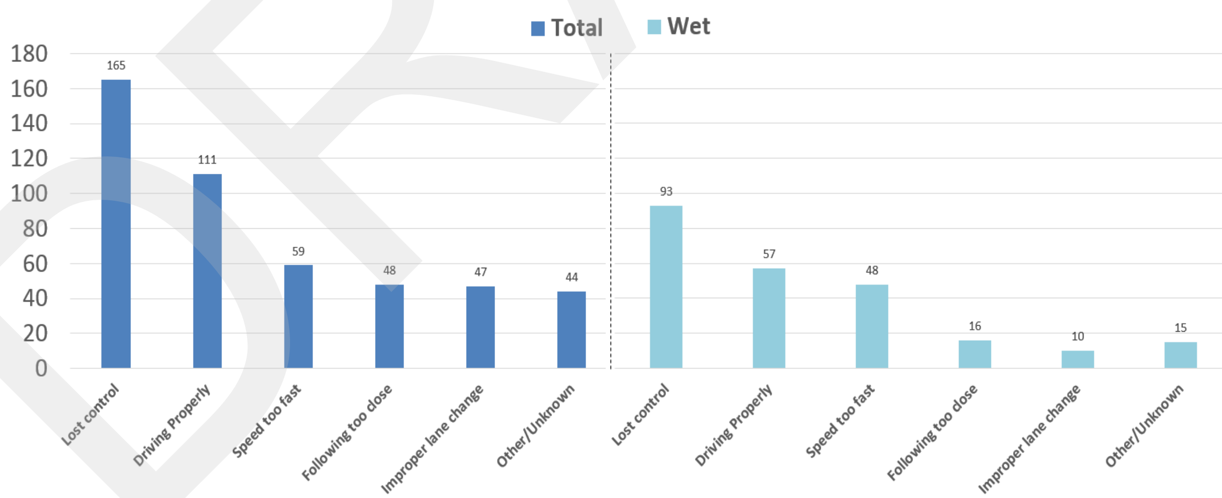

Figure 7: Apparent driver action

B000558

Table 2 provides a comparison of the different apparent driver actions reported in the study area with average proportions for the Province of Ontario and for the City of Hamilton. With the exception of "following too close", all improper driver actions are significantly higher (based on a Chi-Square statistical test) than the provincial and municipal averages. The most outstanding discrepancy is "lost control", with a proportion over five times higher than the municipal average. In the table, the numbers in red indicate a significant difference between the study area and the comparison jurisdictions.

Table 2: Apparent driver action comparison

Apparent Driver Action	Study Area	Ontario	Hamilton
Driving properly	23.4%	50.6%	48.9
Lost control	**34.8%**	9.0%	6.6%
Speed too fast[6]	**12.4%**	2.7%	5.5%
Following too close	10.1%	7.9%	9.9%
Improper lane change	**9.9%**	2.3%	3.4%

With respect to wet surface collisions, the proportions of the different apparent driver actions are generally similar to total collisions, as summarized in **Table 3**. "Speed too fast", however, stands out due to 81.4% of collisions involving this apparent driver action (48 out of 59 – refer to **Figure 7**) having occurred on wet surface.

Table 3: Apparent driver action for total and wet surface collisions

Apparent Driver Action	Total Collisions	Wet Surface Collisions
Driving properly	23.4%	23.8%
Lost control	34.8%	38.9%
Speed too fast[7]	12.4%	20.1%
Following too close	10.1%	6.7%
Improper lane change	9.9%	4.2%

4.1.4 Spatial Distribution

Figure 8 provides the spatial distribution of major collision types[8] within the study area in each direction. The locations with the highest concentration of collisions are:

- Northbound direction:
  - Vicinity of the King Street interchange (200 m upstream of off-ramp to on-ramp); and
  - Vicinity of Mud Street on-ramp.
- Southbound direction:
  - Vicinity of King Street on-ramp;
  - Vicinity of Queenston Road on-ramp; and

B000558

[6] Includes "speed too fast", "speed too fast for condition", and "exceeding speed limit".
[7] Includes "speed too fast", "speed too fast for condition", and "exceeding speed limit".
[8] Includes SMV, rear end, sideswipe, overtaking and head on. These collision types make up 96% of all collisions in the study area.

- Vicinity of Barton Street on-ramp.

Most of these locations have SMV collisions as the predominant collision type, the exception being Queenston Road southbound, where the predominant collision type is sideswipe (which is the second predominant collision type at the above mentioned locations, followed by rear end).

Out of the 249 northbound collisions shown in **Figure 8**, 78 (31%) are concentrated in a 600-metre section around the King Street interchange (between 250 metres south of the King Street off-ramp and the King Street on-ramp), a relatively short section of the 8.1 km study area. There were also 16 (6.4%) northbound collisions over a short 100-metre section near the Mud Street on-ramp.

Out of the 208 southbound collisions shown in **Figure 8**, 19 (9.1%), 21 (10.1%) and 22 (10.5%) are concentrated in 100-metre sections near the on-ramps of Queenston Road, Barton Street and King Street, respectively.

All locations mentioned above are within, on approach to, or leaving a horizontal curve, although some of these curves have a larger curve radius (e.g. Barton Street) and some have a smaller curve radius (e.g. King Street).

Figure 9 provides the spatial distribution of comparing dry and wet surface collisions. In the northbound direction, the ratio of wet to dry surface condition collisions around the King Street interchange is 4.33 wet surface collisions for each dry surface collision. In the southbound direction, this proportion is 3 to 1 near the Queenston Avenue on-ramp, and 2.5 to 1 near the King Street and the Barton Street on-ramps. These ratios exceed the normal expectation of more dry surface than wet surface collisions.

Figure 8: Spatial distribution of collisions considering all collisions

B000558

Figure 9: Spatial distribution of wet vs. dry surface collisions

4.2 Median Related Collisions

The Motor Vehicle Collision (MVC) reports were manually screened to identify median related collisions. The collisions related to median can be grouped into three types:

- Collisions crossing over the median; where vehicles travelled across the centre median and entered the opposing lanes of traffic;
- Collisions mounting the median; where a vehicle ran-off the road and came to rest on the median, not entering opposing lanes of traffic; and,
- Collisions involving a guide rail or concrete barrier installed on the median (left) side of the road; where a vehicle hit the guide rail or concrete barrier and then rested in the same initial direction of travel, not mounting or crossing the median.

4.2.1 Collision Severity

There were 131 (28% of all collisions) median related collisions from January 1, 2008 to July 23, 2015 as illustrated in **Figure 10**. This is a collision frequency of 2.13 collisions / year / km. The number includes:

- 1 fatal collision (crossing over the median; 2 fatalities);
- 56 injury collisions (9 crossing over the median, 17 resting on the median, and 30 involving guide rail/concrete barrier); and
- 74 PDO collisions (7 crossing over the median, 26 resting on the median and 41 involving guide rail/concrete barrier).

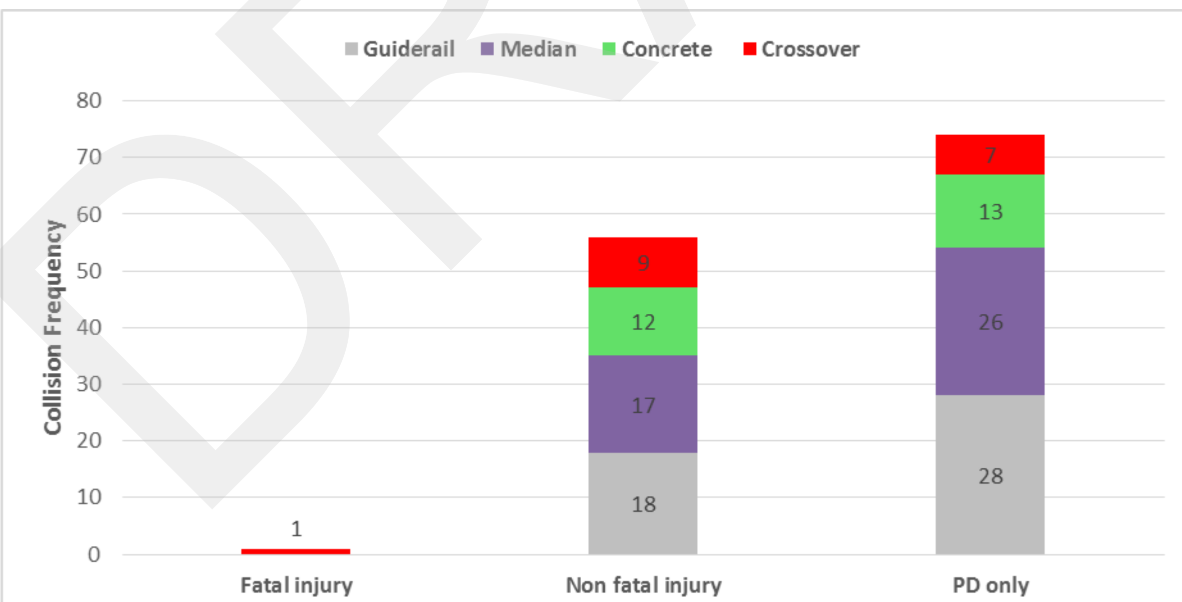

Figure 10: Summary of median related collisions

As can be seen in **Figure 10**, 59% (10 out of 17) of the crossover collisions are severe, a higher proportion than median collisions (17 out of 43 or 40%), concrete barrier collisions (12 out of 25 or 48%), and guide rail collisions (18 out of 46 or 39%). As a result, the need for a median barrier will be investigated in this study.

4.2.2 Light, Environment and Road Surface Conditions

Figure 11 through **Figure 13** summarize the median related collisions in the study area, broken down by light, environment and road surface condition.

The majority of collisions occurred under daylight/daylight artificial conditions, with a total of 81 out of 131 collisions (62%), with the remaining 50 (38%) collisions occurring during non-daylight conditions, which include dark/dark artificial, dusk/dusk artificial, and dawn/dawn artificial. These proportions are very similar to the proportions for all collisions (**Section 4.1.1**).

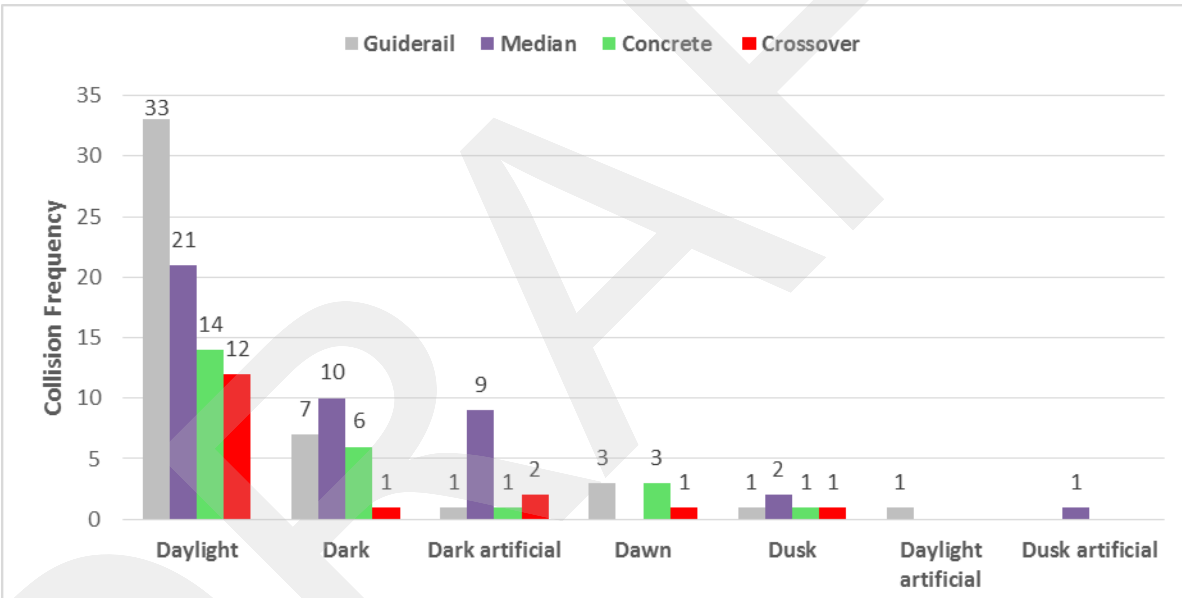

Figure 11: Median related collisions by light condition

With respect to environment condition, 68 out of 131 collisions (52%) occurred with clear weather; 50 (38%) with rainy weather, and the remaining collisions with other weather conditions, including snow, drifting snow, freezing rain, strong wind, and fog/mist/smoke/dust. These proportions are somewhat similar to the proportions for all collisions (**Section 4.1.1**), although non-clear weather conditions are slightly higher for median related collisions than for overall collisions (48% and 42%, respectively).

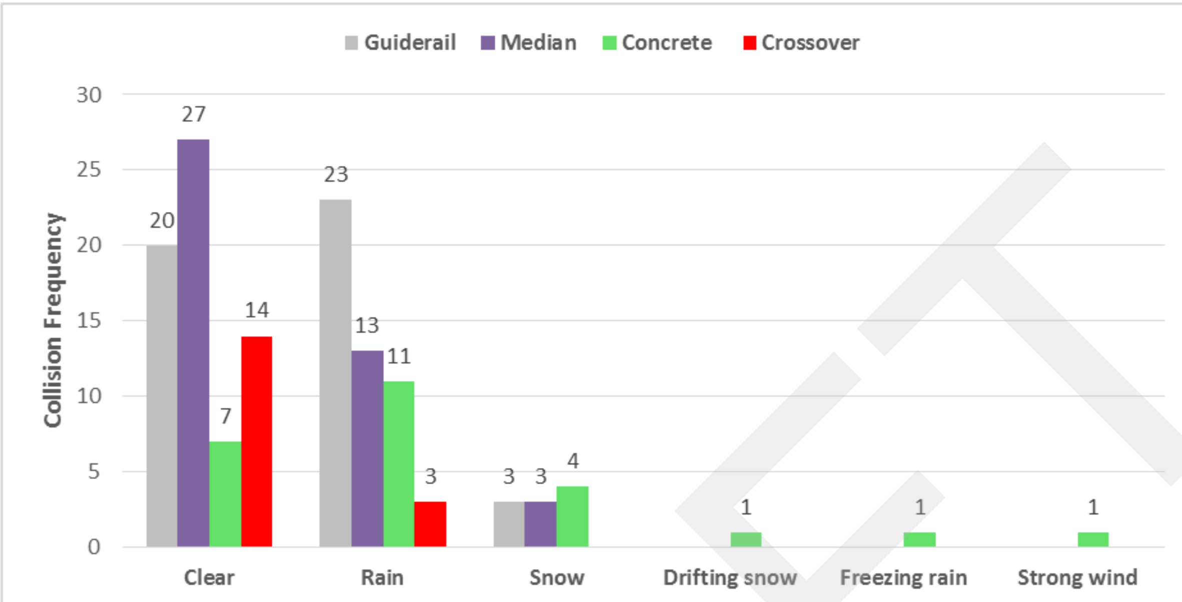

Figure 12: Median related collisions by environment condition

Wet surface collisions make up the majority of median related collisions in the study area, with 53% (70 out of 131), followed by dry surface with 41% (54 out of 131). These proportions are somewhat similar to the proportions for all collisions (**Section 4.1.1**).

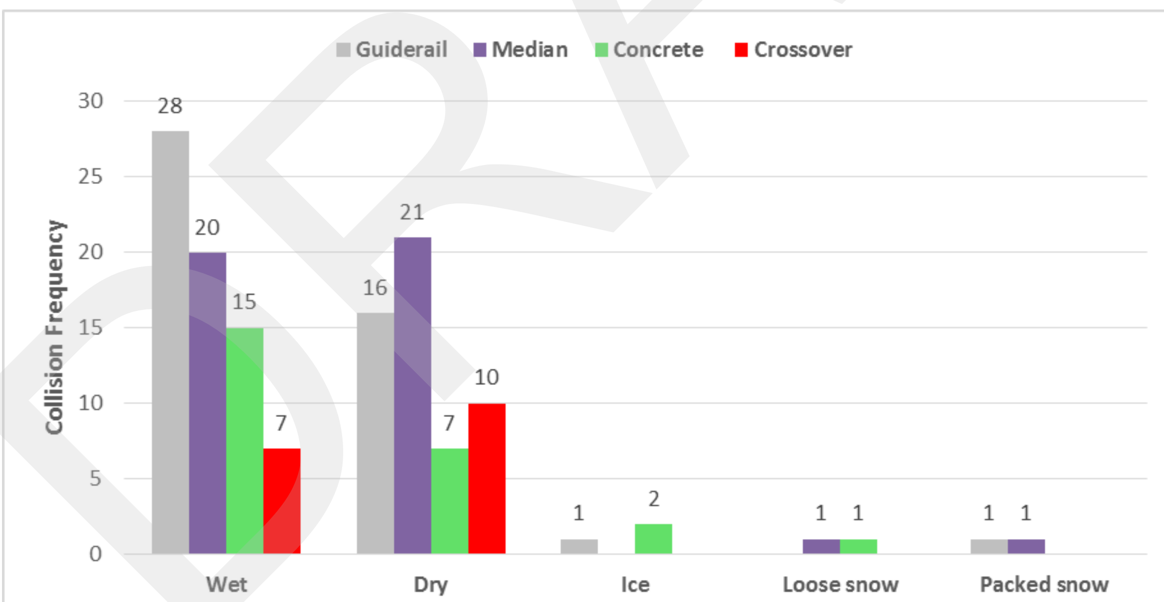

Figure 13: Median related collisions by roadway surface condition

4.2.3 Apparent Driver Action

Figure 14 summarizes the median related collisions in the study area according to the apparent driver action. The most frequent apparent driver action reported is “lost control”, with 60 out of 131 collisions (46%), followed by "speed too fast" (18%), "driving properly" (17%), and "improper lane change" (8%). The proportions of "lost control" and "speed too fast" are 11 and 6 percent points higher than for all collisions (as shown in **Section 4.1.3**). Additionally, 43.5% of median related, wet surface collisions involved "lost control" driver action, as well as 29% "speed too fast".

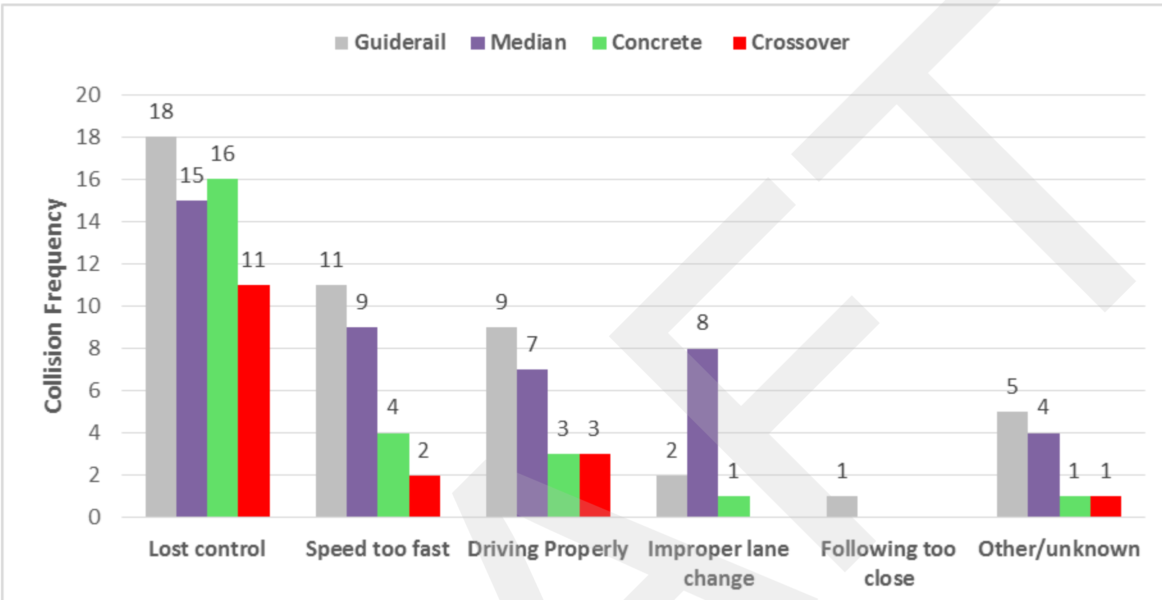

Figure 14: Median related collisions by apparent driver action

4.2.4 Spatial Distribution

Figure 15 provides the spatial distribution of all collisions and median related collisions within the study area in the northbound and the southbound directions.

A considerable proportion of median related collisions are concentrated in the vicinity of the King Street and Queenston Road interchanges. In the northbound direction, 32 out of 81 median related collisions (40%) are concentrated within a 600-metre section of road (between 250 metres south of the King Street off-ramp and the King Street on-ramp), equivalent to approximately 7.5% of the length of the study area. In the southbound direction, 19 out of 50 median related collisions (38%) are concentrated within a 1,100-metre section of road (between the Queenston Road on-ramp and 250 metres south of the King Street on-ramp), equivalent to approximately 13.5% of the length of the study area. Considering both directions combined, 57 out of 131 median related collisions (44%) are concentrated within 1,400 metres or 17% of the study area (between 250 metres south of the King Street NB off-ramp and the Queenston Road SB on-ramp). There were 7 crossover collisions in this section of the RHVP, 41% of a total of 17 in the study area. Out of these, 4 occurred in the northbound direction and 3 in the southbound direction.

The second highest concentration of median related collisions is located in the vicinity of the Mud Street interchange, with 25 collisions (19.5%) having occurred over a 1-km section of road (12.5% of the study area), 19 of which in the northbound direction (or 23.5% over 12.5% of the study area). However, a median concrete barrier is already present along most of this section.

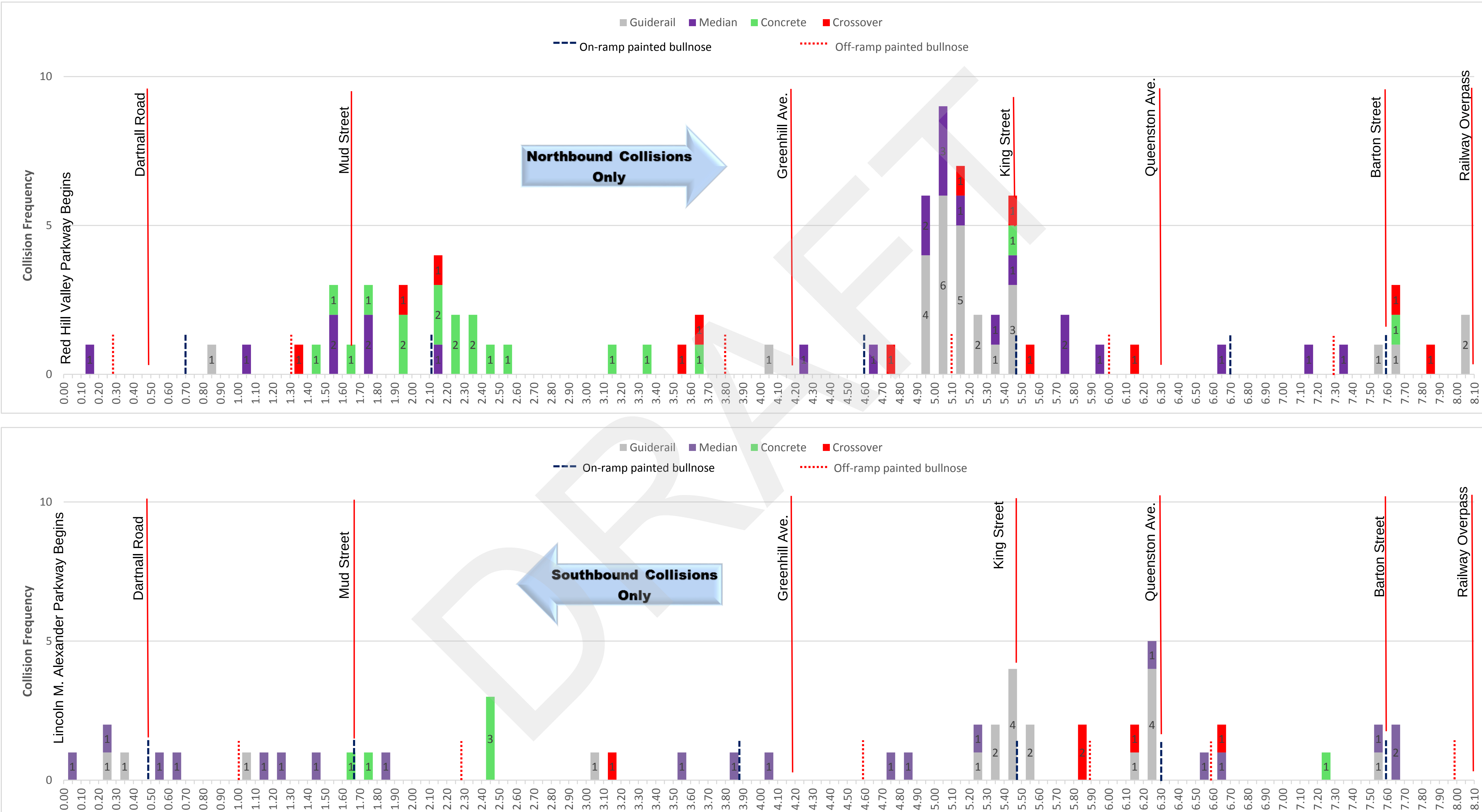

Figure 15: Spatial distribution of median related collisions

CIMA+ Partners in excellence
B000558

Out of the 57 reported collisions in the vicinity of King Street and Queenston Road, 36 had a vehicle striking the guiderail or concrete barrier, 14 had a vehicle ending up resting on the median, and 7 had a vehicle crossing over to the opposing traffic lanes. While 63% of median related collisions in this area are guide rail related, only 36% of this 1,400-metre section of the RHVP has guide rail installations on the median (used to protect fixed object hazards such as overhead sign and bridge structures). This may indicate that locations where median related collisions are more likely to occur are already protected. However, as shown in **Table 4**, crossover collisions, as expected, have a higher proportion of severe collisions than guide rail collisions. Conversely, median collisions have a lower proportion of severe collisions than guide rail collisions. Therefore, the determination of whether a median barrier should be provided throughout this entire section should be made based on a benefit/cost analysis.

Table 4: Median related collisions in the vicinity of King Street and Queenston Road

Median Related Collisions	Total	PDO	Severe
Guide rail/concrete	36	22 (61%)	14 (39%)
Median	14	10 (71%)	4 (29%)
Crossover	7	3 (43%)	4 (57%)

Finally, as discussed in **Section 4.2.2**, wet surface condition is present in 53% of median related collisions in the study area. When reviewing road surface condition for collisions in the vicinity of King Street and Queenston Road, however, it was found that this proportion increases to 74% (42 out of 57 collisions). This may indicate that addressing wet surface collisions could reduce median related collisions and significantly reduce the benefits of providing a median barrier.

4.3 Summary of Collision Review

Overall Findings

- Wet surface collisions were found to represent approximately 50% of all collisions in the study area, which is significantly high compared to typical proportions.
- Single Motor Vehicle (SMV) collisions amount to 44% of all collisions in the study area, followed by rear ends (24%) and sideswipes (23%).
  - 56% of SMV, 39% of rear end, and 52% of sideswipe collisions occurred under wet surface conditions.
- The most frequent apparent driver action reported was "lost control" (35%"), followed by "driving properly" (23%) and "speed too fast" (12%). Both "lost control" and "speed too fast" are significantly high compared to typical proportions.
  - Approximately four out of every five collisions where "speed too fast" was reported occurred under wet surface condition.

Critical Locations

- The locations with the highest collision frequencies along the RHVP are:

- In the northbound direction, a 600-metre section around the King Street interchange (31% of northbound collisions over 7.5% of the RHVP length); and
- In the southbound direction, 100-metre sections near the on-ramps of the Queenston Road, Barton Street and King Street (combined, approximately 30% of southbound collisions over 3.7% of the RHVP length).
- All locations with the highest collision frequencies are located within, on approach to, or leaving horizontal curves (**Figure 16**).

Figure 16: Critical collision locations

Median Related Collisions

- 28% of all collisions in the study area were median related, including:
  - 1 fatal collision (crossover);
  - 56 injury collisions, including 30 guiderail/concrete barrier, 17 median, and 9 crossover; and
  - 74 PDO collisions, including 41 guiderail/concrete barrier, 26 median, and 7 crossover.
- Approximately 53% of median related collisions occurred under wet surface condition.
- The most frequent apparent driver action reported in median related collisions was "lost control" (46%"), followed by "speed too fast" (18%) and "driving properly" (17%). Both "lost control" and "speed too fast" proportions are higher than for all collisions.
  - These proportions are 43% for "lost control" and 29% for "speed too fast" driver actions under wet surface conditions.

Critical Locations for Median Related Collisions

- The locations with the highest collision frequencies along the RHVP are in the vicinity of the King Street and Queenston Road interchanges, including:
  - In the northbound direction, a 600-metre section around the King Street interchange (40% of northbound collisions over 7.5% of the RHVP length); and
  - In the southbound direction, a 1,100-metre section around the King Street and Queenston Road interchanges (38% of southbound collisions over 13.5% of the RHVP length).
  - In both directions combined, a 1,400-metre section around the King Street and Queenston Road interchanges (44% of collisions over 17% of the RHVP length).
  - Most median related collisions at the above locations involved a vehicle striking a guiderail, however crossover collisions were proportionally more severe.

- Wet surface conditions were present in 74% of median related collisions at the above locations.

Potential Contributing Factors to Collisions

The overall findings from the collision review indicate that the proportion of wet surface collisions in the study area is significantly higher than typically observed in the City and in the Province. A high proportion of wet surface condition suggests that one or more than the following conditions may be present:[9]

- Inadequate skid resistance (surface polishing, bleeding, contamination);
- Hazardous manoeuvres that may be related to avoidance manoeuvres or surface deficiencies (potholes, waves, other deformations, water accumulation); and/or
- Excessive speed.

It was also found that the prevalent apparent driver actions involved in collisions in the study area, both in general and median related, are 'lost control', 'speed too fast', and 'improper lane change'. According to the Ministry of Transportation's definition[10], the "lost control" driver action is related to unexpected circumstances such as mechanical malfunction, object on roadway, slippery road surface or losing consciousness. It would not be unreasonable, however, to suppose that other driver actions such as excessive speed or driver distraction/inattention end up being coded as loss of control, especially for SMV collisions or other collisions where the police officer completing the accident report is not able to collect accurate information from witnesses.

Another indication that high speeds may be involved is the fact that some curves within the study area (in particular the four curves in the vicinity of King Street and Queenston Road) appear to have curve radii of approximately 525 metres[11], which is the minimum per Provincial Standards for a design speed of 110 km/h and a maximum superelevation of 6%.[12] Under these circumstances, a vehicle slightly exceeding the design speed could run off the road while negotiating these curves. This section of the RHVP presents the highest concentration of collisions in the study area, with an increased proportion of wet surface collisions.

Finally, the consequences of improper lane changes tend to be aggravated at higher speeds and/or wet surface conditions, since it becomes more difficult for drivers to maintain control of the vehicle.

Further discussion regarding these conditions can be found in **Section 5**.

Conclusions

Based on the collision review, it appears that the combination of high speed and wet surface may be the primary contributing factors to collisions on the RHVP, especially in the vicinity of the interchanges of King Street and Queenston Road, where small-radius horizontal curves are present. This applies both to all collisions in the study area and to median related collisions only. The need for

---

9 Road Safety Manual, World Road Association, 2003.
10 Accident Information System – MS Access Query User Guide, Version 1.4, Ministry of Transportation Ontario, 2004.
11 Design information was not provided for these curves. Approximate measurements were taken from satellite imagery.
12 Geometric Design Standards for Ontario Highways, Ministry of Transportation Ontario, 1985. Table C3-2.

a median barrier, either along the entire study area or limited to the vicinity of the interchanges of King Street and Queenston Road, will be determined based on a benefit/cost analysis.

5. Field Investigation

A field investigation was conducted on Thursday, August 30, 2015 under clear weather conditions and during peak and off-peak periods. A night-time review was also conducted to assess visibility under reduced lighting conditions. CIMA staff was accompanied by City's maintenance staff during the daytime review in order to gain a better understanding of site conditions and operations, based on their daily experience on the RHVP.

The field investigation included a review and/or analysis of:

- Conformance and consistency
  - Related to site geometrics, traffic control devices and safety devices.
- Traffic control
  - Traffic signage and pavement markings (applicability, condition, function, and conspicuity).
- Site operations and road user interactions
  - Site operations;
  - Road user operations and interactions, including human factors analysis;
  - Positive guidance; and
  - Traffic patterns and behaviour throughout the study area.
- Safety devices
  - Guiderail systems, approach/end treatments, crash cushions, post-mounted delineators etc.; and
  - Potential unprotected roadway and roadside hazards (non-existence of safety devices).
- Site conditions
  - Roadway surface, lighting, roadway safety hardware and the roadside; and
  - Physical evidence of road user collisions.

The findings of the field investigations are discussed in the following sections.

5.1 Roadside Safety Devices

The minimum required clear zone for a design speed of 110 km/h, according to the MTO's Roadside Safety Manual (Table 2.2.1) is 9.0 m for tangent road sections. The Roadside Safety Manual also provides Curve Correlation Factors (Table 2.2.2) that vary with design speed and curve radius. For a design speed of 110 km/h, these factors range between 1.00 (R = 1,000 m) and 1.44 (R = 500 m). The Curve Correlation Factor is a multiplier meaning that the minimum required clear zone at a curve section at this design speed can be as wide as 13 m (1.44 x 9.0) at certain locations.

CIMA conducted a review of the barrier systems within the study area. The barrier systems currently employed on the RHVP include steel beam guiderail and concrete barriers, which are provided in limited areas. All overhead signs and bridge columns located in the median within the study area are protected with steel beam guide rails, and a median concrete barrier is present along a 1,100 m section from Mud Street West towards Greenhill Avenue, where the distance between the traffic lanes in opposite directions is approximately 8.5 m (i.e. less than the clear zone).

The review of collision history revealed a large number of median related collisions including one fatal collision. During the field investigation, evidence of vehicles losing control towards the median was found, including skid marks and damage to guide rails, as illustrated in **Figure 17**. With the exception of the 1,100 m section between Mud Street West and Greenhill Avenue, the median does not have a continuous barrier to protect against median cross-over collisions. The study area was further evaluated regarding the benefits and drawbacks of providing a median barrier. Findings are provided in **Section 7**.

Figure 17: Evidence of loss of control towards the median / collisions with guide rails

It was also noted that some "fishtail" leaving end treatments at some guide rails protecting bridge structures are located within the clear zone of the opposite direction of traffic (**Figure 18**). When this is the case, the guide rails at the opposite direction do not provide the required length of need to protect the end treatment (**Figure 19**). This type of end treatment can represent a spearing hazard in the event of a frontal collision and should be protected when located within the clear zone.

Figure 18: RHVP typical guide rail leaving end treatment

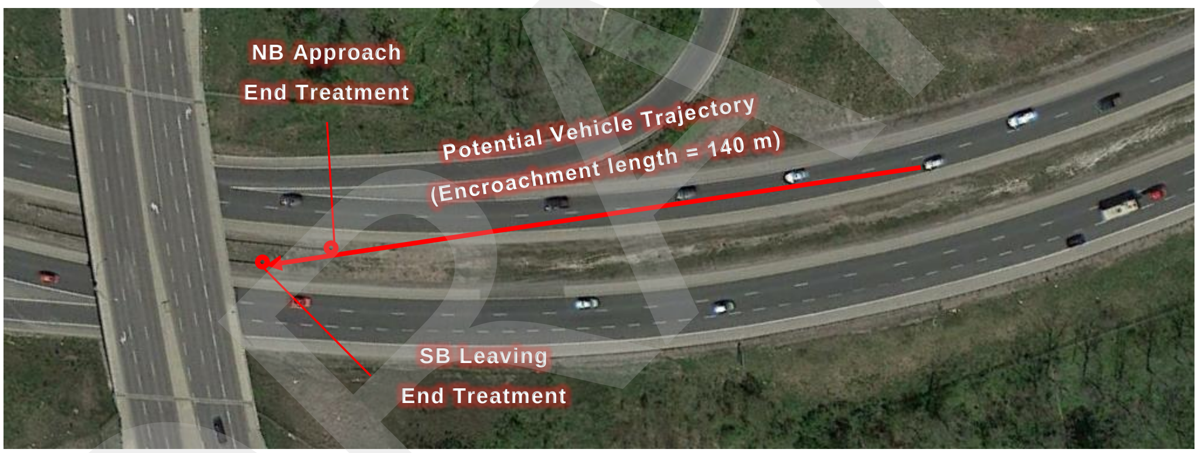

Figure 19: Potential trajectory of a vehicle towards fishtail end treatment

5.2 Traffic Operations

5.2.1 Operating Speeds

During the field investigation, most drivers, during periods of uncongested traffic conditions, were observed to be driving over the speed limit of 90 km/h. CIMA reviewed the speed studies conducted for the 2013 RHVP study, particularly along the mainline section between Mud Street and Greenhill Avenue. The results of the speed studies are summarized in **Table 5**. The results show that the average speeds in each direction are in excess of the posted speed limit. The 85th percentile speed, which is typically used to represent the operating speed of a road, is the same as the assumed design speed of the RHVP for the northbound direction, and 5 km/h in excess of the assumed design speed for the southbound direction. Approximately one in six drivers exceed the design speed in the northbound direction, and approximately one in five in the southbound direction. The high speeds observed on the RHVP may be a contributing factor for collisions, especially SMV and/or wet pavement related collisions. An average of more than 500 vehicles per day were recorded exceeding 140 km/h.

Table 5: RHVP operating speeds

Measure	Northbound	Southbound
Average speed	95 km/h	99 km/h
85th percentile speed	110 km/h	115 km/h
Exceeding speed limit	60%	72%
At or exceeding design speed	15%	22%
Exceeding 140 km/h	> 500 per day	

Location: Mainline between Mud St. and Greenhill Ave.
Date: May 2013

Given the high operating speeds, as well as the high concentration of collisions in the vicinity of the King Street and Queenston Road interchanges, where a sequence of curves of relatively small radii is present[13], a ball bank indicator study was conducted to gain additional understanding of the potential collision contributing factors. Ball bank indicator studies are typically utilized to determine curve advisory speeds. The test provides a combined measure of centrifugal force, vehicle roll and superelevation of the road by measuring the angle of the ball bank indicator while travelling through a curve at a given speed. The study was conducted on Tuesday September 1st, 2015, at travel speeds of 90, 100, and 110 km/h along the left lane (i.e. the lane closest to the median) of the RHVP in each direction. Because the testing required exceeding the speed limit of the road, the study was conducted in a Hamilton Police Service cruiser driven by a police officer to ensure safety of staff and general public. **Table 6** provides a summary of the ball bank indicator study, for each direction and travel speed, compared to thresholds available in the Traffic Engineering Handbook.[14]

Table 6: Ball bank indicator thresholds and test results

Travel Speed	Threshold [14]	Test Speed (km/h)	Maximum Reading NB	Maximum Reading SB
≥ 30 mph (48 km/h)	12	110	**12.2**	10.5
		100	10.8	9.0
		90	9.4	7.1
20-25 (32-40 km/h)	14	Not tested		
≤ 20 (32 km/h)	16			

The results of the ball bank study indicate that a travel speed of 90 km/h, which is equal to the posted speed limit, is well below the maximum threshold of the ball bank indicator. As the test speed increases, the readings also increase, slightly exceeding the threshold in the northbound direction at 110 km/h. This reading was recorded at the King Street interchange. It should be noted that the

[13] Curve radii near the King Street and Queenston Road interchanges are approximately 525 m, which corresponds to the minimum for a design speed of 110 km/h (Geometric Design Standards for Ontario Highways, Table C3-2)
[14] ITE Traffic Engineering Handbook (6th Edition). Table 11-2.

thresholds provided in the Traffic Engineering Handbook are based on driver comfort, not safety. However, the circumstances under which the test was conducted are likely safer than the ones under which collisions are occurring, including:

- The test was conducted under dry surface conditions, while most collisions reported in this area occurred under wet surface conditions;
- The test was conducted with a Police Cruiser (2011 Ford Crown Victoria, Police Package), which may have a more stable suspension and may result in readings lower than the average passenger car; and
- The test was not conducted at speeds higher than 110 km/h. As shown in **Table 6**, at least 15% of drivers exceed this speed.

5.2.2 Merging Behaviour

The RHVP is mostly used by commuter traffic, meaning drivers are expected to be familiar with the road. During the field investigation, it was noted that, occasionally, drivers entering the RHVP from an on-ramp tend to do so in a somewhat aggressive fashion, merging onto the mainline as soon as they reach the dashed line at the acceleration lane. This may be due to a potential perception by drivers that some acceleration lanes along the RHVP are too short (especially considering the high operating speeds as shown in **Section 5.2.1**), and may contribute to sideswipe and SMV collisions (as drivers on the mainline swerve to avoid a sideswipe collision with a merging vehicle). Additionally, some on-ramps in the study area present relatively high vegetation that may restrict visibility, to drivers on the mainline, of approaching vehicles from the ramps (**Figure 20**), which has the potential to violate drivers' expectancy related to merging traffic.

Section 5.4.3 discusses the application of MERGE warning signs on the RHVP, used to alert drivers of unfavorable merging conditions.

Figure 20: Vegetation obscuring view of vehicles approaching from on-ramp

5.3 Pavement Surface

The high proportion of wet surface related collisions observed in the study area may indicate a potential issue with pavement skid resistance. According to City staff, Stone Mastic Asphalt (SMA) was utilized in the RHVP. SMA pavements, originally developed in Germany, are designed to provide better resistance to permanent deformation, wearing, cracking due to cold or mechanical stress[15], as well as to provide reduced noise levels due to its negative surface texture reducing vibrations in the tire and connected air paths reducing 'air pumping' noise.[16]

One industry identified characteristic of SMA pavements is that skid resistance is lower by approximately 30 to 40% (under dry conditions) in newer surfaces, reaching normal levels after 6 to 18 months, depending on local conditions and traffic levels.[16] However, as shown in **Figure 21**, the proportion of wet surface collisions seems to be increasing over the years.[17] This suggests that, if low skid resistance is a contributing factor, it is not necessarily related to the normal early life properties of SMA pavements.

[15] Stone Mastic Asphalt Guide, German Asphalt Association. Bonn, Germany (2000). English Translation: 2005.
[16] Greer, G. Stone Mastic Asphalt – A review of its noise reducing and early life skid resistance properties. Proceedings of ACOUSTICS 2006. Christchurch, New Zealand (2006).
[17] The significant drop in wet surface collisions in 2015 is not conclusive since the data analysis only included collision records between January and July. Wet surface collisions are expected to be lower in the winter period since snow, ice and slush conditions are more frequent than wet surface.

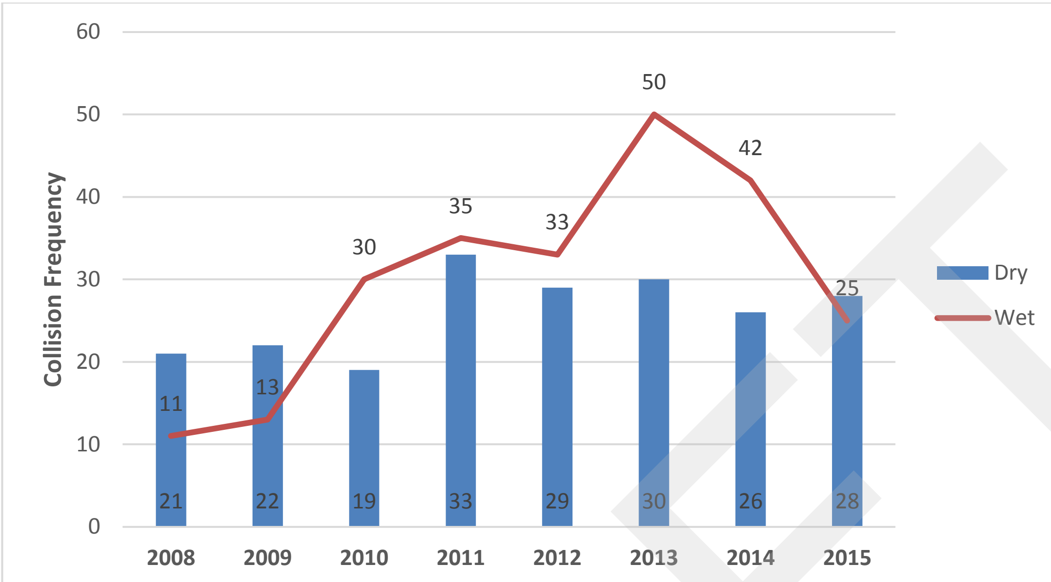

Figure 21: Temporal trend: wet surface collisions

Another potential contributing factor for wet pavement collisions are the high speeds observed on the RHVP. As discussed in **Section 5.2.1**, operating speeds are generally equal to or higher than the design speed of the road. This is reinforced by the high concentration of SMV collisions near horizontal curves.

5.4 Signage

CIMA reviewed signage on approach to and within the study area. Signage was checked for conformity to appropriate OTM Books, for application, size and approximate placement. Our review of the study area revealed the following findings.

5.4.1 'Slippery When Wet' Signs

OTM Book 6 (Warning Signs) states that SLIPPERY WHEN WET signs (Wc-5) should be used:

- At locations where field investigations determine that a pavement has a significantly reduced wet weather skid resistance;
- Where for no other identifiable reason more than one third of all collisions on a given section of highway are occurring on wet pavement;
- At locations which consistently have an abnormally high number of wet weather conflicts or collisions; or
- For other reasons related to wet pavement hazards, under approval from the local Road Authority.

OTM Book 6 also indicates the options to install SLIPPERY WHEN WET tab signs (Wc-5t), to increase motorist familiarity with the symbol, or ADVISORY SPEED tab signs (Wa-7t), to indicate the safe speed for driving along a section of road in conjunction with the Wc-5 sign.

~~Given the existing proportion of wet pavement collisions (50%), oversize SLIPPERY WHEN WET signs (Wc-105) should be used in the study area.~~ Four of these signs are installed along the RHVP, however they are placed immediately in advance of two bridges (one between Mud Street and Greenhill Avenue, and one between Barton Street and the north end of the study area) and combined with BRIDGE ICES tab signs (**Figure 22**). This tab sign is not part of the current version of OTM Book 6, although it will be included in the updated version, expected to be published in 2015. However, this tab will be recommended for use with the new BRIDGE/ROAD ICES sign, which will have the same design as the WC-23 "Bridge Ices" sign from the Manual of Uniform Traffic Control Devices for Canada (MUTCDC). **Figure 23** illustrates the two different signs.

Figure 22: SLIPPERY WHEN WET sign + BRIDGE ICES tab sign

Figure 23: SLIPPERY WHEN WET sign (left) and BRISGE/ROAD ICES sign (right)

Because these two signs are intended to convey different messages, the use of the SLIPPERY WHEN WET sign to represent both "slippery when wet" and "bridge ices" conditions is not recommended, as this may create confusion for drivers (although the tab helps clarify the different conditions). This is especially important on the RHVP, since both conditions are possible and should be signed accordingly.

5.4.2 Object Marker Signs – Various Locations

Several guide rail approach end treatments were found to have missing, damaged, or obscured OBJECT MARKER signs (Wa-33). **Table 7** provides a list of all identified locations, and **Figure 24** illustrates these three conditions.

Table 7: Missing object marker signs at guide rail approach end treatments

Direction	Location	Side	Issue
EB	Upstream of Dartnall interchange	Left	Obscured by vegetation
EB	Upstream of Stone Church/Mud interchange	Left	Obscured by vegetation
NB	Underneath Mud overpass	Left	Obscured by vegetation
NB	Downstream of Mud interchange	Left	Obscured by vegetation
NB	Downstream of Mud interchange	Right	Missing
NB	Underneath Greenhill overpass	Left	Damaged
NB	Downstream of Greenhill interchange	Left	Missing
NB	Underneath railway overpass btwn Greenhill and King	Left	Damaged
SB	Downstream of Barton interchange	Left	Missing
SB	Underneath Mud overpass	Left	Obscured by vegetation
SB	Underneath Pritchard overpass	Left	Damaged / Obscured by vegetation
SB	Downstream of Pritchard overpass	Left	Missing

Figure 24: Examples of Missing, Damaged and Obscured Object Marker Signs

5.4.3 'Merge' Signs

According to OTM Book 6, MERGE signs (Wa-16) alert drivers that vehicles from the other roadway (acceleration lanes from ramps entering a freeway being an example) may soon be entering the lane in which they are travelling, and that they must exert caution and adjust their positioning to accommodate the ingress of vehicles. They are also used to provide warning to traffic entering the roadway that they do not have the right of way and must prepare to merge with through traffic. Some interchanges in the study area have MERGE signs warning about the acceleration lane, while some do not.

OTM Book 6 indicates that a MERGE sign should be used:

- Where the merging traffic conditions are unexpected, out of the road user's view, or otherwise not obvious to the road user; and
- Where the length of an acceleration lane and/or taper is within the range of values specified in [*OTM Book 6 Table 9*].[18]

The RHVP presents some unexpected merging traffic conditions, including some on-ramps and acceleration lanes within horizontal curves and aggressive merging behaviour, as discussed in **Section 5.2.2**. **Table 8** indicates the locations where MERGE signs are present/not present, as well as requirement for the sign based on length of acceleration lane and/or taper.

Table 8: MERGE sign presence and requirements on the RHVP

Direction	Ramp	Merging Condition	Accel.+Taper	Present	Required
EB	Dartnall S-E	On-ramp located within horizontal curve	293+58 m	Yes	No
NB	Mud E-N	On-ramp located within horizontal curve	443+62 m	Yes	No
NB	Greenhill E-N	Weaving area	n/a	No	No
NB	King E/W-N	Weaving area; vehicles on ramp may become obscured by vegetation	n/a	No	No
NB	Queenston E/W-N	On-ramp located within horizontal curve	150+85 m	No	Yes
NB	Barton E/W-N	No concerns	145+65 m	Yes	Yes
SB	Barton E/W-S	Vehicles on ramp partially obscured by vegetation	165+77 m	No	Yes
SB	Queenston E/W-S	Weaving area within horizontal curve	n/a	Yes	No
SB	King E/W-S	Vehicles on ramp significantly obscured by vegetation	173+60 m	Yes	Yes
SB	Greenhill E-N	Acceleration lane becomes through lane	n/a	No	No
SB	Mud E-S	On-ramp located within horizontal curve	130+85 m	Yes	Yes
SB	Dartnall S-W	On-ramp located within horizontal curve, however acceleration lane on tangent	202+72 m	Yes	No

5.5 Pavement Markings and Delineation

Pavement markings within the study area were generally found to be in good condition at the time of the review and no issues were identified during daytime.

During night time, however, the absence of illumination makes it difficult for drivers to see the pavement markings ahead of the vehicle. The lane lines become visible for a longer distance south of Greenhill Avenue, where Permanent Raised Pavement Markers (PRPM) are installed. The PRPMs were recommended by CIMA in the 2013 RHVP Safety Review and seem to have improved visibility of lane lines. However, the edge lines remain difficult to see. **Figure 25** through **Figure 27**

[18] For a posted speed limit of 90 km/h, minimum and maximum lengths of acceleration lane and/or taper for the use of a MERGE sign are, respectively, 80 and 200 m. Where the length of acceleration lane and/or taper is less than the minimum or greater than the maximum lengths specified, MERGE signs must not be used.

illustrate pavement marking visibility under different conditions, including daytime, nighttime without PRPMs, and nighttime with PRPMs.

It was also observed that, where present, guide rails or concrete barriers on the median are not visible due to the lack of delineation along these devices.

Figure 25: Pavement markings during daytime condition

Figure 26: Pavement markings during nighttime condition (without PRPMs)

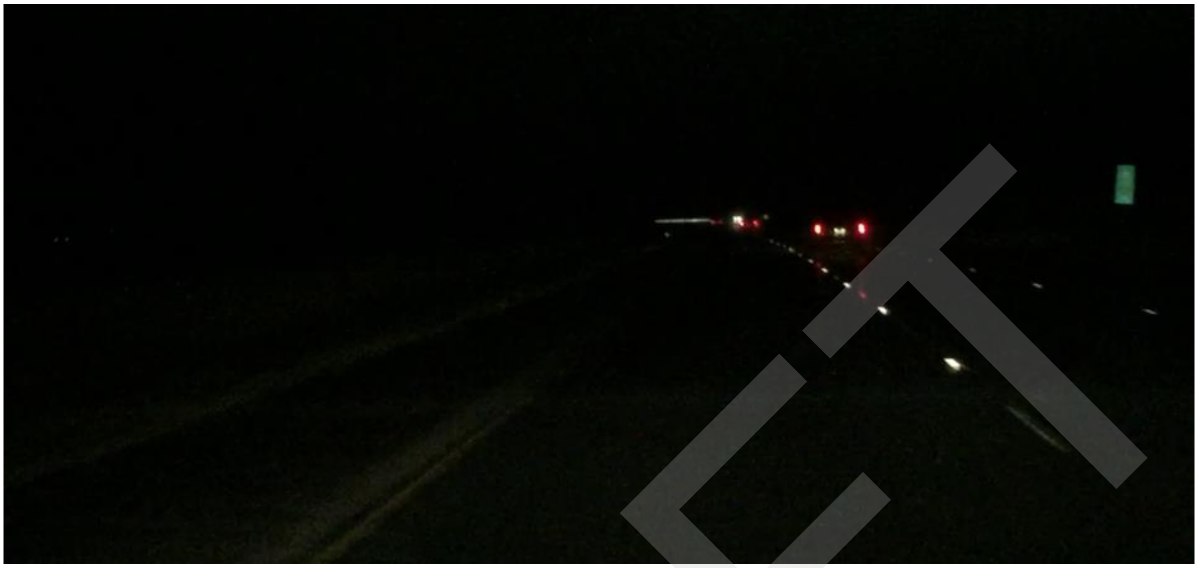

Figure 27: Pavement markings during nighttime condition (with PRPMs)

6. Illumination Review

The primary objective of illumination is to increase safety by providing drivers with improved nighttime visibility of roadway conditions and potential hazards. Although nighttime collision proportions were not found to be significantly higher than provincial or municipal averages, the review of the need for illumination was part of the scope of this study, as requested by the City.

It should be noted that design choices that were made during the design phase were intimately linked to approvals. Reference materials note that, *"The sole reason for making design changes was to reduce environmental impacts."*[19] The Valley section of the Parkway traverses the Niagara Escarpment, a UNESCO World Biosphere Reserve, designated for its unique landform characteristics and the presence of a provincial land use plan to guide development in its area. Because of this unique area, and because of the costs associated with building a roadway on the escarpment, the City identified several design refinements that included restricting illumination to intersections and on/off ramps.[20]

In order to determine whether additional illumination should be considered for installation within the study area, the Transportation Association of Canada (TAC) Roadway Lighting Guide was used, as well as the Ministry of Transportation Ontario (MTO) Policy for Highway Illumination. These policies are based on an analytical approach where several factors have been incorporated. The determination of the need for illumination is performed through the use of warrants which consider road geometry, operations, environmental, and collision factors. For each factor, a rating between 1 and 5 is assigned depending on the conditions encountered. The higher the rating, the greater the hazard and the more critical is the need for illumination. A weight is also attributed to each factor,

B000558

[19] Red Hill Valley Impact and Design Process, City of Hamilton, Page 3
[20] Red Hill Valley Project Public Consultation Report, March 2003, Lura Consulting, Page 136

indicating its relative importance. When factors vary within the portion of roadway for which the warrant is being undertaken, the worst case rating is recommended for the entire segment.

The warrant forms used to determine the need for illumination in the sections of the RHVP between the Lincoln Alexander Parkway and Greenhill Avenue, and between Greenhill Avenue and the Queen Elizabeth Way, are provided in **Appendix B**. This segmentation was chosen for the following reasons: it is approximately the midpoint of the study area, as well as the study limit for the study conducted in 2013; and some notable changes in characteristics occur, including the beginning of a third lane in the southbound direction just south of Greenhill, the presence of a grade between Mud Street and Greenhill Avenue, and generally smaller curve radii in the vicinity of King Street and Queenston Road (north of Greenhill Avenue).

The results of the illumination warrant analysis are summarized in **Table 9**.

Table 9: Illumination Warrant Analysis Results

Section	Warranting Condition	Result	Warranted
Lincoln Alexander Parkway to Greenhill Avenue	**TAC: 60** **MTO: 80**	TAC: 57 MTO: 117	Yes
Greenhill Avenue to Queen Elizabeth Way		TAC: 61 MTO: 117	Yes

Legend: (TAC) [MTO]

According to both TAC and MTO policies, illumination is warranted on the RHVP. However, the MTO warrant provides additional criteria based on the Benefit/Cost ratio of providing illumination. Warranting thresholds are summarized in **Table 10**.

Table 10: MTO Benefit/Cost Warranting Thresholds

Benefit/Cost Ratio	Warrant	
Greater than 2.0	Lighting is warranted	
Greater than 1.0	Lighting is optional	Lighting is warranted
Equal or less than 1.0	Lighting is not warranted	Lighting is optional
Percentage points from the Forms	**50%**	**100%**

The resulting percentage points from the MTO warrant is 146% for both sections north and south of Greenhill Avenue. In this case, illumination will be warranted if the Benefit/Cost ratio of providing it is greater than 1.0, and optional if otherwise. The Benefit/Cost of providing illumination will be discussed in **Section 7.1.3**.

Other factors, however, should be taken into account in the decision to provide illumination along the RHVP mainline, including the context of the surrounding roadway network. For example, while illumination may improve visibility at night, it may also create the situation where drivers' eyes must adjust back to darkness when leaving the illumination portion of the roadway. Currently, the Lincoln Alexander Parkway present only partial interchange illumination, and, considering the approval conditions previously mentioned, installing illumination could create a situation where drivers enter a short illuminated section, followed by a non-illuminated section, and finally back to an illuminated section. Another consideration is roadside safety. Luminaires must be installed in safe locations that recognize their potential hazard to vehicles. The location and placement of luminaires must also take into account the need for maintenance, meaning they must be accessible to workers.

7. Determination of Potential Countermeasures

This section summarizes potential countermeasures for the study area based on our findings of collision analysis and field investigation. The results of the collision analysis identified:

+ A high proportion of wet surface collisions highly concentrated in the vicinity of the King Street and Queenston Road interchanges, where horizontal curves are present; with high speeds suspected to be a major contributing factor; and
+ Median related collisions under the same conditions described above.

Based on these results, the following sections provide potential countermeasures for the study area. Potential countermeasures are provided in two parts. The first part covers potential countermeasures that are generally intended to reduce number of collisions. The second part covers mitigation measures that are expected to reduce severity of collisions.

7.1 Potential Countermeasures for Reduction of Overall Collisions

7.1.1 Speed Management

7.1.1.1 Speed Enforcement and Speed Feedback Signs

The findings from the collision review indicate that excessive speeds are likely a major contributing factor to collisions in the study area. Targeted police enforcement of areas with known high collision frequency can be an effective means to reduce speeds and, by consequence, collisions. There is no CMF for this countermeasure, and costs are expected to be included in regular police activities. However, there is a possibility that this measure is not operationally feasible due to a lack of safe locations to park patrol vehicles near the high-collision areas. This countermeasure should be discussed with Hamilton Police Service.

Changeable speed feedback signs for individual drivers are intended to influence driver behaviour and reduce excessive speeds. The signs consist of boards connected to speed measuring devices that display text such as “Your speed is XX km/h” or “You are driving too fast”. This countermeasure should be implemented in conjunction with speed enforcement, for two main reasons; first, it would provide individual feedback to most drivers 24 hours per day, 7 days per week, which police enforcement cannot achieve; and second, compliance with speed limit as a result of speed feedback signs alone may be reduced over time if drivers do not perceive that speeds are being enforced (especially considering the commuter nature of the RHVP).

The CMF for this countermeasure is 0.54 with an adjusted standard error of 0.17[21] (meaning it can range from 0.2 to 0.88 with a 95% confidence interval), and the construction cost is $12,500 per site for a service life of 10 years.

7.1.1.2 Oversized Speed Limit Signs

Oversized speed limit signs (90x120 cm) provide improved visibility and impact on drivers. Larger speed limit signs are reported to be more effective when used with increased police enforcement.[22]

There is no CMF available for this countermeasure, and installation costs is $500 per sign.

7.1.2 Pavement Friction

~~7.1.2.1 Perform Friction Testing~~

~~Pavement friction plays a vital role in keeping vehicles on the road by enabling the drivers to control/manoeuver the vehicle in a safe manner (in both the longitudinal and lateral directions). Several methods and devices are available for measuring pavement frictional characteristics. Pavement surface texture is influenced by many factors, including aggregate type and size, mixture proportions, and texture orientation and details. Texture is defined by two levels: microtexture and macrotexture. Currently, there are no direct means for measuring microtexture in the field. However because microtexture is related to low slip speed friction, it can be estimated using a surrogate device. Macrotexture is characterized by the mean texture depth and the mean profile depth; several types of equipment are available for measuring these indices.~~

~~Because of the high proportion of wet surface condition and SMV collisions, the City could consider undertaking pavement friction testing on the asphalt to get a baseline friction coefficient for which to compare to design specifications. It is important to perform the tests under normal conditions as well as under typical wet pavement conditions encountered on the RHVP in order to simulate, as best as possible, the conditions under which collisions occur. For example, if more water accumulates on the pavement under typical conditions than under normal testing conditions, the tests may result satisfactory, when in reality friction may be reduced. Tests should also be performed near locations with the highest frequencies of wet surface collisions, especially curves.~~

~~The estimated costs to undertake these are approximately $40,000. Based on the results, the City may be in a better position to determine if further action is required.~~

7.1.3 Illumination

The primary objective of illumination is to increase safety by providing drivers with improved nighttime visibility of roadway conditions and potential hazards. As discussed in **Section 6**, continuous illumination along the RHVP is either warranted or optional, although restrictions from the

B000558

[21] http://www.cmfclearinghouse.org/detail.cfm?facid=78
[22] Handbook of Speed Management Techniques. Texas Transportation Institute. September, 1998.

approvals phase may result in an undesired condition where illuminated and non-illuminated sections alternate, forcing drivers' eyes to adjust between light and darkness.

The CMF for this countermeasure is 0.97[23], and expected construction costs are $100,000 / centreline km over a 20-year service life.

7.1.4 Signs and Delineation

7.1.4.1 'Slippery When Wet' and 'Bridge Ices' Signs

The purpose for the 'Slippery When Wet' sign is to advise drivers that the surface of the roadway has a significantly reduced wet weather skid resistance. Competent drivers are aware that the friction of the road surface is reduced in wet weather; therefore this sign is reserved for use where the skid resistance of the road is reduced to an unexpectedly low level. OTM Book 6 guidelines indicate that these signs should be installed at locations where field investigations determine that the pavement has a significantly reduced wet weather skid resistance, or where for no identifiable reason more than one third of all collisions on a given section of road are occurring on wet pavement (among other criteria). As found during the collision review, more than half of all collisions are occurring on wet pavement, and approximately 70 to 80% of all collisions in the vicinity of the King Street and Queenston Road interchanges involve wet surface conditions. The City should consider installing Wc-105 SLIPPERY WHEN WET signs, combined with Wc-5t SLIPPERY WHEN WET tab sign along the study area, in intervals of 1 km or less (in accordance with OTM Book 6 guidelines for urban areas). Additionally, the City should replace the existing Wc-105 signs located at the two bridges (refer to **Section 5.4.1**) with WC-23 BRIDGE/ROAD ICES signs.

There is no specific CMF for the installation of 'Slippery When Wet' signs. Installation cost is $500 per sign resulting in a total cost of $8,000. If the City would like to place additional emphasis on the area near the King Street and Queenston Road interchanges, consideration may be given to installing rain activated flashing beacons on the 'Slippery When Wet' signs within this section. This would raise installation costs to approximately $128,000 (considering 4 solar powered flashing beacons), however it is expected to draw driver's attention and increase their awareness about the wet surface conditions in the critical area.

Another alternative is to display messages related to road and environment conditions using Dynamic Message Signs (DMS) that can be implemented as part of the City's planned Advanced Traffic Management System (ATMS) project, consisting of an Intelligent Transportation System (ITS) Freeway Traffic Management System (FTMS) inclusive of the entire Linc and RHVP freeway system from Hwy 403 to the QEW. **Figure 28** provides examples of DMSs used on Ontario Highways under MTO's jurisdiction.[24]

---

[23] MTO Safety Analyst tool

[24] http://www.mto.gov.on.ca/english/traveller/trip/compass-ftms.shtml#vms

Figure 28: Examples of Dynamic Message Signs

7.1.4.2 'Merge' Signs and Vegetation at On-Ramps/Merging Areas

As highlighted in **Section 5.4.3**, two RHVP on-ramps require the use of MERGE warning signs (Wa-16), however they are not present at these locations. The City should consider installing these signs at the Queenston Road E/W-N and Barton Street E/W-S on-ramps to increase driver awareness of the possibility of merging vehicles and potentially reduce evasive manoeuvres that can lead to SMV and sideswipe collisions.

Some locations were identified to have MERGE signs installed, even though not required by OTM Book 6. However, the City may opt not to remove these signs, given the overall geometry of the RHVP and its merging areas, as well as the presence of vegetation between some on-ramps and the adjacent mainline, merging traffic conditions may not be obvious to some drivers.

Finally, as discussed in Section **5.2.2**, some on-ramps present vegetation that may restrict the ability for drivers on the mainline to see vehicles approaching from the ramp. The City should consider trimming the vegetation in these areas low enough so approaching vehicles are visible.

The estimated cost to install the two 'Merge' signs is $1,000; vegetation trimming is expected to be undertaken as part of regular maintenance activities, therefore no additional cost is associated.

7.1.4.3 Permanent Recessed Pavement Markers (PRPMs)

PRPMs are delineation devices that are often used to improve preview distances and guidance for drivers in inclement weather and low-light conditions. Given the wet surface and rainy weather trend in collisions along the RHVP, combined with the curvilinear geometry of the roadway, PRPMs have the potential to positively affect the collision experience on the roadway as well as increase driver security. This countermeasure had been recommended in the previous study, conducted in 2013, and was implemented in the southern section of the study area. Installing PRPMs in the northern section would also provide consistency throughout the entire length of the RHVP and improve night-time visibility for drivers, since no illumination is present.

The CMF for this countermeasure is 0.67 for nighttime collisions[24], and the estimated installation cost is $20,000 per kilometre.[25]

7.2 Potential Countermeasures for Mitigating Median Related Collisions

7.2.1 Median Barrier

7.2.1.1 Evaluation of the Benefits and Drawbacks of Providing a Median Barrier

Median barriers are very effective in preventing median crossover collisions, which are generally fatal or high severity collisions. Median barriers do not eliminate the collisions. However, they are very effective in mitigating outcomes of collisions by reducing severity of collisions. Median barriers generally result in an increase in overall collisions, which are generally PDO. Therefore, these barriers should be evaluated for the potential benefit as compared to drawbacks.

The collision review revealed that median crossover collisions correspond to 13% of all median related collisions in the study area, including 1 fatal, 9 injury, and 7 PDO collisions within 7.5 years (2008 to July-2015), amounting to a societal cost of approximately $ 2.17 M based on current MTO's societal costs.[26]

The benefits and drawbacks of providing a median barrier along the entire section of the RHVP within the study area were evaluated. The prevailing guidance in Ontario with respect to roadside barriers is the MTO Roadside Safety Manual (RSM). The RSM provides a median barrier warrant guide for divided highways, shown in **Figure 29**. The assessment is based on median width, (measured between edges of driving lanes) and predicted 10 years traffic volume (AADT).[27]

B000558

[24] NCHRP Report 518 – Safety Evaluation of Permanent Raised Pavement Markers. Transportation Research Board. 2004.
[25] MTO SafetyAnalyst tool.
[26] Societal cost of a fatal collision is $1,582,000, an injury collision is $59,000 and a PDO collision is $8,000
[27] MTO's Roadside Safety Manual, Figure 2.10.1

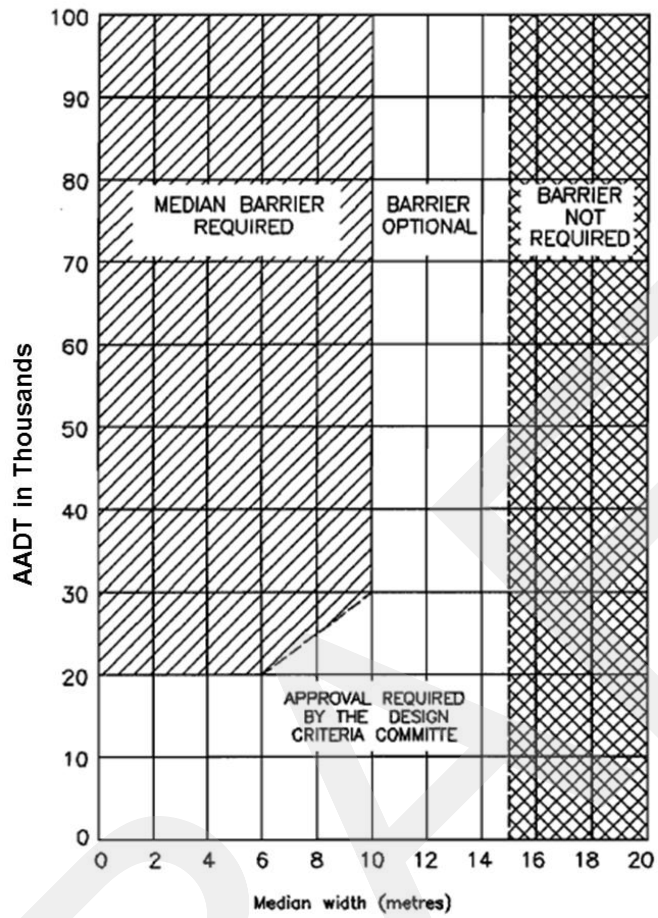

Figure 29: Median Barrier Warrant Guide for Divided Highways

According to the figure, median barriers are only warranted for highways with AADTs of 20,000 and higher and median widths less than 10.0 metres. For median widths between 10.0 metres and 15.0 metres, median barriers are optional and for median widths greater than 15.0 metres, median barriers are deemed "not required".

The guidance indicates that, within the optional range, the barriers should be only installed in special circumstances such as for highways with identified median crossover collision problem, where an identified geometric deficiency cannot be readily corrected, or for continuity with adjacent sections.[28]

The TAC Geometric Design Guide for Canadian Roadways (TAC) also provides a similar median barrier warrant guide. It also suggests conducting benefit-cost analysis for implementing median barriers.

CIMA conducted warrants for implementing median barriers within the study area by utilizing the MTO's median warrant guide demonstrated in **Figure 29** and utilizing the following data:

- AADT – 59,123 based on year 2011;

[28] Roadside Safety Manual, Section 2.10.1

- Median Width – 15.0 m to 22.7 m (measured using aerial photography); and
- The history of median cross-over collisions.

Based on the AADT and the median width, the RHVP is in the area "not required". However, based on a history of median crossover collisions, the study area should be considered for providing a median barrier. TAC suggests conducting a benefit-cost analysis to the median barrier problem.[29]

CIMA conducted a detailed analysis to determine various feasible types of median barrier systems for the study area and also performed a cost-benefit analysis to select the best alternative for the study area.

The selection of best type of median barrier system within the study area was undertaken in the following steps:

- Determination of feasible barrier types for the study area;
- Development of alternatives; and
- Selection of the best alternative based on cost-effective analysis.

7.2.1.2 Determination of Feasibility of Barrier Types for the Study Area

CIMA conducted an analysis of various types of prevailing median barrier technologies in Canada based on MTO's Roadside Safety Manual and AASHTO Roadside Design Guide to determine feasible barrier types for the RHVP. The results of the analysis along with the characteristics of each barrier type that makes it suitable or unsuitable for the RHVP are included in **Table 11**.

[29] TAC Geometric Design Guide for Canadian Roadways, Section 3.1.6.3

Table 11: Analysis for the Feasibility of Various Barrier Systems for the Linc

Type of Median Barrier	Relevant Characteristics	Feasibility for the RHVP
6 Cable (Wood Post)	• Not approved for use on high speed facilities	Not feasible for the RHVP due to high speed
6 Cable (Steel Post)	• Recommended for AADT < 20,000 • Ideal for median width greater than 9 m	Not feasible for the RHVP due to high AADT
Median Box Beam Barrier	• Restricted to facilities with posted speeds less than 80 km/h • Recommended for AADT < 30,000	Not feasible for the RHVP due to high AADT and speed
Median Steel Beam Guide Rail with Channel	• Recommended for AADT > 20,000 • Can be installed in medians greater than 9.0 m	Feasible for the RHVP
Standard Concrete Barrier and Ontario "Tall Wall"	• No curbs, gutters or ditches allowed between the barrier and the driving lanes • Area directly in front of barrier must be paved • Should not be located more than 4.0 metres from the edge of the driving lane (maximum width of median to be 9.0 metres)	Not feasible for the RHVP due to a median width larger than 9.0 metres
High-Tension Cable Barrier*	• 2011 AADT range – 25,820 to 46, 200 • Posted Speed – 110 km/h	Feasible for the RHVP

*Based on Successful Alberta experience in addressing cross median collisions by using the High-Tension Cable Barrier system on Highway 2 between Airdrie and Red Deer

As can be seen in **Table 11**, Median Steel Beam Guide Rail, and High-Tension Cable Barriers are feasible options for providing a median barrier for the RHVP. It should be noted that all kinds of barrier systems can be transitioned from one type to another by using standard methods. The guidance is available in MTO's Roadside Manual and AASHTO Roadside Design Guide. The appropriate types of transitions should be determined at the detailed design stage.

Based on the feasible barrier options detailed above, various alternatives available for providing a median barrier on the RHVP are as follows:

Alternative 1: Standard Steel Beam Guide Rail with Channel System on Both Sides of the Median

Provide Standard Steel Beam Guide Rail with Channel systems on both sides of the median. It should be noted that for medians, steel beam guide rails are provided with channel elements to increase the stiffness of the installation[30]. An example Standard Steel Beam Guide Rail with Channel System installed on a median on Highway 403 is demonstrated in Figure 30.

B000558

[30] Section 4.3.5, MTO's Roadside Safety Manual

Figure 30: Example of standard steel beam guide rail with channel

Alternative 2: High Tension Cable Barrier on Both Sides of the Median

Provide High-Tension Cable Barrier on both sides of the median. An example of High Tension Cable Barrier installed on both sides of a median location on Highway 2 in Alberta is demonstrated in Figure 31.

Figure 31: Example of high tension cable barrier

Estimated costs for these alternatives are provided in **Appendix C**.

7.2.2 Guide Rail Leaving End Treatments

As highlighted in **Section 5.1**, "fishtail" leaving end treatments at some guide rails protecting bridge structures are located within the clear zone of the opposite direction of traffic, and the approaching end treatment in the opposite direction does not provide the required length of need, exposing vehicle occupants to a spearing hazard. The City should consider replacing the existing extruder and "fishtail" end treatments with CAT-350 attenuators at bridge structures, which is the recommended end treatment according to the RSM. The City may also choose similar options such as the SMART crash cushion (OPSD 923.483). The estimated cost is $7,000 per unit.

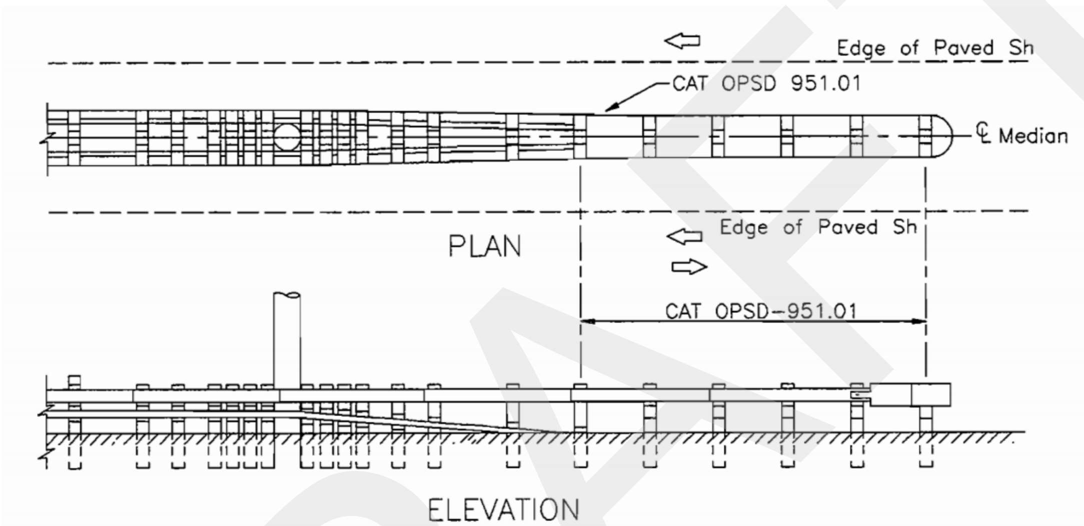

Figure 32: Steel beam protection of structures located on the median[31]

Additionally, as identified in **Section 5.4.2**, **Table 7**, several guide rail approach end treatments were found to have missing, damaged, or obscured OBJECT MARKER signs (Wa-33). These signs should be installed, replaced, or made visible by trimming the vegetation, respectively. The estimated cost is approximately $500 per sign.

8. Benefit-Cost Analysis

In order to assist in determining the effectiveness of a countermeasure, collision modification factors (CMFs) were utilized where available. CMFs were examined from a number of sources including the HSM, the FHWA CMF Clearinghouse[32]. The CMF of a countermeasure can assist in determining safety benefits of the countermeasure over the analysis period by calculating the expected number of collisions reduced.

The Benefit-Cost (B/C) ratio is the ratio of the present value of the safety benefit of a given countermeasure calculated for its service life to the present value of the cost of the countermeasure. A B/C ratio of greater than 1.0 represents an economically efficient countermeasure. In this criterion,

31 MTO's Roadside Safety Manual, Figure 2.8.6. OPSD number displayed in the Figure is outdated. Current applicable version is OPSD 922.330.

32 http://www.cmfclearinghouse.org/

the monetary value of the collisions reduced as a result of implementation of a countermeasure is considered as the benefit of the countermeasure. For the purposes of calculating the societal costs of collisions, MTO costs were utilized. The benefit-cost analysis is detailed in the following sections.

8.1 Median Barrier

The benefit-cost analysis of median barriers was conducted in two steps. In the first step the analysis was conducted to compare different alternatives to select the possible alternative. In the second step, the analysis was conducted to obtain the overall B/C of the preferred alternative.

In order to select the best possible alternative of installing a median barrier from the available alternatives detailed in Section 7.2.1.2, an incremental benefit-cost analysis was conducted. Barrier systems have an assumed service life of 30 years. Median barriers generally eliminate all cross-over outcomes of collisions, including cross-over fatal collisions. However, median barriers tend to increase overall number of collisions, primarily PDO collisions.

The cost-effective analysis to compare both alternatives was conducted using a benefit-cost ratio (B/C) and on incremental basis, to realize the greatest benefit at the least cost. In this methodology, the alternatives are first ordered from lowest to highest cost. The incremental benefits of the second over the first are calculated by dividing the incremental costs of the second over the first. If the ratio is greater than 1, then alternative 2 is preferred. If the ratio is less than 1 then alternative 1 is superior alternative. The better of these is then compared with the next most costly alternative and so on. The following steps were performed for calculating B/C:

+ Estimate life cycle cost of each alternative including capital cost and operating and maintenance cost. The capital cost includes the purchase price, installation cost, and the activities that would not take place otherwise, such as paving, modifications to drainage, etc.)Operating and maintenance cost includes recurring cost of operating and maintaining the system during its useful life;
+ Estimate the societal cost[33] of collision for each year that will be prevented by installing the barrier system as estimated over the service life of the barrier system. This was considered as benefit;
+ Estimate the societal cost of less severe collisions for each year involving the barrier system, after the barrier system has been put into place. This was considered as negative benefit; and
+ Calculate B/C by dividing the present value of the societal benefits by the present value of the life cycle cost.

The methodology with detailed assumptions, calculations and results of the analysis are provided in Appendix A. The results of the analysis are presented in Table 12 and Table 13.

The life cycle cost of each alternative, as shown in Table 12, includes capital cost and operating and maintenance cost. Further details are available in Appendix A. It should be noted that alternatives in Table 12 are ordered from lowest to highest life-cycle cost for conducting incremental benefit cost

B000558

[33] Societal costs of collisions used were based on MTO's current costs of collisions ($ 1,582,000 for a fatal collision, $ 59,000 for an injury collision, and $ 8,000 for a PDO collision)

analysis. The Monetary Benefit of implementing each alternative, as shown in Table 13, includes the estimate of societal cost of collisions that will be reduced by installing the barrier system as estimated over the service life of the barrier system.

Table 12: Costs and benefits of median barrier alternatives

Alternative	Life Cycle Cost	Monetary Benefit
Do-Nothing	$ 0	$ 0
Alternative 2: High Tension Cable Barrier	$2,528,400	$ 13,290,077
Alternative 1: Steel Beam Guide Rail	$3,088,500	$ 11,259,159

Table 13: Results of cost-effective analysis

Comparison	Incremental Cost	Incremental Benefit	Incremental B/C	Preferred Option
Alternative 1 vs. Do-Nothing	$2,528,400	$ 13,290,077	5.26	Alternative 1
Alternative 2 vs. Alternative 1	$560,100	-$2,030,917	-3.63	Alternative 1

As demonstrated in **Table 13**, the only positive increase of more than 1 in incremental B/C is for Alternative 2. Therefore, Alternative 2 consisting of High-Tension Cable Barrier on both sides of the median is the preferred alternative.

The overall B/C of Alternative 2 consisting of High-Tension Cable Barrier on both sides of the median is included in **Table 14**.

Table 14: B/C for High-Tension Cable Barrier

Countermeasure	Target Collisions	Severity	Expected Collisions Before	Expected Crash Reduction	Benefit ($)	Cost ($)	Overall B/C
Install Median Barrier System[34]	Median Related Collisions	Fatal	6.22	4.35	13,290,077	2,528,400	5.26
		Injury	161.69	126.24			
		PDO	205.22	-130.59			

As can be seen in **Table 14**, Alternative 2 is expected to provide a B/C of 5.26 and is a cost-effective option.

8.2 Other Countermeasures

The results of the B/C Analysis for other countermeasures are provided in **Table 15**. The detailed calculations are included in Appendix C.

[34] Reduction in collisions was estimated based on the proportions of severity of collisions involving High Tension Cable Barriers as identified in the study the results of the study "High Tension Cable Barrier Performance Evaluation Study for Highway 2 in Alberta"

Table 15: B/C for Other Countermeasures

Countermeasure	Target Collisions (Severity)	CMF	Expected Collisions Before	Expected Crash Reduction[35]	Benefit ($)	Cost (Life Cycle)	B/C
Speed Enforcement & Feedback Signs	All (All)	0.88	321.73	38.61	1,178 M	$100,000 (10 years)	11.78
Illumination	Nighttime (All)	0.97	1,728.47	51.85	2,247 M	$810,000 (20 years)	2.77
Permanent Recessed Pavement Markers	Nighttime (All)	0.67	68.65	22.66	1,236 M	$98,800 (5 years)	12.51
Oversized Speed Limit Signs	CMF Not Available						
Slippery When Wet Signs Only	CMF Not Available						
Slippery When Wet Signs with Rain Activated Flashing Beacons	CMF Not Available						
'Merge' Signs	CMF Not Available						
Trim Vegetation Near On-Ramps	CMF Not Available						
Guide Rail End Treatments	CMF Not Available						

9. Recommendations

CIMA was retained by the City of Hamilton to evaluate safety and operational performance of the RHVP and to determine any mitigation measures to improve parkway's performance and reduce number and severity of collisions with special emphasis on median related collisions. CIMA conducted a thorough investigation of the RHVP including investigation of road-related factors, roadside safety assessment, and evaluated the necessity of providing a median barrier and other countermeasures to enhance the safety of road users. After completing the above review, a list of potential countermeasures was developed and a benefit-cost analysis was conducted to determine the cost effectiveness of countermeasures. The following sections provide recommended improvements and a summary table with construction cost and recommended timing for installation.

9.1 Recommended Improvements

The following improvements are recommended for the RHVP.

B000558

[35] Numbers shown are up to two decimals only. Dollar amounts shown may look slightly off due to high societal costs.

9.1.1 Install High – Tension Cable Median Barrier System

Two median barrier system alternatives for the RHVP were evaluated. The preferred alternative for the RHVP is High-Tension Cable Median Barrier System with present value cost (including the cost of maintenance for 30 years) of $ 2.53 M. The alternative is expected to provide a B/C of 5.26. However, this B/C does not consider the reduction of median related collisions achieved by other countermeasures. It is possible that a reduction of median related collisions will be achieved by addressing speed and wet surface related collisions, potentially reducing the benefits of installing a median barrier system.

The City should consider implementing the countermeasures that target speed and wet surface related collisions in the shorter term, and the high-tension cable barrier in the longer term, considering the reduction in median related collisions that may be achieved by the short-term countermeasures.

9.1.2 Install Speed Feedback Signs with Enforcement

The installation of two sets of two speed feedback signs is recommended for the RHVP (two sets in each direction, one sign on each side of the road). The recommended locations for the installation of these signs are:

- Northbound direction:
  - Upstream of the curve between Greenhill Avenue and King Street; and
  - Between the King Street on-ramp and the Queenston Road off-ramp.
- Southbound direction:
  - Upstream of the curve between Barton Street and Queenston Road; and
  - Between the Queenston Road on-ramp and the King Street off-ramp.

The purpose of these signs is to influence drivers to reduce speeds and, consequently, collision frequency and severity, especially in the vicinity of the King Street and Queenston Road interchanges. The estimated cost of this countermeasure is $100,000, providing a B/C of 11.78.

It should be noted, however, that the presence of acceleration/deceleration lanes where the signs would be located may reduce their conspicuity for drivers on the mainline right lane. As an alternative, the City may consider to install overhead speed feedback signs.

For increased effectiveness, it is important that the installation of the speed feedback signs be accompanied by regular speed enforcement by Hamilton Police.

The City may also consider investigating the technical feasibility of integrating speed feedback messages (either individual or collective) with the planned ATMS project (refer to **Section 7.1.4.1**).

9.1.3 Install Oversized Speed Limit Signs

The purpose of oversized speed limit signs (90x120 cm) is to influence drivers to reduce speeds and, consequently, collision frequency and severity. A benefit-cost analysis for this countermeasure was not conducted as a CMF for this countermeasure is not available. The estimated cost of this countermeasure is $7,000 (14 signs at $500 per sign).

9.1.4 Conduct Pavement Friction Testing

In order to determine whether low pavement friction may be contributing to collisions (especially wet surface), the City should consider conducting pavement friction tests under normal conditions as well as under typical wet pavement conditions encountered on the RHVP. Special focus should be given to the curves near the King Street and Queenston Road interchanges (**Figure 33**). The estimated cost to conduct friction testing is $40,000. Depending on the test results, the City will be able to determine if further action is required.

I don't have any frame of reference to pass or fail this against.

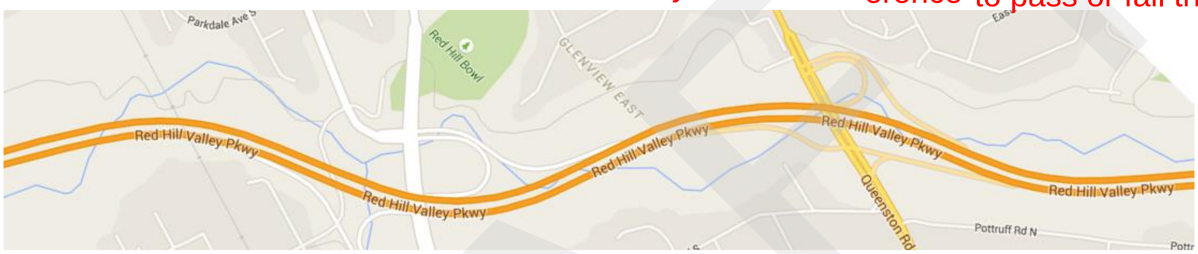

Figure 33: Critical RHVP section for friction testing

9.1.5 Install Continuous Illumination

The collision review found that the proportion of non-daylight collisions is higher than provincial and municipal averages, and a review of MTO's policy and warrant indicated that continuous illumination is warranted in the study area. The estimated installation cost for providing continuous illumination is $810,000, providing a B/C of 2.77. However, other factors should be taken into account in the decision to provide illumination along the RHVP mainline, including the context of the surrounding roadway network. For example, while illumination may improve visibility at night, it may also create the situation where drivers' eyes must adjust back to darkness when leaving the illumination portion of the roadway. Currently, the Lincoln Alexander Parkway present only partial interchange illumination, and, considering approval conditions established in the Environmental Assessment, installing illumination could create a situation where, for example, northbound drivers enter a short illuminated section at the south end of the RHVP, followed by a non-illuminated section, and finally back to an illuminated section. For these reasons, illumination is does not appear to be the most adequate solution for the RHVP. All illumination must be assessed in relation to the environmental approval constraints which exist, as well as cost of installation and maintenance implications. Therefore, the decision to provide roadway lighting should be looked at using sound criteria, but illumination decisions must also be done in the context of the surrounding roadway network.

9.1.6 Install Permanent Recessed Pavement Markers (PRPMs)

As an alternative to illumination, the City may consider installing PRPMs in the northern section of the RHVP (i.e. north of Greenhill Avenue). The installation of PRPMs is expected to reduce collisions under low-visibility conditions (nighttime and inclement weather), as well as provide consistency throughout the entire length of the RHVP (PRPMs are already present in the southern section, as a result of a previous study conducted in 2013). The estimated cost of installing PRPMs in the north section is $247,000, providing a B/C of 5.

9.1.7 Install Special Oversize Curve Warning Signs

In order to increase drivers' awareness of the curves near the King Street and Queenston Road interchanges, where a high concentration of collisions was found, the City should consider installing special oversize curve warning signs (900x900 mm).[36] A benefit-cost analysis for this countermeasure was not conducted as a CMF for this countermeasure is not available. The estimated cost of this countermeasure is $8,000 (16 signs at $500 per sign).

9.1.8 Install 'Slippery When Wet' and 'Bridge Ices' Signs

The City should consider installing Wc-105 SLIPPERY WHEN WET signs, combined with Wc-5t SLIPPERY WHEN WET tab sign along the study area, in intervals of 1 km or less, in accordance with OTM Book 6 guidelines and to warn drivers of the increased risk of collisions under wet surface conditions. To further highlight the hazard, the signs in the vicinity of the King Street and Queenston Road interchanges may be supplemented with flashing beacons activated by a rain sensor. A benefit-cost analysis for this countermeasure was not conducted as a CMF for this countermeasure is not available. The estimated cost of this countermeasure is $8,000 if only signs are installed (16 signs at $500 per sign), or $128,000 if rain activated flashing beacons are added to 4 signs in the critical section. An alternative, however, is to display 'slippery when wet' messages via the City's planned ATMS project (refer to **Section 7.1.4.1**), which would absorb at least part of this costs.

Additionally, the existing 'Slippery When Wet' signs installed at the two bridges (between Mud Street and Greenhill Avenue, and between Barton Street and the north end of the study area) should be replaced with WC-23 BRIDGE/ROAD ICES signs (MUTCD for Canada), at an estimated cost of $2,000 (4 signs at $500 per sign). A benefit-cost analysis for this countermeasure was not conducted as a CMF for this countermeasure is not available.

9.1.9 Install Merge' Signs and Trim Vegetation at On-Ramps/Merging Areas

As discussed in **Section 7.1.4.2**, Wa-16 MERGE warning signs are recommended for installation at the Queenston Road E/W-N and Barton Street E/W-S on-ramps to increase driver awareness of the possibility of merging vehicles and potentially reduce evasive manoeuvres that can lead to SMV and sideswipe collisions. A benefit-cost analysis for this countermeasure was not conducted as a CMF for this countermeasure is not available. The estimated cost of this countermeasure is $1,000 (2 signs at $500 per sign).

Additionally, vegetation at the areas between the mainline and some on-ramps should be regularly trimmed and maintained low enough so vehicles approaching from the ramp are visible to drivers on

B000558

[36] This sign size is not available in the current version of OTM Book 6, however it will be included in the updated version.

the mainline. This countermeasure is expected to be undertaken as part of regular maintenance activities, therefore no additional cost is associated to it.

9.1.10 Upgrade Guide Rail End Treatments and Improve Object Marker Signs

The City should consider replacing the existing extruder and “fishtail” end treatments of guide rails protecting the bridge structures at Greenhill Avenue, Mount Albion Road, King Street, Queenston Road, and the railway overpass south of King Street, with CAT-350 attenuators, SMART crash cushions or other similar alternatives that comply with the MTO Roadside Safety Manual recommended configuration.

This countermeasure would not apply if and/or where a continuous median barrier is installed. There is no CMF available for upgrading these end treatments, and the estimated cost is $70,000 (2 units x 5 locations at $7,000 per unit).

Additionally, the OBJECT MARKER signs (Wa-33) identified in **Section 5.4.2**, **Table 7** as being missing or damaged should be installed or replaced, respectively. The estimated cost is $3,500 (7 signs at $500 per sign). The signs identified as being obscured by vegetation should be made visible by trimming the vegetation. The cost is expected to be included in the City’s regular maintenance activities.

9.2 Summary Table

Table 16 summarizes a prioritized list of countermeasures. The priority has been assigned based on ease of implementation, importance, ability to reduce collisions, and ability to reduce severity. The recommended timing for implementation of each of the countermeasure is also provided in the table.

Table 16: Countermeasures Summary Table

Countermeasure	Construction Cost ($)	Timeline	Comment
Conduct Speed Enforcement	-	Ongoing	
Trim Vegetation at On-Ramps	-	Ongoing	
Install Oversized Speed Limit Signs	$7,000	Short Term	
Install ‘Slippery When Wet Signs’	$8,000	Short Term	
Install Special Oversize Curve Warning Signs	$8,000	Short term	16 signs in the vicinity of King and Queenston interchanges
Supplement ‘Slippery When Wet Signs’ with Rain Activated Flashing Beacons*	$120,000	Short Term	4 signs in the vicinity of King and Queenston interchanges
Install ‘Merge’ signs	$1,000	Short Term	
Install ‘Bridge Ices’ signs	$2,000	Short Term	
Upgrade median guide rail end treatments	$70,000	Short Term	
Install, replace or trim vegetation obscuring Wa-33 signs at guide rail end treatments	$3,500	Short Term	
Conduct Pavement Friction Testing	$40,000	Short Term	
Install Speed Feedback Signs*	$120,000	Short Term	In conjunction with regular speed enforcement; costs may be higher depending on design
Install PRPMs from Greenhill to QEW	$247,000	Short Term	
Short Term Total	**$430,300**		
Install Continuous Illumination	$810,000	Long Term	Requires sound evaluation in the context of the surrounding network and environment. An Environmental Assessment will be required.
Install High-Tension Cable Guide Rail	$2,528,400	Long Term	Consider effect on median related collisions of countermeasures to reduce speed and wet surface collisions
Grand Total	**$4,395,200**		

* Implementation costs may be different if integrated with the City’s planned ATMS project, for which the estimated cost is $600,000.

Appendix A: Over-Representation Analysis

Theoretical Basis

The objective of the over-representation analysis is to help identify which collision factors are over-represented. In other words, this analysis is performed to identify the relationship between collisions and the characteristics of a given location. This process assists in identifying contributing factors at each location. If suitable countermeasures are selected to address the contributing factors, the chance of success significantly increases.

The over-representation analysis is based on the Chi-Square statistical test. To determine if a collision contributing factor is over-represented in collisions at a specific location, both the overall characteristics and the individual category must be found to have a computed value of Chi-Square exceeding the critical theoretical value.

Overall Characteristic

Overall characteristics include the following:

- Collision Classifications;
- Collision Impact Type;
- Day of Week; and
- Season.

The computed value of Chi-Square is calculated using Equation 1, as shown below:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \qquad \text{Eq. 1}$$

Where:

$\mathrm{O_i}$ is the observed collision frequency;

n is the total number of categories for the characteristic variable; and

E_i is the expected collision frequency, found by multiplying the total observed collisions at the location with the overall percentage (proportional distribution) of collisions in the category (i.e. A site with 10 observed collisions within a group with 70% as the overall percentage of PDO collisions would have an expected collision frequency of 7).

As shown in Equation 7, the computed Chi-Square value is a measure of discrepancy between the observed and expected collision frequencies. A Chi-Square value of 0 represents no discrepancies between the observed and expected collision frequencies, while a larger value of Chi-Square represents a larger discrepancy.

The computed value of Chi-Square is then compared to the lower and upper theoretical Chi-Square values for the appropriate degrees of freedom and a specified significance level, according to Equation 2.

$$\chi^2_{\mathrm{lower}} \leq \chi^2 \leq \chi^2_{\mathrm{upper}} \qquad \text{Eq. 2}$$

If Equation 2 is false, in other words if the value of the computed Chi-Square is less than the lower theoretical value, or greater than the upper theoretical value, the overall characteristic is found to be over-represented, and the analysis is taken to the individual category level.

The specified significance level for this project was chosen to be 0.05, equivalent to a 95% level of significance. The number of degrees of freedom is calculated using Equation 3 below:

$$df = n - 1 \qquad \text{Eq. 3}$$

The following table shows the degrees of freedom for each characteristic, along with the corresponding critical theoretical values of Chi-Square for a level of significance of 0.05.

Collision Characteristics	Number of Variable Categories (n)	Degrees of Freedom (n-1)	Lower Theoretical χ^2 Value	Upper Theoretical χ^2 Value
Collision Classifications	3	2	0.051	7.38
Light Condition	2	1	0.001	5.02
Environment Condition	7	6	1.24	14.45
Surface Condition	6	5	0.83	12.83
Collision Impact Types	7	6	1.24	14.45
Initial Source of Impact	7	6	1.24	14.45
Driver Action	5	4	0.48	11.14

Individual Category

The individual categories for each overall characteristic considered to conduct the over-representation analysis are presented in the table below.

Overall Characteristics	Individual Categories
Collision Classification	Fatal, Injury, PDO
Light Condition	Daylight, Non-Daylight
Collision Impact Type	Angle, Head On, Rear End, Sideswipe, Turning Movement, SMV, Other
Environment Condition	Clear, Rain, Snow, Freezing Rain, Strong Wing, Fog / Mist / Smoke / Dust, Drifting Snow
Surface Condition	Dry, Wet, Loose Snow, Packed Snow, Ice, Slush
Collision Impact Type	SMV, Overtaking, Animal/Peds, Head On, Angle, Rear End, Sideswipe
Driver Action	Lost Control, Driving Properly, Speed Too Fast, Following Too Close, Improper Lane Change

Once the overall characteristic has been determined to be over-represented, the individual category is analyzed by calculating the Chi-Square value of each category among the characteristic, using Equation 4.

$$\chi_k^2 = \frac{(O_k - E_k)^2}{E_k} + \frac{(X_k - Y_k)^2}{Y_k} \qquad \text{Eq. 4}$$

Where:

$X_k = T_k - O_k$ and $Y_k = R_k - E_k$

O_k is the observed collision frequency for individual collision characteristic category *k*;

E_k is the expected collision frequency for individual collision characteristic category *k*;

T_k is the observed total collision frequency at the location; and

R_k is the expected total collision frequency at the location.

As shown in Equation 4, the computed Chi-Square value is again a measure of the discrepancy between the observed and expected collision frequencies for the collision characteristic category *k*. A Chi-Square value of 0 represents no discrepancies between the observed and expected collision frequencies, while a larger value of Chi-Square represents a larger discrepancy.

The computed value of Chi-Square is then also compared to the lower and upper theoretical Chi-Square values for the appropriate degrees of freedom and a specified significance level, according to Equation 2. If Equation 2 is false, the individual category *k* is found to be over-represented.

The specified significance level remains 0.05 and the number of degrees of freedom is 1, which gives a lower theoretical Chi-Square value of approximately 0.00, and an upper theoretical Chi-Square value of 5.02.

Appendix A Over-Representation Analysis

Results – Light Condition

Light Condition	Ontario			Hamilton		
	Total	Daylight	Non-Daylight	Total	Daylight	Non-Daylight
Observed (Oi)	473	300	173	473	300	173
Other Observed (Xk)	-	173	300	-	173	300
Database (Ontario/Hamilton)	172639	119759	52880	2927	2188	739
Expected (Ei)	473	328.12	144.88	473	353.58	119.42
Other Expected (Yk)	-	144.88	328.12	-	119.42	353.58
Chi-Value (Oi-Ei)^2/Ei	-	2.41	5.46	-	8.12	24.04
Other Chi-Value (Xk-Yk)^2/Yi	-	5.46	2.41	-	24.04	8.12
Total Chi-Value	7.87			32.16		
Lower_Chi-Value	0.001			0.001		
Upper_Chi-Value	5.02			5.02		
Total Over-rep?	Yes			Yes		
Category Chi-Values	-	7.87	7.87	-	32.16	32.16
Category Over-rep?	-	No	Yes	-	No	Yes

Results – Environment Condition

Environment Condition	Ontario								Hamilton							
	Total	Clear	Rain	Snow	Freezing Rain	Strong Wing	Fog Mist Smoke Dust	Drifting Snow	Total	Clear	Rain	Snow	Freezing Rain	Strong Wing	Fog Mist Smoke Dust	Drifting Snow
Observed (Oi)	330	275	16	28	3	2	1	5	330	275	16	28	3	2	1	5
Other Observed (Xk)	-	55	314	302	327	328	329	325	-	55	314	302	327	328	329	325
Database (Ontario/Hamilton)	172306	136034	18793	13046	1558	398	1492	985	3436	2708	457	190	16	20	32	13
Expected (Ei)	330	260.53	35.99	24.99	2.98	0.76	2.86	1.89	330	260.08	43.89	18.25	1.54	1.92	3.07	1.25
Other Expected (Yk)	-	69.47	294.01	305.01	327.02	329.24	327.14	328.11	-	69.92	286.11	311.75	328.46	328.08	326.93	328.75
Chi-Value (Oi-Ei)^2/Ei	-	0.80	11.10	0.36	0.00	2.01	1.21	5.14	-	0.86	17.72	5.21	1.39	0.00	1.40	11.27
Other Chi-Value (Xk-Yk)^2/Yi	-	3.01	1.36	0.03	0.00	0.00	0.01	0.03	-	3.18	2.72	0.31	0.01	0.00	0.01	0.04
Total Chi-Value	20.63								37.86							
Lower_Chi-Value	1.24								1.24							
Upper_Chi-Value	14.45								14.45							
Total Over-rep?	Yes								Yes							
Category Chi-Values	-	3.82	12.46	0.39	0.00	2.01	1.22	5.17	-	4.04	20.44	5.52	1.40	0.00	1.41	11.31
Category Over-rep?	-	No	No	No	No	No	No	Yes	-	No	No	Yes	No	No	No	Yes

Appendix A Over-Representation Analysis

Results – Surface Condition

Road Surface Condition	Ontario							Hamilton						
	Total	Dry	Wet	Loose Snow	Packed Snow	Ice	Slush	Total	Dry	Wet	Loose Snow	Packed Snow	Ice	Slush
Observed (Oi)	471	208	239	8	4	9	3	471	208	239	8	4	9	3
Other Observed (Xk)	-	263	232	463	467	462	468	-	263	232	463	467	462	468
Database (Ontario/Hamilton)	171582	121339	30490	6375	3667	6406	3305	3417	2421	752	96	38	75	35
Expected (Ei)	471	333.08	83.70	17.50	10.07	17.58	9.07	471	333.71	103.66	13.23	5.24	10.34	4.82
Other Expected (Yk)	-	137.92	387.30	453.50	460.93	453.42	461.93	-	137.29	367.34	457.77	465.76	460.66	466.18
Chi-Value (Oi-Ei)^2/Ei	-	46.97	288.18	5.16	3.66	4.19	4.06	-	47.36	176.72	2.07	0.29	0.17	0.69
Other Chi-Value (Xk-Yk)^2/Yi	-	113.44	62.27	0.20	0.08	0.16	0.08	-	115.11	49.87	0.06	0.00	0.00	0.01
Total Chi-Value	352.21							227.30						
Lower_Chi-Value	0.83							0.83						
Upper_Chi-Value	12.83							12.83						
Total Over-rep?	Yes							Yes						
Category Chi-Values	-	160.41	350.45	5.36	3.74	4.35	4.14	-	162.47	226.59	2.13	0.30	0.18	0.70
Category Over-rep?	-	No	Yes	No	No	No	No	-	No	Yes	No	No	No	No

Results – Apparent Driver Action

Apparent Driver Action	Ontario						Hamilton					
	Total	Lost Control	Driving Properly	Speed Too Fast	Following Too Close	Improper Lane Change	Total	Lost Control	Driving Properly	Speed Too Fast	Following Too Close	Improper Lane Change
Observed (Oi)	430	165	111	59	48	47	430	165	111	59	48	47
Other Observed (Xk)	-	265	319	371	382	383	-	265	319	371	382	383
Database (Ontario/Hamilton)	224518	19923	147890	16535	29974	10196	3870	488	2727	105	427	123
Expected (Ei)	430	38.16	283.24	31.67	57.41	19.53	430	54.22	303.00	11.67	47.44	13.67
Other Expected (Yk)	-	391.84	146.76	398.33	372.59	410.47	-	375.78	127.00	418.33	382.56	416.33
Chi-Value (Oi-Ei)^2/Ei	-	421.66	104.74	23.59	1.54	38.65	-	226.32	121.66	192.04	0.01	81.30
Other Chi-Value (Xk-Yk)^2/Yi	-	41.06	202.15	1.88	0.24	1.84	-	32.66	290.27	5.36	0.00	2.67
Total Chi-Value	590.18						621.33					
Lower_Chi-Value	0.48						0.48					
Upper_Chi-Value	11.14						11.14					
Total Over-rep?	Yes						Yes					
Category Chi-Values	-	462.72	306.89	25.46	1.78	40.49	-	258.98	411.93	197.39	0.01	83.97
Category Over-rep?	-	Yes	No	Yes	No	Yes	-	Yes	No	Yes	No	Yes

Appendix B: Illumination Warrants

FORM 2
FREEWAY - CONTINUOUS ILLUMINATION

Highway: *Red Hill Valley Parkway* ***WP No.:***

Limits: *from: Lincoln M. Alexander Parkway to: Greenhill* ***Name:*** *GB + KH* ***Date:*** *August 31, 2015*

2 pages

CLASSIFICATION FACTOR	RATING (I) 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHT - ED WEIGHT (B)	DIFF (A - B)	SCORE [RATING X (A - B)]
Geometric Factors No. of Lanes (2-way)	4	5	6	7	8	1.0	0.5	0.5	1.00
Lane Width (m)	> 3.75	3.75	3.66	3.50	< 3.50	3.0	2.5	0.5	1.50
Median Width (m)	> 15.0 or barrier		10.0 - 15.0		< 10.0	1.0	0.5	0.5	1.50
Shoulders (m)	3.5	3.25	3.0	2.75	2.5	1.0	0.5	0.5	2.50
Slopes	7:1	6:1	5:1	4:1	< 4:1	1.0	0.5	0.5	2.00
Critical Curves m (deg.)	>3,500 (< 1/2°)	3,500-1,800 (2 - 1°)	1,799-850 (1.1 - 2°)	849-600 (2.1 - 3°)	599-450 (3.1 - 4°)	13.0	4.5	8.5	34.0
Grades (vertical)	< 3%	3 - 3.9%	4 - 4.9%	5 - 6.9%	7%	3.2	2.8	0.4	0.80
Interchange Spacing (km)	>3.0	2.1 - 3.0	1.6 - 2.0	1.0 - 1.5	< 1.0	4.0	1.0	3.0	12.0
							Geometric Total		**55.30**
Operational Factors Level of Service (ii) (any dark hour)	A	B	C	D	E, F	6.0	1.0	5.0	25.0
							Operational Total		**25.0**
Environmental Factors % Development	0%	25%	50%	75%	100%	3.5	0.5	3.0	3.0
Illumination adjacent to Freeway	none	0 - 40%	41 - 60%	61 - 80%	essentially continuous	3.0	1.0	2.0	2.0
							Environmental Total		**5.0**

FORM 2
FREEWAY - CONTINUOUS ILLUMINATION

Highway: *Red Hill Valley Parkway* ***WP No.:***

Limits: *from: Lincoln M. Alexander Parkway to: Greenhill* ***Name:*** *GB + KH* ***Date:*** *August 31, 2015*

2 pages

CLASSIFICATION FACTOR	**RATING (I)**					UNLIT WEIG HT (A)	LIGHT - ED WEIG HT (B)	DIFF (A - B)	SCOR E [RATIN G X (A - B)]
	1	**2**	**3**	**4**	**5**				
<u>Accidents</u> % of Night-to-Total Accidents (3 yr. avg.) (iii)	< 20%	20 - 30%	31 - 40%	41 - 50%	> 50%	10.0	2.0	8.0	32.0
							Accidents Total		**32.0**
Benefit Cost Ratio (B/C)									

GEOMETRIC TOTAL = 55.3
OPERATIONAL TOTAL = 25.0
ENVIRONMENTAL TOTAL = 5.0
ACCIDENTS TOTAL = 32.0

SUM = **<u>117.3</u> POINTS**
CONTINUOUS ILLUMINATION WARRANTING CONDITION = **<u>80 points</u>**

i. A rating of between 1 and 5 shall be assigned for each factor in the FORM depending on the conditions that are encountered by motorists on the roadway. The higher the rating, the more critical the need for illumination with regard to that particular factor.
ii. Use LOS methodology approved by the MTO.
iii. For night-to-total accident ratio, accidents during darkness are used (including dusk/dawn).
iv. The number of points for the warranting condition is based on 50% of the total points attainable, if all factors were rated 5.

Note: Worst case scenarios should be considered when assigning the ratings. For example, a section of roadway could have rush hour volumes during the hours of darkness in wintertime.

CIMA+ Note Level of Service is expected to reach E during winter season (PM peak hours can occur during dark hours)

FORM 2
FREEWAY - CONTINUOUS ILLUMINATION

Highway: *Red Hill Valley Parkway* ***WP No.:***

Limits: *from: Greenhill to: QEW* ***Name:*** *GB + KH* ***Date:*** *August 31, 2015*
2 pages

CLASSIFICATION FACTOR	RATING (I)					UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF (A - B)	SCORE [RATING X (A - B)]
	1	**2**	**3**	**4**	**5**				
Geometric Factors No. of Lanes (2-way)	4	5	6	7	8	1.0	0.5	0.5	0.50
Lane Width (m)	> 3.75	3.75	3.66	3.50	< 3.50	3.0	2.5	0.5	1.50
Median Width (m)	> 15.0 or barrier		10.0 - 15.0		< 10.0	1.0	0.5	0.5	1.50
Shoulders (m)	3.5	3.25	3.0	2.75	2.5	1.0	0.5	0.5	2.50
Slopes	7:1	6:1	5:1	4:1	< 4:1	1.0	0.5	0.5	2.0
Critical Curves m (deg.)	>3,500 (< 1/2º)	3,500-1,800 (2 - 1º)	1,799-850 (1.1 - 2º)	849-600 (2.1 - 3º)	599-450 (3.1 - 4º)	13.0	4.5	8.5	42.50
Grades (vertical)	< 3%	3 - 3.9%	4 - 4.9%	5 - 6.9%	7%	3.2	2.8	0.4	0.40
Interchange Spacing (km)	>3.0	2.1 - 3.0	1.6 - 2.0	1.0 - 1.5	< 1.0	4.0	1.0	3.0	12.0
							Geometric Total		**62.90**
Operational Factors Level of Service (ii) (any dark hour)	A	B	C	D	E, F	6.0	1.0	5.0	25.0
							Operational Total		**25.0**
Environmental Factors % Development	0%	25%	50%	75%	100%	3.5	0.5	3.0	3.0
Illumination adjacent to Freeway	none	0 - 40%	41 - 60%	61 - 80%	essentially continuous	3.0	1.0	2.0	2.0
							Environmental Total		**5.0**

FORM 2
FREEWAY - CONTINUOUS ILLUMINATION

Highway: *Red Hill Valley Parkway* ***WP No.:***

Limits: *from: Greenhill to: QEW* ***Name:*** *GB + KH* ***Date:*** *August 31, 2015*
2 pages

CLASSIFICATION FACTOR	RATING (I)					UNLIT WEIGHT (A)	LIGHT-ED WEIGHT (B)	DIFF (A - B)	SCORE [RATING X (A - B)]
	1	2	3	4	5				
Accidents % of Night-to-Total Accidents (3 yr. avg.) (iii)	< 20%	20 - 30%	31 - 40%	41 - 50%	> 50%	10.0	2.0	8.0	24.0
							Accidents Total		**24.0**
Benefit Cost Ratio (B/C)									

GEOMETRIC TOTAL = 62.9
OPERATIONAL TOTAL = 25.0
ENVIRONMENTAL TOTAL = 5.0
ACCIDENTS TOTAL = 24.0

SUM = 116.9 POINTS
CONTINUOUS ILLUMINATION WARRANTING CONDITION = 80 points

i. A rating of between 1 and 5 shall be assigned for each factor in the FORM depending on the conditions that are encountered by motorists on the roadway. The higher the rating, the more critical the need for illumination with regard to that particular factor.
ii. Use LOS methodology approved by the MTO.
iii. For night-to-total accident ratio, accidents during darkness are used (including dusk/dawn).
iv. The number of points for the warranting condition is based on 50% of the total points attainable, if all factors were rated 5.

Note: Worst case scenarios should be considered when assigning the ratings. For example, a section of roadway could have rush hour volumes during the hours of darkness in wintertime.

CIMA+ Note Level of Service is expected to reach E during winter season (PM peak hours can occur during dark hours)

Road Name Red Hill Valley Parkway
From Linc to Greenhill
City Hamilton, ON
Warrant Undertaken by GB+KH
Company name CIMA+
Date August 31, 2015

Warrants for Lighting Freeways (See Note 2)

Item No.	Classification Factor	Rating Factor 'R' 1	2	3	4	5	Weight 'W'	Enter 'R' Here	Score 'R' x 'W'	
	Geometric Factors (See Note 4)									
1	Number of Lanes	≦4	5	6	7	≧ 8	0.15	2	0.30	
2	Lane Width (m)	>3.6	3.4 to 3.6	3.2 to 3.4	3.0 to 3.2	<3.0	0.30	2	0.60	
3	Median Width (m)	>12	7.5 to 12	3.5 to 7.5	1.2 to 3.5	<1.2	0.30	2	0.60	
4	Shoulder Width (m)	>3	2.5 to 3	1.8 to 2.5	1.2 to 1.8	<1.2	0.30	3	0.90	
5	Off Roadway Embankment Slopes	>6:1	6:1	4:1	3:1	<3:1	0.30	3	0.90	
6	Horizontal Curve Radius (m)	>3500	1750 to 3500	1750 to 875	575 to 875	<575	4.90	4	19.60	
7	Vertical Grades (%)	<3	3 to 4	4 to 5	5 to 7	>7	0.25	2	0.50	
8	Interchange Frequency (No. per km)	>6.5	5.0 to 6.5	3.5 to 5.0	1.5 to 3.5	<1.5	1.85	5	9.25	
								Subtotal Geometric Factors	32.65	G
	Operational Factors									
9	Level of Service (Night, at any Hour)	A	B	C	D	≧ E	3.05	5	15.25	
								Subtotal Operational Factors	15.25	O
	Environmental Factors									
10	Percentage of Development Adjacent to Road (%)	nil	nil to 24	25 to 50	50 to 75	75 >	1.85	1	1.85	
11	Distance from Development to Roadway (m) (See Note 3)	>60	45 to 60	30 to 45	15 to 30	<15	1.85	1	1.85	
								Subtotal Environmental Factors	3.70	E
	Collision Factors									
12	Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0 (See Note 1)	4.90	1	4.90	
								Subtotal Collision Factors	4.90	A
								G + O + E + A = Total Warranting Points	56.50	
								Warranting Condition	**60.00**	
								Difference ±	-3.50	D

Notes:
1 Lighting Warranted
2 Operating Speed 80 km/hr (95th percentile night speed should be used if available, other wise posted speed shall be used
3 Development Meaning Commercial, Industrial, Residential Buildings
4 Worst Case Geometric Factors for a Segment of Roadway Shall Apply

CIMA Note Level of Service is expected to reach E during winter season (PM peak hours can occur during dark hours)

v1.0

Figure 9-11 – Warrant for Lighting Freeways

Road Name Red Hill Valley Parkway
From Greenhill to QEW
City Hamilton, ON
Warrant Undertaken by GB+KH
Company name CIMA+
Date August 31, 2015

Warrants for Lighting Freeways (See Note 2)

Item No.	Classification Factor	Rating Factor 'R' 1	2	3	4	5	Weight 'W'	Enter 'R' Here	Score 'R' x 'W'	
	Geometric Factors (See Note 4)									
1	Number of Lanes	≦4	5	6	7	≧ 8	0.15	1	0.15	
2	Lane Width (m)	>3.6	3.4 to 3.6	3.2 to 3.4	3.0 to 3.2	<3.0	0.30	2	0.60	
3	Median Width (m)	>12	7.5 to 12	3.5 to 7.5	1.2 to 3.5	<1.2	0.30	2	0.60	
4	Shoulder Width (m)	>3	2.5 to 3	1.8 to 2.5	1.2 to 1.8	<1.2	0.30	3	0.90	
5	Off Roadway Embankment Slopes	>6:1	6:1	4:1	3:1	<3:1	0.30	3	0.90	
6	Horizontal Curve Radius (m)	>3500	1750 to 3500	1750 to 875	575 to 875	<575	4.90	5	24.50	
7	Vertical Grades (%)	<3	3 to 4	4 to 5	5 to 7	>7	0.25	1	0.25	
8	Interchange Frequency (No. per km)	>6.5	5.0 to 6.5	3.5 to 5.0	1.5 to 3.5	<1.5	1.85	5	9.25	
							Subtotal Geometric Factors		37.15	G
	Operational Factors									
9	Level of Service (Night, at any Hour)	A	B	C	D	≧ E	3.05	5	15.25	
							Subtotal Operational Factors		15.25	O
	Environmental Factors									
10	Percentage of Development Adjacent to Road (%)	nil	nil to 24	25 to 50	50 to 75	75 >	1.85	1	1.85	
11	Distance from Development to Roadway (m) (See Note 3)	>60	45 to 60	30 to 45	15 to 30	<15	1.85	1	1.85	
							Subtotal Environmental Factors		3.70	E
	Collision Factors									
12	Night-to-Day Collision Ratio	<1.0	1.0 to 1.2	1.2 to 1.5	1.5 to 2.0	>2.0 (See Note 1)	4.90	1	4.90	
							Subtotal Collision Factors		4.90	A
							G + O + E + A = Total Warranting Points		61.00	
							Warranting Condition		**60.00**	
							Difference ±		1.00	D

Notes:
1 Lighting Warranted
2 Operating Speed 80 km/hr (95th percentile night speed should be used if available, other wise posted speed shall be used
3 Development Meaning Commercial, Industrial, Residential Buildings
4 Worst Case Geometric Factors for a Segment of Roadway Shall Apply

CIMA Note Level of Service is expected to reach E during winter season (PM peak hours can occur during dark hours)

v1.0

Figure 9-11 – Warrant for Lighting Freeways

Appendix C: Evaluation of Providing a Median Barrier

Appendix C Evaluation of Providing a Median Barrier

The selection of best type of median barrier system within the study area was undertaken in the following steps:

- Determination of feasibility of barrier types for the study area;
- Development of alternatives; and
- Selection of the best alternative based on cost-effective analysis.

Determination of Feasibility of Barrier Types for the Study Area

CIMA conducted an analysis of various types of prevailing median barrier technologies in Canada based on MTO's Roadside Safety Manual and AASHTO Roadside Design Guide to determine feasible barrier types for the RHVP. The results of the analysis along with the characteristics of each barrier type that makes it suitable or unsuitable for the RHVP are included in Table 1.

Table 1: Analysis for the Feasibility of Various Barrier Systems for the RHVP

Type of Median Barrier	Relevant Characteristics	Feasibility for the RHVP
6 Cable (Wood Post)	• Not approved for use on high speed facilities	Not feasible for the RHVP due to high speed
6 Cable (Steel Post)	• Recommended for AADT < 20,000 • Ideal for median width greater than 9 m	Not feasible for the RHVP due to high AADT
Median Box Beam Barrier	• Restricted to facilities with posted speeds less than 80 km/h • Recommended for AADT < 30,000	Not feasible for the RHVP due to high AADT and speed
Median Steel Beam Guide Rail with Channel	• Recommended for AADT > 20,000 • Can be installed in medians greater than 9.0 m	Feasible for the RHVP
Standard Concrete Barrier and Ontario "Tall Wall"	• No curbs, gutters or ditches allowed between the barrier and the driving lanes • Area directly in front of barrier must be paved • Should not be located more than 4.0 metres from the edge of the driving lane (maximum width of median to be 9.0 metres)	Not feasible for the RHVP due to a median width larger than 9.0 metres
High-Tension Cable Barrier*	• 2011 AADT range – 25,820 to 46, 200 • Posted Speed – 110 km/h	Feasible for the RHVP
*Based on Successful Alberta experience in addressing cross median collisions by using the High-Tension Cable Barrier system on Highway 2 between Airdrie and Red Deer		

As can be seen in Table 1, Median Steel Beam Guide Rail, and High-Tension Cable Barriers are feasible options for providing a median barrier for the RHVP. It should be noted that all kinds of barrier systems can be transitioned from one type to another by using standard methods. The guidance is available in MTO's Roadside Manual and AASHTO Roadside Design Guide. The appropriate types of transitions should be determined at the detailed design stage.

Based on the feasible barrier options detailed above, various alternatives available for providing a median barrier on the RHVP are as follows:

Appendix C Evaluation of Providing a Median Barrier

Alternative 1: Standard Steel Beam Guide Rail with Channel System on Both Sides of the Median

Provide Standard Steel Beam Guide Rail with Channel systems on both sides of the median. It should be noted that for medians, steel beam guide rails are provided with channel elements to increase the stiffness of the installation[1]. An example Standard Steel Beam Guide Rail with Channel System installed on a median on Highway 403 is demonstrated in Figure 1.

Figure 1: An Example Standard Steel Beam Guide Rail with Channel System

Alternative 2: High Tension Cable Barrier on Both Sides of the Median

Provide High-Tension Cable Barrier on both sides of the median. An example of High Tension Cable Barrier installed on both sides of a median location on Highway 2 in Alberta is demonstrated in Figure 2.

Figure 2 : An Example High Tension Cable Barrier

[1] Section 4.3.5, MTO's Roadside Safety Manual

Appendix C Evaluation of Providing a Median Barrier

Cost Estimate

The detailed cost estimates for the two alternatives are provided in Table 2

Table 2: Alternatives Cost Estimate

	Description	Unit	Qty.	Unit Price $	Total Price $
Alternative 1	Earth Works	M.R.	6000	100	600,000
	Supply & Install Standard Steel Beam Guide Rail with Channel Systems	M.R.	11200	120	1,344,000
	Supply & Install Extruder and Treatment	No.	10	3250	32,500
	Supply & Install Object Marker Warning Sign	No.	10	500	5,000
	30 Years Maintenance Cost ($4500 x 8.2 x 30)				1,107,000
	Total Alternative 1				**$3,088,500**
Alternative 2	Earth Works	M.R.	6000	100	600,000
	Supply & Install High-Tension Cable Barrier	M.R.	11200	72	806,400
	Supply & Install Anchor End Terminal	No.	20	500	10,000
	Supply & Install Object Marker Warning Sign	No.	10	500	5,000
	30 Years Maintenance Cost ($4500 x 8.2 x 30)				1,107,000
	Total Alternative 2				**$2,528,400**

Cost-effective Analysis

In order to select the best possible alternative of installing a median barrier from the available alternatives detailed in Section 1.2, a cost-benefit analysis was conducted. Barrier systems have an assumed service life of 30 years. Median barriers generally eliminate all cross-over collisions including cross-over fatal collisions. However, median barriers tend to increase overall number of collisions, primarily PDO collisions. The methodology and results of the analysis are provided in the following sections.

Methodology

The cost-effective analysis to determine most cost-effective median barrier type was conducted by utilizing the following steps.

Estimate Number of Collisions Likely to Occur

CIMA attempted to develop Safety Performance Functions (SPFs) for median related collisions of the study area. Statistically significant models could not be developed as a result of limited number of segments that can be utilized for the prediction of long term average of median related collisions for the study area. In the absence of SPFs, we used annual average crash rates (Collisions per 100 million vehicles kilometers) to estimate the expected number of median related collisions for future 30 years. Collision distribution (proportions of fatal, injury and PDO collisions) was assumed based on the historical collision data.

Estimate the Severity of Collisions

The next step is based on the assumption that each alternative barrier system would prevent the above number of median related high severity collisions over next 30 years. However, there would be an equal number of collisions of less severity involving each type of barrier system with a different potential of posing harm as a result of a collision.

AASHTO provides Severity Indices (SI) for all types of barrier systems to quantify the potential for harm posed as a result of a collision. Each type of barrier system is assigned a Severity Index (SI), which correlates to the likelihood that the collision will result in a PDO, injury, or a fatality collision. By utilizing the SI for a barrier system, and estimated number of collisions from the previous step, it is possible to estimate the proportions of different collision types. Based on this approach, a collision distribution (PDO, injury, and fatal) for each alternative barrier system can be estimated.

The severity indices provided by AASHTO were further revised based on the recent studies involving median barriers. In this analysis, we utilized the severity results from the following two studies:

- High Tension Cable Barrier Performance Evaluation Study for Highway 2 in Alberta; and
- Cable Median Barrier Program in Washington State.

Table 3 provides the proportions of collisions with different severity levels based on the above noted studies.

Table 3: Proportions of Median Barrier Collisions by Severity

Type of Median Barrier System	Proportions of Median Barrier Collisions		
	Fatal	Injury	PDO
Steel Beam Guiderail	0.007	0.140	0.853
High Tension Cable Barrier	0.005	0.095	0.900

Cost-effective Analysis

The cost-effective analysis to compare both alternatives was conducted using a benefit-cost ratio (B/C) and on incremental basis, to realize the greatest benefit at the least cost. In this methodology, the alternatives are first ordered from lowest to highest cost. The incremental benefits of the second over the first are calculated by dividing the incremental costs of the second over the first. If the ratio is greater than 1, then alternative 2 is preferred. If the ratio is less than 1 then alternative 1 is superior alternative. The better of these is then compared with the next most costly alternative and so on. The following steps were performed for calculating B/C:

- Estimate life cycle cost of each alternative including capital cost and operating and maintenance cost. The capital cost includes the purchase price, installation cost, and the activities that would not take place otherwise, such as paving, modifications to drainage, etc.)Operating and maintenance cost includes recurring cost of operating and maintaining the system during its useful life;

- Estimate the societal cost of collision for each year that will be prevented by installing the barrier system as estimated over the service life of the barrier system. This was considered as benefit;
- Estimate the societal cost of less severe collisions for each year involving the barrier system, after the barrier system has been put into place. This was considered as negative benefit; and
- Calculate B/C by dividing the present value of the societal benefits by the present value of the life cycle cost.

Calculations

The following assumptions were utilized for performing cost-effective analysis calculations according to the methodology detailed above.

- An annual average collision rate of 6.88 collisions per 100 million vehicles kilometres was used for calculating expected number of collisions under existing conditions (without implementing a median barrier system). This collision rate calculated was based on 8 years historical collision data from 2008 to 2015[2].
- Collision distribution used was based on the actual proportions of historical collision data from 2008 to 2015 (1.67% for fatal, 43.33% for injury, and 55.00% for PDO);
- Expected collisions after implementing different types of median barriers were calculated based proportions of fatal, injury, and PDO median related collisions associated with different types of median barrier systems obtained from recent before and after studies[3,4]. Table 4 shows the proportions collisions used for different alternatives.

Table 4: Proportions of Median Related Collisions for Various Alternatives

Alternative	Proportions of Median Related Collisions		
	Fatal	Injury	PDO
Alternative 1 (Steel Beam)	0.007	0.140	0.853
Alternative 2 (High Tension Cable)	0.005	0.095	0.900

- Societal costs of collisions used were based on MTO's current costs of collisions ($ 1,582,000 for a fatal collision, $ 59,000 for an injury collision, and $ 8,000 for a PDO collision).
- An annual average growth factor of 2% was used to project AADT.
- The expected implementation year was considered as 2015.
- The analysis was conducted based on a service life of 30 years for each type of barrier system.

[2] 2015 Collision data is only for the first 7 months (1/1/2015 – 23/07/2015)
[3] High Tension Cable Barrier Performance Evaluation Study for Highway 2 in Alberta
[4] Cable Median Barrier Program in Washington

Appendix C Evaluation of Providing a Median Barrier

Collision rate in collisions per 100 million vehicles kilometres based on historical collision data (2008 – 2015) are shown in Table 5

Table 5: Collision Rate Based on Historical Data

Year	AADT	Number of Collisions	Collision Rate
2008	45,748	6	6.53
2009	55,261	5	4.51
2010	59,123	8	6.74
2011	60,305	5	4.13
2012	61,511	5	4.05
2013	62,741	9	7.15
2014	63,996	13	10.12
2015	65,276	9	11.82
		Average of Collision Rate	**6.88**

Estimate of numbers of collisions likely to occur based on the historical collision rate (6.88 Collisions per 100 Million Vehicles Kilometres) and societal cost of collisions without implementing a median barrier are shown in Table 6

Table 6: Expected Collisions and Societal Cost before Implementing Median Barrier

Year	AADT	Expected Collisions Before	Fatal (1.67%)	Injury (43.33%)	PDO (55.00%)	Expected Societal Cost
2016	66,582	9.20	0.15	3.99	5.06	$518,127.88
2017	67,914	9.38	0.16	4.07	5.16	$528,493.24
2018	69,272	9.57	0.16	4.15	5.26	$539,060.92
2019	70,657	9.76	0.16	4.23	5.37	$549,838.72
2020	72,070	9.96	0.17	4.31	5.48	$560,834.40
2021	73,511	10.15	0.17	4.40	5.59	$572,047.98
2022	74,981	10.36	0.17	4.49	5.70	$583,487.23
2023	76,481	10.56	0.18	4.58	5.81	$595,159.93
2024	78,011	10.78	0.18	4.67	5.93	$607,066.08
2025	79,571	10.99	0.18	4.76	6.05	$619,205.69
2026	81,162	11.21	0.19	4.86	6.17	$631,586.54
2027	82,785	11.44	0.19	4.96	6.29	$644,216.40
2028	84,441	11.66	0.19	5.05	6.42	$657,103.07
2029	86,130	11.90	0.20	5.16	6.54	$670,246.53
2030	87,853	12.14	0.20	5.26	6.67	$683,654.57

Year	AADT	Expected Collisions Before	Fatal (1.67%)	Injury (43.33%)	PDO (55.00%)	Expected Societal Cost
2031	89,610	12.38	0.21	5.36	6.81	$697,327.19
2032	91,402	12.63	0.21	5.47	6.94	$711,272.18
2033	93,230	12.88	0.21	5.58	7.08	$725,497.31
2034	95,095	13.14	0.22	5.69	7.22	$740,010.37
2035	96,997	13.40	0.22	5.81	7.37	$754,811.36
2036	98,937	13.67	0.23	5.92	7.52	$769,908.05
2037	100,916	13.94	0.23	6.04	7.67	$785,308.24
2038	102,934	14.22	0.24	6.16	7.82	$801,011.91
2039	104,993	14.50	0.24	6.28	7.98	$817,034.64
2040	107,093	14.79	0.25	6.41	8.14	$833,376.42
2041	109,235	15.09	0.25	6.54	8.30	$850,045.04
2042	111,420	15.39	0.26	6.67	8.47	$867,048.28
2043	113,648	15.70	0.26	6.80	8.63	$884,386.13
2044	115,921	16.01	0.27	6.94	8.81	$902,074.16
2045	118,239	16.33	0.27	7.08	8.98	$920,112.38
2016	66,582	9.20	0.15	3.99	5.06	$518,127.88
					Total Expected Societal Cost	**$21,019,352.86**

Estimate of numbers of collisions likely to occur after implementation of a median barrier and societal cost of collisions for each alternative are shown in Table 7 to **Error! Reference source not found.** and using proportions from Table 4.

Table 7: Expected Number of Collisions after Implementing Alternative 1 (Steel Beam Guiderail)

Year	Excepted Collisions (Before)	Expected Collisions After			
		Fatal	Injury	PDO	Societal Cost
2016	9.20	0.06	1.29	7.85	$240,589.16
2017	9.38	0.07	1.31	8.00	$245,402.24
2018	9.57	0.07	1.34	8.16	$250,309.27
2019	9.76	0.07	1.37	8.33	$255,313.87
2020	9.96	0.07	1.39	8.49	$260,419.64
2021	10.15	0.07	1.42	8.66	$265,626.59
2022	10.36	0.07	1.45	8.84	$270,938.32

Year	Excepted Collisions (Before)	Expected Collisions After			
		Fatal	Injury	PDO	Societal Cost
2023	10.56	0.07	1.48	9.01	$276,358.46
2024	10.78	0.08	1.51	9.19	$281,887.01
2025	10.99	0.08	1.54	9.38	$287,523.95
2026	11.21	0.08	1.57	9.56	$293,272.91
2027	11.44	0.08	1.60	9.75	$299,137.50
2028	11.66	0.08	1.63	9.95	$305,121.34
2029	11.90	0.08	1.67	10.15	$311,224.41
2030	12.14	0.08	1.70	10.35	$317,450.35
2031	12.38	0.09	1.73	10.56	$323,799.14
2032	12.63	0.09	1.77	10.77	$330,274.40
2033	12.88	0.09	1.80	10.99	$336,879.74
2034	13.14	0.09	1.84	11.21	$343,618.78
2035	13.40	0.09	1.88	11.43	$350,491.52
2036	13.67	0.10	1.91	11.66	$357,501.57
2037	13.94	0.10	1.95	11.89	$364,652.54
2038	14.22	0.10	1.99	12.13	$371,944.43
2039	14.50	0.10	2.03	12.37	$379,384.48
2040	14.79	0.10	2.07	12.62	$386,972.67
2041	15.09	0.11	2.11	12.87	$394,712.63
2042	15.39	0.11	2.15	13.13	$402,607.97
2043	15.70	0.11	2.20	13.39	$410,658.68
2044	16.01	0.11	2.24	13.66	$418,872.00
2045	16.33	0.11	2.29	13.93	$427,247.92
Total Expected Societal Cost After Barrier Implementation					**$9,760,193.47**

Table 8: Expected Number of Collisions after Implementing Alternative 2 (High Tension Cable)

Year	Expected Collisions Before	Expected Collisions After			
		Fatal	Injury	PDO	Societal Cost
2016	9.20	0.05	0.87	8.28	$190,526.96
2017	9.38	0.05	0.89	8.44	$194,338.53

Year	Expected Collisions Before	Expected Collisions After			
		Fatal	Injury	PDO	Societal Cost
2018	9.57	0.05	0.91	8.61	$198,224.50
2019	9.76	0.05	0.93	8.78	$202,187.73
2020	9.96	0.05	0.95	8.96	$206,231.09
2021	10.15	0.05	0.96	9.14	$210,354.57
2022	10.36	0.05	0.98	9.32	$214,561.03
2023	10.56	0.05	1.00	9.51	$218,853.34
2024	10.78	0.05	1.02	9.70	$223,231.49
2025	10.99	0.05	1.04	9.89	$227,695.49
2026	11.21	0.06	1.07	10.09	$232,248.20
2027	11.44	0.06	1.09	10.29	$236,892.48
2028	11.66	0.06	1.11	10.50	$241,631.18
2029	11.90	0.06	1.13	10.71	$246,464.32
2030	12.14	0.06	1.15	10.92	$251,394.75
2031	12.38	0.06	1.18	11.14	$256,422.48
2032	12.63	0.06	1.20	11.36	$261,550.35
2033	12.88	0.06	1.22	11.59	$266,781.25
2034	13.14	0.07	1.25	11.82	$272,118.02
2035	13.40	0.07	1.27	12.06	$277,560.66
2036	13.67	0.07	1.30	12.30	$283,112.05
2037	13.94	0.07	1.32	12.55	$288,775.03
2038	14.22	0.07	1.35	12.80	$294,549.62
2039	14.50	0.07	1.38	13.05	$300,441.53
2040	14.79	0.07	1.41	13.31	$306,450.76
2041	15.09	0.08	1.43	13.58	$312,580.17
2042	15.39	0.08	1.46	13.85	$318,832.63
2043	15.70	0.08	1.49	14.13	$325,208.14
2044	16.01	0.08	1.52	14.41	$331,712.42
2045	16.33	0.08	1.55	14.70	$338,345.47

Appendix D: Benefit-Cost Analysis for Other Countermeasures

The Benefit-Cost (B/C) ratio is the ratio of the present value of the safety benefit of a given countermeasure calculated for its service life to the present value of the cost of the countermeasure. A B/C ratio of greater than 1.0 represents an economically efficient countermeasure. In this criterion, the monetary value of the collisions reduced as a result of implementation of a countermeasure is considered as the benefit of the countermeasure. For the purposes of calculating the societal costs of collisions, MTO costs were utilized. Details of the B/C analysis for countermeasures other than median barrier are included in the following tables.

Provide Speed Feedback Signs

The CMF for this countermeasure is 0.88, and the construction cost is $10,000 per site for a service life of 10 years.

Collision rate of total collisions in collisions per 100 million vehicles kilometres based on historical collision data (2008 – 2015[1]):

Year	AADT	Number of Total Collisions	Collision Rate
2008	45,748	10	26.04
2009	55,261	11	23.71
2010	59,123	22	44.32
2011	60,305	29	57.28
2012	61,511	24	46.48
2013	62,741	38	72.15
2014	63,996	37	68.87
2015	65,276	26	81.69
		Average of Collision Rate	**52.57**

Estimate of number of total collisions likely to occur based on the historical collision rate (36.14 collisions per 100 million vehicles kilometres) and societal cost of collisions without implementing speed feedback signs during next 10 years (service life of signs). 2015 is the assumed implementation year. The proportions of different severity collisions of total collisions shown in the header of the following table are based on the actual experienced during the history period.

[1] 2015 Collision data is only for the first 7 months (1/1/2015 – 23/07/2015)

Year	AADT	Total Collisions	Fatal (0.00%)	Injury (44.16%)	PDO (55.84%)	Expected Societal Cost
2016	66,582	29.38	0.00	12.98	16.41	$896,843.06
2017	67,914	29.97	0.00	13.24	16.73	$914,784.77
2018	69,272	30.57	0.00	13.50	17.07	$933,076.70
2019	70,657	31.18	0.00	13.77	17.41	$951,732.31
2020	72,070	31.80	0.00	14.05	17.76	$970,765.07
2021	73,511	32.44	0.00	14.33	18.11	$990,174.98
2022	74,981	33.09	0.00	14.61	18.48	$1,009,975.51
2023	76,481	33.75	0.00	14.91	18.85	$1,030,180.14
2024	78,011	34.43	0.00	15.20	19.22	$1,050,788.87
2025	79,571	35.11	0.00	15.51	19.61	$1,071,801.68
	Total	**321.73**	**0.00**	**142.08**	**179.65**	**$9,820,123.09**

Societal Cost of Expected Collisions = 0.00 x 1,582,000 + 142.08 x 59,000 + 179.65 x 8,000
= $9,820,123.09

Average Cost of Total Expected Collisions = $9,820,123.09/ 321.73 = $30,522.84

<u>Reduction in Collisions after Implementing Speed Feedback Signs (CMF = 0.88)</u>

Expected Reduction in collisions = 321.73 x (1 – CMF)
= 38.61

Monetary Benefits = 38.61 x $30,522.84 = $1,178,486.85

Construction Cost = $12,500 x 8
= $100,000

B/C = 11.78

Illumination

The CMF for this countermeasure is 0.97, and the construction cost is $100,000 per site for a service life of 20 years.

Collision rate of total collisions in collisions per 100 million vehicles kilometres based on historical collision data (2008 – 2015):

Year	AADT	Number of Total Collisions	Collision Rate
2008	45,748	43	31.79
2009	55,261	37	22.65
2010	59,123	51	29.18
2011	60,305	71	39.82
2012	61,511	67	36.84
2013	62,741	80	43.13
2014	63,996	71	37.53
2015[2]	65,276	54	48.17
		Average of Collision Rate	**36.14**

Estimate of number of total collisions likely to occur based on the historical collision rate (36.14 collisions per 100 million vehicles kilometres) and societal cost of collisions without implementing illumination during next 20 years (service life of illumination). 2015 is the assumed implementation year. The proportions of different severity collisions of total collisions shown in the header of the following table are based on the actual experienced during the history period.

Year	AADT	Total Collisions	Fatal (0.84%)	Injury (43.25%)	PDO (55.91%)	Expected Societal Cost
2016	66,582	71.14	0.60	30.77	39.77	$3,083,123.33
2017	67,914	72.56	0.61	31.38	40.57	$3,144,802.46
2018	69,272	74.01	0.62	32.01	41.38	$3,207,685.55
2019	70,657	75.49	0.64	32.65	42.21	$3,271,818.88
2020	72,070	77.00	0.65	33.30	43.05	$3,337,248.78
2021	73,511	78.54	0.66	33.97	43.91	$3,403,975.23
2022	74,981	80.11	0.68	34.65	44.79	$3,472,044.55
2023	76,481	81.72	0.69	35.34	45.68	$3,541,503.04
2024	78,011	83.35	0.70	36.05	46.60	$3,612,350.69
2025	79,571	85.02	0.72	36.77	47.53	$3,684,587.52
2026	81,162	86.72	0.73	37.50	48.48	$3,758,259.82
2027	82,785	88.45	0.75	38.25	49.45	$3,833,413.91
2028	84,441	90.22	0.76	39.02	50.44	$3,910,096.08
2029	86,130	92.02	0.78	39.80	51.45	$3,988,306.33
2030	87,853	93.87	0.79	40.60	52.48	$4,068,090.98

[2] 2015 Collision data is only from the first 7 months (1/1/2015 – 23/07/2015)

Year	AADT	Total Collisions	Fatal (0.84%)	Injury (43.25%)	PDO (55.91%)	Expected Societal Cost
2031	89,610	95.74	0.81	41.41	53.53	$4,149,450.02
2032	91,402	97.66	0.82	42.24	54.60	$4,232,429.76
2033	93,230	99.61	0.84	43.08	55.69	$4,317,076.50
2034	95,095	101.60	0.86	43.94	56.80	$4,403,436.56
2035	96,997	103.64	0.87	44.82	57.94	$4,491,509.92
	Total	**1728.47**	**14.59**	**747.54**	**966.34**	**$74,911,209.91**

Societal Cost of Expected Collisions = 14.59 x 1,582,000 + 747.54x 59,000 + 966.34x 8,000

= $74,911,209.91

Average Cost of Total Expected Collisions = $74,911,209.91/ 11728.47= $43,339.66

<u>Reduction in Collisions after Implementing Rumble Strips (CMF = 0.97)</u>

Expected Reduction in collisions = 1728.47 x (1 – CMF)

= 51.85

Monetary Benefits = 51.85 x $43,339.66 = $2,247,336.30

Construction Cost = $100,000 x 8.1

= $810,000

B/C = 2.77

Provide Permanent Recessed Pavement Markings

The CMF for this countermeasure is 0.67, and the construction cost is $19,000 per km of length for a service life of 5 years.

Collision rate of total night collisions in collisions per 100 million vehicles kilometres based on historical collision data (2008 – 2015):

Year	AADT	Number of Total Collisions	Collision Rate
2008	45,748	7	10.22
2009	55,261	9	10.88
2010	59,123	9	10.17
2011	60,305	11	12.19
2012	61,511	12	13.04
2013	62,741	22	23.43
2014	63,996	19	19.84
2015[3]	65,276	6	6.14
		Average of Collision Rate	**13.24**

Estimate of number of total collisions likely to occur based on the historical collision rate (13.24 collisions per 100 million vehicles kilometres) and societal cost of collisions without implementing permanent raised pavement markings during next 5 years (service life of PRPM). 2015 is the assumed implementation year. The proportions of different severity collisions of total collisions shown in the header of the following table are based on the actual experienced during the history period.

Year	AADT	Total Collisions	Fatal (2.11%)	Injury (26.32%)	PDO (71.58%)	Expected Societal Cost
2016	66,582	13.19	0.28	3.47	9.44	$719,727.60
2017	67,914	13.46	0.28	3.54	9.63	$734,126.04
2018	69,272	13.72	0.29	3.61	9.82	$748,805.54
2019	70,657	14.00	0.29	3.68	10.02	$763,776.89
2020	72,070	14.28	0.30	3.76	10.22	$779,050.92
	Total	**68.65**	**1.45**	**18.07**	**49.14**	**$3,745,486.99**

Societal Cost of Expected Collisions = 1.45 x 1,582,000 + 18.07 x 59,000 + 49.14 x 8,000

= $3,745,486.99

Average Cost of Total Expected Collisions = $3,745,486.99/ 49.14 = $54,557.89

<u>Reduction in Collisions after Implementing Speed Feedback Signs (CMF = 0.67)</u>

Expected Reduction in collisions = 68.65 x (1 – CMF)

= 22.66

[3] 2015 Collision data is only from the first 7 months (1/1/2015 – 23/07/2015)

Monetary Benefits	= 22.66 x \$54,557.89 = \$1,236,010.71
Construction Cost	= \$247,000.00
B/C	= 5.00

3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
CANADA
T. 289.288.0287
F. 289.288.0285

www.cima.ca

Partners in excellence