City of Hamilton

Red Hill Valley Parkway Safety Review (DRAFT)

B000325 | July 2013

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List of Appendices

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1. Introduction and Background

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 RHVP was completed in January of 1990.

Construction of the Valley portion of the Parkway was begun in the early as1990. 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 was completed and construction on the Parkway recommenced. In 2007, the Red Hill Valley Parkway was opened to traffic and has been in operation since.

This safety study was commenced by the City following a motion put forward by City Council to investigate a section of the RHVP. The motion came as a result of residents' input relating primarily to illumination around the Mud Street interchange, visibility of signage and pavement markings and a need to review of other potential devices to assist motorists in safely traversing the roadway. The City proactively decided to undertake a safety and operational review of a portion of the parkway to examine the issues put forward by the motion as well as other aspects.

2. Study Objectives and Limitations

2.1 Study Objectives

The objectives of this study are to review a portion of the RHVP between Dartnall Road and Greenhill Road to determine the safety performance of the roadway since opening in 2007 and recommend viable potential measures that could be implemented to increase the safety performance and/or drivers' sense of security.

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2.2 Study Limitations

When conducting road safety studies two generic areas of review are roadway geometry and design and illumination. However, as part of the Parkway's long history, the road design has been analyzed and refined several times, up to and including the design changes put forward in 2003, which formed party of the critical environmental agreements and approvals have been made.

Design choices on the facility were intimately linked to approvals. Reference materials note; "The sole reason for making design changes was to reduce environmental impacts."[1] 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. It is one of only 16 biosphere reserves in Canada, and is part of a network of 598 in 117 countries. It is a rich mosaic of forests, farms, recreation areas, scenic views, cliffs, streams, wetlands, rolling hills, waterfalls, mineral resources, wildlife habitats, historic sites, villages, towns and cities. The Escarpment is home to more than 300 bird species, 53 mammals, 36 reptiles and amphibians, 90 fish and 100 varieties of special interest flora including 37 types of wild orchids. The Escarpment is home to almost 40% of Ontario's rare flora[2].

Because of this unique area, and because of the costs associated with building a roadway on the escarpment, the City identified several design refinements to the alignment of the roadway within the Valley. These refinements, "…consider environmental benefits, driver safety, and construction cost..."[3] and include the following specific to this review:

+ Reducing through lanes from 3 northbound and 3 southbound to 2 northbound (with a truck climbing lane from Greenhill Avenue to Dartnall Road) and 2 southbound to reduce the footprint of the road and increase potential areas for restoration and reforestation;
+ Redesigning the interchange with Greenhill Avenue (from a loop interchange to a diamond interchange) to reduce the required area (which protects specialized dry meadow, marsh and Escarpment habitats) and reduce the speed of vehicles existing and entering the Parkway; and
+ Restricting illumination to intersections and on/off ramps[4]

Through the City's IADP, these design changes were well scrutinized and the following[5] was found:

+ The four-lane facility could safety accommodate 2021 projected traffic volumes;
+ The Parkway could operate at the 90 km/h posted speed during peak hours in the year 2021;

[1] Red Hill Valley Impact and Design Process, City of Hamilton, Page 3
[2] http://www.escarpment.org/about/overview/index.php, Accessed July 2013
[3] Red Hill Valley Impact and Design Process, City of Hamilton, Page 6
[4] Red Hill Valley Project Public Consultation Report, March 2003, Lura Consulting, Page 136
[5] Red Hill Valley Impact and Design Process, City of Hamilton, Page 106

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- Interchanges at Mud Street and Greenhill Avenue would operate within an acceptable level of service;
- The design of the Parkway has taken into consideration the posted 90 km/h speed;
- Redesigns of the interchanges has considered the level of service; and
- The Parkway will operate safely.

Given the extensive history of the Parkway, the unique geography that is traverses, the many design refinements and assessments undertaken over the years, the many environmental agreements and approvals required and the "urban expressway" nature of the design, it was determined that a review of the fundamental roadway design geometry of the roadway and illumination throughout the study area was beyond the scope of this study.

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3. Scope and Study Area

3.1 Study Scope

The scope of this study included the review, analysis, development and assessment of the following key aspects:

- Review and analysis of traffic volumes, speed and collisions;
- Review and analysis of signs and markings;
- Review of human factors (and road user security);
- Review of roadside safety and hardware;
- Review of illumination in specific areas only (i.e. not throughout study area);
- Development of a long-list of viable potential countermeasures;
- Assessment of countermeasures using collision modification factors where available;
- Assessment of cost-benefit of countermeasures; and
- Recommendation of viable countermeasures.

3.2 Study Area

The study area included the RHVP between Dartnall Road and Greenhill Avenue as well as the Mud Street/Stone Church Road intersection. **Figure 1** illustrates the basic study area.

Figure 1 - Study Area

4. Safety Review

The purpose of the collision analysis is to identify locations that have a higher than average number of collisions and to identify locations where proportion of different collision types are unusually high. CIMA conducted the analysis using two different methods. The first analysis used strictly the historical observed number of collisions. Segmentation of the collision data was performed at a high level where each ramp was treated separately while the mainline was divided by sections in between interchanges. The second analysis involved the use of analytical tool known as the Enhanced Interchange Safety Analysis Tool (ISATe) which required a further, more detailed segmentation. Therefore, the collision data was segmented a second time to meet the data input requirements of ISATe.

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4.1 Collision Analysis

4.1.1 Methodology

Collision data were obtained from the City for a five-year period from October 10, 2008 to October 9, 2013. The collisions were provided for ten (10) ramps and a four kilometre stretch of RHVP from Dartnall Road to Greenhill Avenue.

The identification of collision trends within the study area was performed through a collision data review which considered descriptive statistics of collision conditions and locations. To help summarize collision data and to facilitate the identification of collision patterns, each collision was mapped and assigned to a road element; either a ramp or a mainline segment. The data needed to

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be segmented into homogeneous sections. A homogeneous section is one where the key characteristics of traffic volume, key geometric design features, and traffic control are unchanged throughout the section. A simple and straightforward segmentation was used in that each ramp was treated separately while the mainline was divided by sections in between interchanges. The various road elements included in the study area are listed in **Table 1** and illustrated in **Figure 2**.

Table 1 – List of Road Elements Included in the Study Area

Ramp Names	Mainline
+ Ramp #1: Dartnall Rd EB-SB off ramp + Ramp #2: Dartnall Rd NB-EB on ramp + Ramp #3: Dartnall Rd NB-WB Loop on ramp + Ramp #4: Dartnall WB off ramp + Ramp #5: Mud NB-EB off ramp + Ramp #6: Mud + Ramp #7: Mud WB-NB on ramp + Ramp #8: Mud SB-EB off ramp + Ramp # 9: RHVP NB to Greenhill + Ramp #10: Greenhill to RHVP SB	+ Lincoln Parkway west of Dartnall Rd + Lincoln Parkway between Dartnall Rd and Mud St. + RHVP between Mud St. and 0.8 km South of Greenhill Ave + RHVP North 0.8 km South of Greenhill Ave

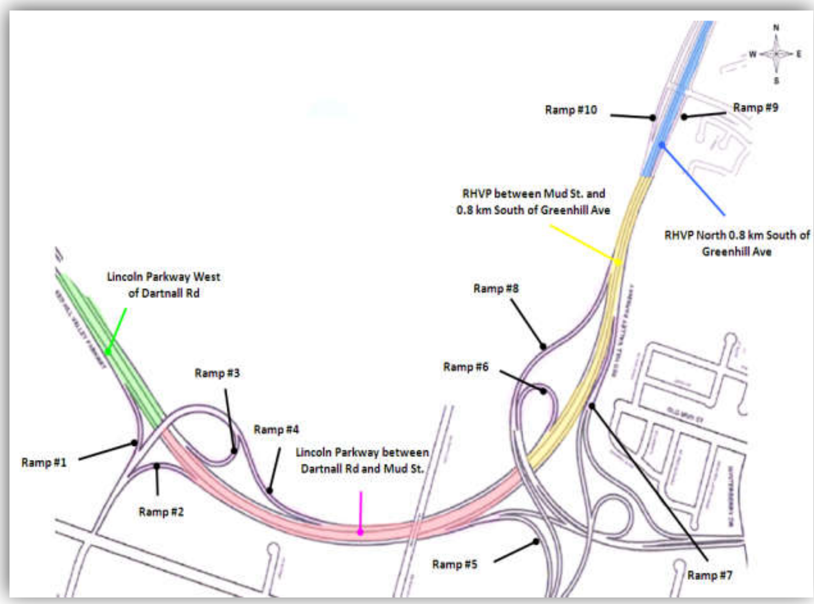

Figure 2 - Road Elements Included in the Study Area

The purpose of this collision analysis is to identify collision types that are over represented at different locations. The collision types that were analyzed included the following factors:

- Collision Severity: property damage only (PDO), non-fatal injury and fatal collisions;
- Collision Impact Type: single-motor vehicle (SMV), side swipe, rear-end, overtaking, head-on, right-turn, pedestrian and other collisions;
- Lighting: daylight and non-daylight; and
- Road Surface: dry, snow/ice, wet and other.

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4.1.2 Collision Analysis Results

The study area experienced a total of 186 collisions in the five years period reviewed, of which 82 occurred on ramps and the remaining 104 occurred on mainline segments. The collision distribution is shown in **Table 2**.

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Table 2 - Collision Distribution on Ramps and Mainline Segments

Road Elements	Length (m)	No. of Collisions	Proportion

Road Elements	Length (m)	No. of Collisions	Proportion
Ramps			
Ramp #1	285	3	4%
Ramp #2	300	0	0%
Ramp #3	490	0	0%
Ramp #4	585	0	0%
Ramp #5	160	7	9%
Ramp #6	450	41	50%
Ramp #7	850	12	15%
Ramp #8	420	2	2%
Ramp #9	390	16	20%
Ramp #10	305	1	1%
Total (Ramps)	***4,235***	***82***	***100%***
Mainline Segments			
West of Dartnall Rd	240	13	13%
Between Dartnall Rd and Mud St.	1,160	29	28%
Between Mud St. and 0.8 km South of Greenhill Ave	1,400	45	43%
North 0.8 km South of Greenhill Ave	1,200	17	16%
Total (Mainline)	***4,000***	***104***	***100%***

During the study period, no collisions were observed on Ramps 2, 3 and 4. Just two collisions were observed on Ramp 8 and one collision on Ramp 10. Half of all the ramp collisions reported were observed on Ramp 6 (from Mud Street westbound to the Linc westbound).

For mainline, the segment that experienced the highest proportion of collisions (43%) was between Mud Street and 0.8 km South of Greenhill Avenue, which also represents the longest segment with a total length of 1.5 kilometres. The next highest segment was between Dartnall Road and Mud Street which experienced 28% of the mainline collisions.

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Breakdown of Collisions

The following collision bar diagrams for each road element in the study area are provided in this section and document the severity, impact type, lighting and road surface.

COLLISION SEVERITY

Figure 3 provides collision bar diagrams for each collision severity attribute (PDO, non-fatal injury and fatal).

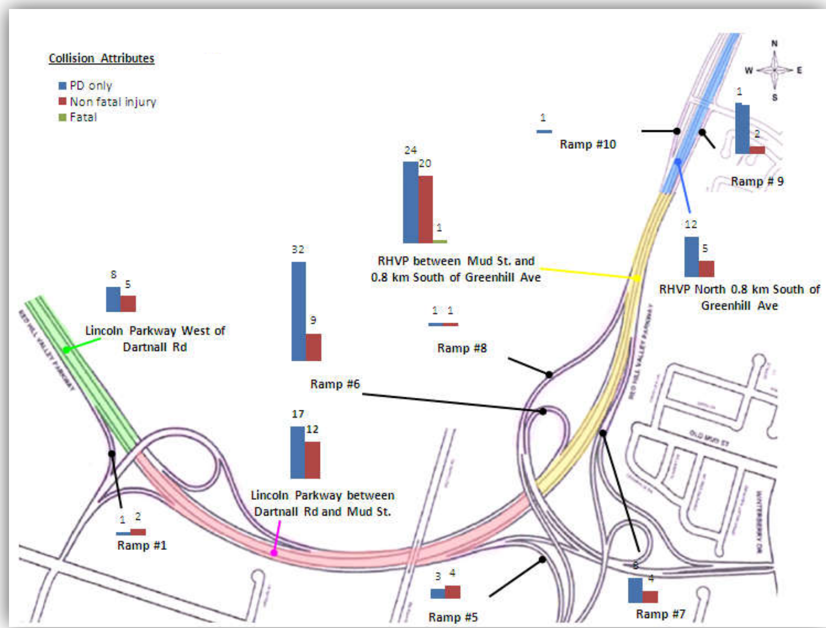

Figure 3 - Collision Bar Diagrams – Severity

Only one fatal collision occurred during the study period. The fatal collision was observed on the mainline segment of the RHVP between Mud Street and 0.8 km South of Greenhill Avenue.

The overall proportion of non-fatal injury collision within the study area is 34%. For two of the mainline segments, the Linc between Dartnall Rd and Mud Street and RHVP between Mud Street and 0.8 km South of Greenhill Avenue, the proportion of non-fatal injury collision is higher than the study area average, with 41% and 44% respectively. While the mainline segments are all different lengths, the length of the section does not impact the proportion of collision severity. In other words, collisions along these two mainline segments are more likely to be severe than compared to other locations along RHVP.

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COLLISION IMPACT TYPE

Figure 4 provides collision bar diagrams for each collision impact type attribute (single motor vehicle [SMV], side swipe, rear-end, overtaking, head-on, right-turn, pedestrian and other).

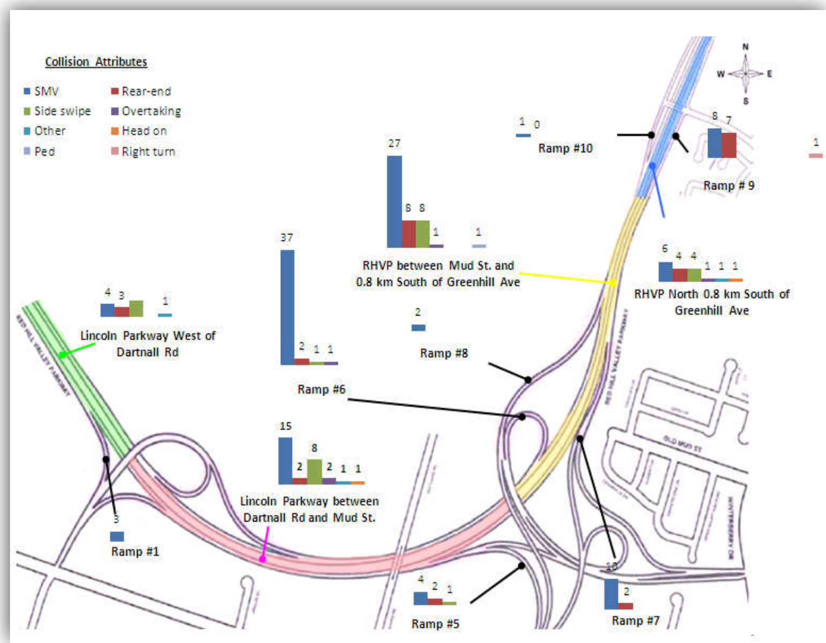

Figure 4 - Collision Bar Diagram – Impact Type

The most common impact type observed within the study area is SMV, with an overall proportion of 63%. The proportion of SMV collisions is significantly higher than all other locations on Ramp 6, where more than 90% of collisions are SMVs. These findings are notable, especially when compared to the 2004-2011 Provincial average of SMV collisions occurring on ramps[6], which is 57%.

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[6] Ministry of Transportation of Ontario SafetyAnalyst project, CIMA. 2013.

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LIGHTING

Figure 5 provides collision bar diagrams for each collision impact type attribute (daylight and non-daylight), where non-daylight includes dusk/dawn as well as dark conditions.

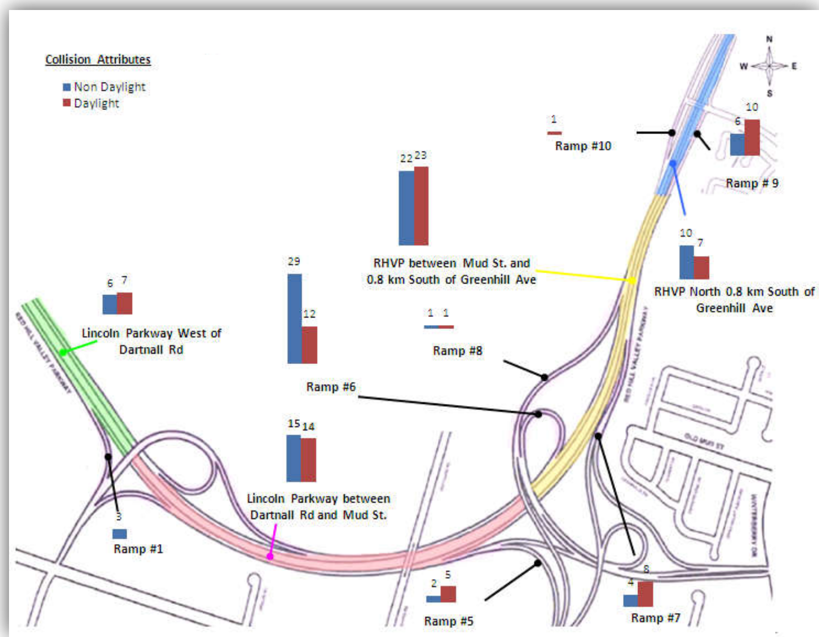

Figure 5 - Collision Bar Diagram – Lighting

The study area experienced an atypically high proportion of non-daylight collisions. In fact, according to the 2010 Ontario Road Safety Annual Report (ORSAR)[7], less than 30% of all collisions in Ontario occurred during non-daylight conditions. By comparison, the proportion of non-daylight collisions within the study area is 53% which is much higher than the provincial average. The road element within the study area that experienced the highest proportion of non-daylight collisions is Ramp 6, with a proportion of 71%.

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[7] Ontario Road Safety Annual Report (ORSAR), Ontario Ministry of Transportation, 2010

ROAD SURFACE

Figure 6 provides the collision bar diagram for collision road surface attribute (dry, snow/ice, wet and other).

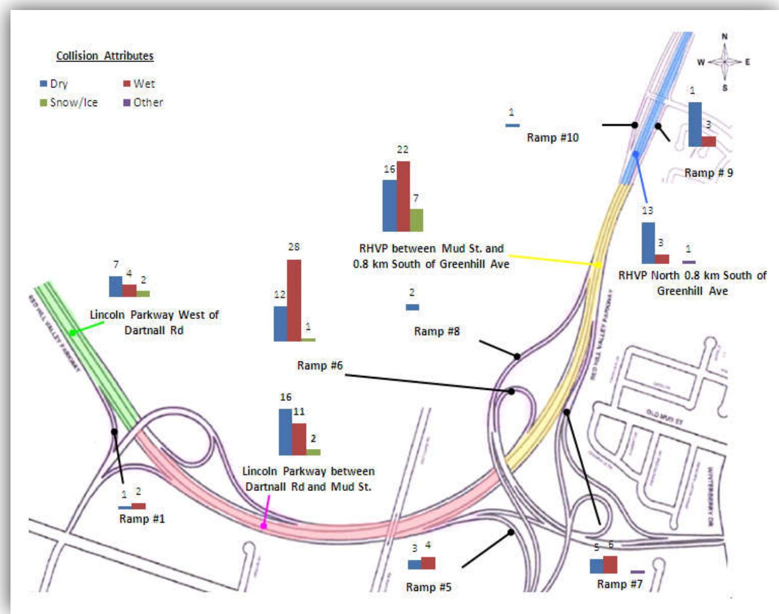

Figure 6 - Collision Bar Diagram – Road Surface

The study area overall average of collisions that occurred under wet road surface condition is 45%. When compared to the Provincial average of 17.4%[8], the proportion of collisions under wet road surface is significantly higher. This difference is mainly attributable to Ramp 6 and the mainline segment of RHVP between Mud Street and 0.8 km South of Greenhill Avenue, where the proportions of collisions that occurred under wet road surface conditions are 68% and 49%, respectively.

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Commented [N2]: Data on the percent of collisions on wet roads on just curves is not available.

Findings Summary

The following bullets summarize the most notable findings of the collision analysis:

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[8] Ontario Road Safety Annual Report (ORSAR), Ontario Ministry of Transportation, 2010

- Among the ten ramps included in the study area, 50% of the ramp collisions were recorded on Ramp #6;
- The proportion of non-fatal injury collisions for the mainline segments between Dartnall Road and Mud Street and Mud Street and 0.8 km south of Greenhill Avenue is higher than the study area average;
- The most common impact type observed within the study area is SMV, with an overall proportion of 63%;
- The proportion of SMV collisions on Ramp 6 is more than 90%;
- The proportion of non-daylight conditions (53%), and the proportion of non-daylight collisions on Ramp 6 (71%) are much greater than the Provincial average proportion of collisions which is approximately 30%; and
- The proportion of collisions that occurred under wet road surface for Ramp 6 and the mainline segment of RHVP between Mud Street and 0.8 km South of Greenhill Avenue are 68% and 49%, respectively, which is much greater than the Provincial average of 17.4%.

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4.2 Safety Analysis Using the Enhanced Interchange Safety Analyst Tool (ISATe)

4.2.1 Terminology: Observed, Predicted, and Expected Number of Collisions

The number of collisions that occur at a location is referred to the observed number of collisions. Since collisions have a highly random component, the observed collision data is quite noisy and can vary greatly from year to year. If we had 50 years of collision data on a ramp, then the average number of collisions over the 50 years would be a very good estimate of the true safety of the ramp. This would assume of course that nothing changed over the 50 years including traffic volume, drivers (age, education, experience), vehicles, the characteristics of the ramp itself, and the environment. Obviously it is not reasonable to have available 50 years of collision data at a location that has not changed. Instead, a jurisdiction may only have five years of collision data since the last major geometric change and five years is not sufficient to calculate a long term average. Imagine however that we have 50 ramps with similar characteristics along with their corresponding traffic volumes. This means having 5 years × 50 ramps = 250 years of data which can then be used to calculate an overall average number of collisions.

A Safety Performance Function (SPF) is a mathematical equation which describes the best fit relationship between the number of collisions on a road and the characteristics of the road where the characteristics can include traffic volume, road functional class, and environment type. SPFs are published in the literature or are developed by using all of the data from a jurisdiction to determine the best fit equation. By plugging key information into a SPF, one can then calculate what is referred to as the predicted number of collisions. The predicted number of collisions may be thought of as the average number of collisions of the particular type of entity with that particular traffic volume for a typical location.

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The observed number of collisions provides site specific information, whereas the SPF provides overall average information. By combining the information from the observed and predicted number of collisions a better estimate of the true safety of a location can be determined. The empirical Bayes methodology combines observed collision data with the number of collisions predicted for similar sites. The combined number is known as the expected number of collisions. The expected number of collisions combines the observed number of collisions (obtained from the actual data) with the predicted number of collisions (obtained from the SPF for similar sites).

The expected number of collisions is estimated by using the empirical Bayes method to create a weighted combination of the actual number of collisions (obtained from the frequency data) and the predicted number of collisions (obtained from the SPF). This empirical Bayes method was developed by Dr. Ezra Hauer and described in his book Observational Before-After Studies in Road Safety (Pergamon Press, 1997). The approach was first used in the Ministry of Transportation of Ontario's Science of Highway Safety initiative and developed by Dr. Ezra Hauer. Details relating to the empirical Bayes method may be found in the White Paper for Module 1 – Network Screening (www.safetyanalyst.org/whitepapers/module1.pdf) developed for SafetyAnalyst, an AASHTOWare software program. In addition, the Ministry of Ontario has recently migrated their collision, traffic volume, and roadway inventory data into SafetyAnalyst for the purpose of network screening (www.tac-atc.ca/english/annualconference/tac2012/docs/session15/izadpanah.pdf).

The empirical Bayes methodology is also used by the ISATe tool as described in the next section.

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4.2.2 Methodology

ISATe[9] is an automated tool for assessing the safety of freeway facilities, including mainline sections and interchanges. This tool is intended to assist designers in making more informed decisions about the level of safety of design alternatives. Three main types of analysis can be performed using ISAT, including:

- Reconstruction Project Prioritization: to estimate the safety performance of a facility by determining its priority for reconstruction;
- System Safety Management: to evaluate the safety performance of several facilities and determine what countermeasures and where to implement them so that the greatest impact on safety is achieved; and

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[9] Bonneson, J. A.; Pratt, M. P. ; Geedipally, S.; Lord, D.; Neuman, T.; Moller, J. A. Enhanced Interchange Safety Analysis Tool: User Manual. National Cooperative Highway Research Program Project 17-45. 2012.

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- Economic Analyst: to estimate the cost associated with the expected total number of collisions or to evaluate the safety benefits due to the number of collisions saved after the implementation of a countermeasure.

ISATe incorporates the safety prediction method which is included in Part C of the Highway Safety Manual (HSM). It uses a disaggregate safety evaluation approach. Freeway facilities are disaggregated into freeway mainline sections and/or interchanges, and an interchange subsequently disaggregated into ramps, collector-distributor (C-D) roads and crossroad terminals. Therefore, a safety analysis performed using ISATe can include the following basic roadway facility components:

- Freeway sections (with or without speed-change lanes);
- Ramps or C-D roads; and,
- Crossroads ramp terminals.

Each component is further divided into segments or intersections as individual sites. The corresponding safety performance functions (SPFs) and collision modification factors (CMFs) are then used to evaluate the predicted average collision frequency at a site. The disaggregate approach also provides the ability to estimate the impacts on safety (collision frequency, type and severity) of modifying a specific geometric element (shoulder width, presence of a barrier, curve length, curve radius, speed-change lane, etc.).

The following provides a list of the different road characteristics that were to develop the SPFs available ISATe:

- For freeway segments:
  - Site types: freeway segment, ramp-entrance speed-change lane, ramp-exit speed-change lane
  - Severity: fatal and injury, property damage only
  - Area type: rural, urban
  - Freeway through lanes: 4, 6, 8, 10
  - Collision type: multiple vehicle, single vehicle
- For Ramps:
  - Site types: entrance ramp, exit ramp, C-D road
  - Severity: fatal-and-injury (FI), property-damage-only (PDO)
  - Area type: rural and urban
  - Ramp through lanes: 1 and 2
  - Collision type: multiple vehicle, single vehicle

The CIMA team obtained all of the required input information and entered it into ISATe for the RHVP study area.

For ISATe, the corridor needed to be further segmented resulted in creating 15 freeway segments and 8 ramp segments.

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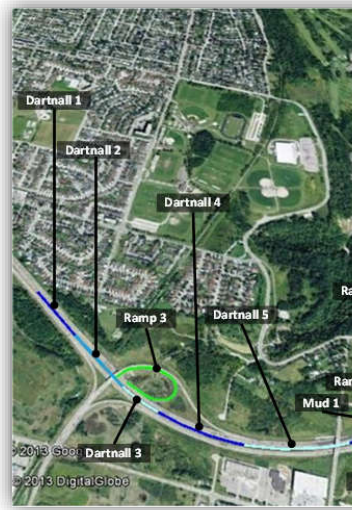

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Limitations of ISATe

The use of ISATe to conduct safety analysis has one significant limitation. The SPFs used in ISATe are not calibrated for the collision experience in Hamilton. Calibration ensures that the evaluation results are meaningful and accurate for a specific jurisdiction. The default SPFs found in ISATe are calibrated for the U.S. through NCHRP Project 17-45. Therefore, when one compares the observed number of collisions to the predicted number of collisions generated from ISATe, one is comparing local Hamilton data against the overall average number of collisions found at freeways and ramps in states in the U.S. This means that the output of ISATe is suitable only for relative rankings and not for absolute collision values. In other words, the location with the highest predicted number of collisions will most likely remain the highest compared to other RHVP locations even after recalibration (relative ranking). However, the number of calculated collisions will likely change after recalibration (absolute values).

There is insufficient data in the current study to calibrate the SPFs in ISATe for the Hamilton. The ISATe User Manual states that for each site type there should be at least 100 collisions per year. For the RHVP study corridor there were only 160 total collisions for all site types spread over five years. In addition, generally many locations are needed for recalibration whereas this project covers only one highway.

4.2.3 ISATe Tool Results

ISATe was used to calculate the predicted and expected number of collisions as provided in **Table 3** for freeway segments (for both directions) and **Table 4** for ramp segments (note that there was not collision information provided for Ramps #1, 2 or 4). In general, when the observed number of collisions is less than the predicted, then this is an indication that the location is performing better than average. When the observed number of collisions is greater than the predicted, this is an indication that the location is performing worse than average. The expected number of collisions is an empirical Bayes weighted average of the observed and predicted values. Therefore, the expected value is always a value in between the observed and predicted values.

Table 3 - Observed, predicted and expected number of collisions for the freeway segments

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Freeway Segments										
				Observed Number of Collisions						
	Description	Lanes	Length (km)	Daylight	Non-Daylight	SMV	Multi-Vehicles	Total Observed	Predicted	Expected

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Dartnall 1 & 2	Portion 1	4	0.24	1	4	1	4	5	15.4	8.9
	Portion 2	4	0.27	6	4	5	5	10	17.1	12.5
	Dartnall 3	4	0.16	3	0	1	2	3	9.9	6.1
	Dartnall 4	4	0.31	3	3	4	2	6	30.9	14.0
	Dartnall 5	5	0.34	5	5	5	5	10	22.3	12.8
	Mud 1	5	0.35	6	9	8	7	15	16.5	15.9
	Mud 2	5	0.24	5	1	5	1	6	8.0	7.3
	Mud 3	5	0.19	2	3	4	1	5	8.0	6.4
	Mud 4	6	0.16	6	6	6	6	12	6.6	8.9
	Mud 5	6	0.10	4	2	6	0	6	9.0	6.4
	Mud 6	5	0.34	4	7	6	5	11	51.0	16.4
	Greenhill 1	5	0.39	2	3	1	4	5	26.4	13.7
	Greenhill 2	5	0.71	4	9	5	8	13	43.2	25.3
	Greenhill 3	5	0.16	1	0	0	1	1	8.8	4.5
	Greenhill 4	4	0.34	4	0	1	3	4	17.8	10.2

Table 4 - Observed, predicted and expected number of collisions for the ramp segments

Ramp Segments					
Des	Lan	Len	Observed Number of Collisions	Pre	Exp

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cription	es	gth (mi)	Daylight	Non-Daylight	SMV	Multi-Vehicles	Total Observed	dicted	ected
Ramp #3	1	0.48	1	0	1	0	1	40.1	7.6
Ramp #5	2	0.16	4	1	2	3	5	2.0	2.6
Ramp #6	1	0.42	11	29	37	3	40	23.3	37.1
Ramp #7a	1	0.60	2	1	3	0	3	6.4	5.1

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Ramp #7b	1	0.21	5	2	6	1	7	1.9	3.7
Ramp #8	2	0.50	0	1	1	0	1	11.4	6.0
Ramp #9	1	0.35	3	1	3	1	4	1.4	1.8
Ramp #10	1	0.27	1	0	1	0	1	0.9	1.0

Overall the number of observed collisions is less than the predicted number of collisions, except for the following locations:

+ Freeway segment Mud 4;
+ Ramps 5, 6, 7b 9 and 10.

For example, for Ramp #5 there were 5 observed collisions, however the ISATe tool predicts there would be only 2 collisions.

This difference between the expected and predicted number of collisions is referred to the as the potential for a safety improvement (PSI) and also referred to as the excess number of collisions in the Highway Safety Manual. In other words these locations stand out as performing worse than a typical location of the same facility type with similar traffic volume. These locations deserve special consideration since the number of collisions which have occurred is worse than average.

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4.3 Traffic Operations

A high level review of traffic operations was undertaken for the study area. Highway Capacity Software (HCS) 2010 was utilized to examine the mainline and the ramps during the AM and PM peak periods. It was found that, generally, the study area operates well with most segments and ramps experiencing LOS "C" or better, although there are some exceptions. **Figure 8** summarizes the LOS for the various elements for the AM and PM peak periods.

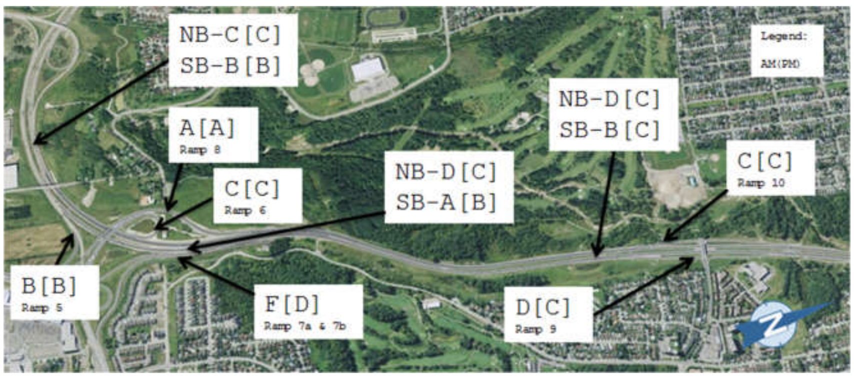

Figure 7 - Results of Operational Analysis for AM and PM Peak Periods – AM[PM]

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4.4 Illumination Review

4.4.1 Methodology

The primary objective of illumination is to increase safety by providing drivers with improved nighttime visibility of roadway conditions and potential hazards. However, 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. Therefore, the decision to provide roadway lighting should be looked using sound criteria, but also in the context of the whole roadway network.

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.

Additional consideration must be given to other environmental factors as well, including "light pollution". Light pollution is often a concern of neighbours living adjacent to a roadway facility. This excess light may detract from the enjoyment of the nighttime setting and have negative effects on biological systems. Therefore, the reduction in light pollution should be a major consideration in the installation of illumination. Finally, the understanding that the decision to not illuminate the entire RHVP section was inextricably linked to environmental concerns and approvals, review of full illumination was not undertaken but restricted to spot locations.

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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[10]. This policy is based on an analytical approach where several factors have been incorporated. The factors included in the warrants require the collection of the following types of data: geometric, operational, environmental, and collision data.

The guide differentiates the following four types of illumination: full lighting, partial interchange lighting, continuous lighting (not being examined as part of this study), and transition lighting.

Full Lighting

Full lighting refers to lighting of the entire width within a defined area in a uniform manner, beginning at the start of the warranted area and ending where lighting is no longer warranted.

Partial Interchange Lighting

Refers to lighting at decision points where identification is required, typically at on-ramps and off-ramps. Few luminaires are needed for partial interchange lighting than for full lighting.

Transition Lighting

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Continuous lighting is defined as the full lighting between intersections or interchanges that are fully lighted.¶

Refers to lighting at locations where a continuously lighted roadway tapers to fewer lanes, or locations where the continuous lighting ends and the road continues. This type of lighting assists the road users to adapt from a lighted area to an unlighted area.

Warrants

The determination of the need for illumination on freeway interchanges and freeways is performed through the use of warrants. Based on the factors included in the warrants, a rating of between 1 and 5 is assigned depending on the conditions encountered. The higher the rating, greater the hazard and the more critical is the need for illumination. To each factor a weight is also attributed, to indicate its relative importance. When factors vary for within the portion of roadway for which the warrant is being undertaken, the worst case rating is recommended for the entire segment.

The forms used to determine the lighting need for freeway interchange (mainline interchange segments) and freeway (mainline segments) are provided in **Appendix XX**.

Full lighting is warranted when a total point score of 60 or more is achieved, or when the night-to-day collision ratio is 2:1 or greater (which is not the case for the study area – night-to-day collision ratio is 1.10:1).

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[10] Guide for the Design of Roadway Lighting, Transportation Association of Canada (TAC), 2006

4.4.2 Illumination Results

The full illumination justification was completed for three interchanges; Dartnall Road, Mud Street and Greenhill Avenue. The two factors included in the warrants with the highest weights are the proportion of night collisions and the presence of curves, followed by the night-time operational Level of Service.

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The following was found:

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- Illumination at the Dartnall Road interchange was not warranted;
- Illumination at the Mud Street interchange was warranted with a total point score of 62.35 (minimum score of 60.00 required for illumination); and
- Illumination at the Greenhill Avenue interchange was not warranted.

Based on the TAC warrant, full interchange illumination is warranted for the Mud Street interchange.

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However, it must be noted that the achievement of a warrant does not automatically mean that illumination must be installed. All illumination must be assessed in relation to the approval constraints which falls outside the scope of this study.

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4.5 Field Investigation and Human Factors Assessment

4.5.1 Methodology

The daytime field investigation took place on Tuesday, May 14, 2013, during morning peak and off-peak periods (07:00 a.m. – 12:00 p.m.) and during the afternoon peak (4:30 p.m. – 6:00 p.m.). At the time of the investigation the weather was cool and cloudy with no precipitation. One nighttime site investigation was also conducted during the early morning hours of Tuesday, May 14, 2013 during dark lighting conditions. At the time of the investigation the weather was cool, cloudy, with no precipitation.

High Definition video and a picture inventory from the perspective of a driver, from each lane, was collected for each of the mainline and ramp sections. Stationary observations were also undertaken from four separate locations along the mainline; from the pedestrian bridge overpass between the Dartnall Road and Mud Street interchanges, from the Pritchard Road overpass, from the east end of Mud Street (Mountain Brow Boulevard - view of the Mud Street E-W on-ramp, and from the Greenhill Avenue overpass.

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4.5.2 Field Investigation Results – Overall Systematic Findings

This section describes systemic findings that were identified within the study area overall.

Signage

One of the critical tasks that a road user must complete it to collect, understand, make decisions about and react to information obtained from various sources, including regulatory, warning, information and guide signs. Therefore, it is critical that signs present the needed information

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quickly, effectively, and in a timely manner. This must be accomplished without overloading, confusing, preoccupying or distracting the road user.

Generally, it was found that the freeway signage follows OTM guidance for placement and message, however, in some instances it appears that there is more signing in place than what is required. It was found that the positioning of some signs could be improved. In a few locations (sometimes where critical decisions are required to be made by drivers), signs are so closely spaced that they eclipse each other and/or send a convoluted message. Additional details are provided in latter sections of this report.

TRAILBLAZER INFORMATION SIGN DISPLAYS

The primary purpose of a guide or information sign is to direct road users along a roadway. As noted, guide signs must present the needed information quickly, effectively, and in a timely manner.

The trailblazer information sign displays for the RHVP and the Linc contain a lot of information for an approaching road user to read, process, and make an appropriate decision. The displays contain varying colours, shapes, text sizes, and individual signs separated by boarders and copy faces. **Figure 9** illustrates some instances of the identified cases. For example, the sign on the far left includes specific direction to the QEW and 403. For an unfamiliar driver, this information is important and is missing on the sign in the middle.

Figure 8 - Trailblazer Information Sign Displays (Various Locations Leading to RHVP/Link On-Ramps)

LANE EXIT SIGNS

This sign is normally reserved for freeway mainlines to provide advance warning where an entire lane exits from the one side of the road and leads to a different destination from that of the remaining lanes comprising the through roadway. This sign is used in a few instances on ramps where the driver has already made the decision to leave the mainline and there is no through roadway. **Figure 11** provides an illustrative example of one such case.

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Deleted: Each display contains a number of individual pieces of information, and in some, a number of different physical signs. The displays are located at decision points where an unfamiliar driver must make a determination in which direction they are intending to travel. **Figure**

Deleted: Also note that in the far right photo the largest font for the sign at Mud Street is for the word "TO". ...

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Deleted: The information on the Trailblazer Information sign for the "Mohawk 4 Ice Centre" appears to be too small. **Figure 10** provides an illustrative example of this case.¶

Deleted: Figure 10 - Trailblazer Information Sign Display for the "Mohawk 4 Ice Centre"¶

Figure 9 - Lane Exit Warning Sign on Ramp (Off-Ramp to Stone Church Road)

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Evidence of Roadway Departure Collisions

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Roadside steel beam guide rail systems and concrete barriers contain evidence of impacting collisions at a number of locations. For the steel beam guide rail systems, depending on the severity, the damage could impede the structural integrity of the system. This could cause the system to function unexpectedly on a subsequent impact. **Figure 12** through **Figure 14** provides illustrative examples of some of the identified cases. Also, a number of plough markers mounted in advance of guide rail system end treatments were damaged and/or not vertically plumb.

Figure 10 - Dartnall E-S OFF Ramp (View West from the Off-Ramp)

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Figure 11 - NB Main Line (View North from the Mainline); SB Mainline just west of Dartnall off-ramp (View West from the Mainline)

Figure 12 - Dartnall S-W Ramp (View North from the On-Ramp); Dartnall westbound on-ramp (View West from the On-Ramp)

4.5.3 Field Investigation Results – Location Specific Issues

This section describes issues identified throughout the study area by location.

RHVP Southbound Mainline

CLOSELY-SPACED SIGNAGE AND "SLOWER TRAFFIC KEEP RIGHT" SIGN AT DIVERGE POINT (MUD 5)

A group of closely-spaced signs exists between immediately upstream of the Stone Church Road and Mud Street off-ramp. Given the amount of information in a short stretch of road and the fact that this is a critical decision point on the mainline, the message of each sign could be lost and could

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Deleted: ALIGNMENT DISCONTINUITY THROUGH MAINLINE CURVE (DARTNALL 5)¶
The mainline alignment discontinues through the horizontal curve just south of the Pritchard Road overpass. The horizontal curve contains a tangent section part way through the curve. The discontinuity is very noticeable when viewed from the Pritchard Road overpass. **Figure 15** provides an illustrative example of this issue.¶

Figure 15 - View of Discontinuity in Horizontal Curve on the Mainline (View West from Pritchard Road Overpass)¶
Many drivers were observed traversing or closely approaching the inside (median) edge line of the highway. Some vehicles were observed driving over the rumble strips and then overcorrecting to position themselves back into their travel lane. Overcorrection actions were observed less often during the peak hours, possibly due to lower speeds. **Figure 16** provides illustrative examples of this case.¶

Figure 16 - Observed Cases of Swerve- and Overcorrection-Manoeuvers (View West from Pritchard Road Overpass)¶ ... [1]

contribute to driver confusion. **Figure 17** provides an illustrative example. There is also a “SLOWER TRAFFIC KEEP RIGHT” sign installed essentially right at the diverge point for the Stone Church Road / Mud Street diverge point where the right lane becomes a dedicated exit lane. This message may be confusing to road users, and could possibly lead to weaving conflicts. **Figure 18** provides an illustrative example.

Figure 13 - Closely-Spaced Signage Upstream of the Stone Church Road and Mud Street Off-Ramp (View South from the Mainline)

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Figure 14 - “SLOWER TRAFFIC KEEP RIGHT” Sign Upstream of the Stone Church Road and Mud Street Off-Ramp (View South from the Mainline)

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OBSCURED FREEWAY EXIT SIGN (MUD 5)

The Freeway Exit sign in the gore area of the Stone Church Road / Mud Street off-ramp is partially eclipsed by the Object Marker warning sign on approach. **Figure 19** provides and illustrative example.

Figure 15 - Freeway Exit sign Partially Eclipsed by the Object Marker Warning Sign (View South from the Mainline)

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ALIGNMENT DISCONTINUITY THROUGH MAINLINE CURVE (DARTNALL 5)

The mainline alignment discontinues through the horizontal curve just south of the Pritchard Road overpass. The horizontal curve contains a tangent section part way through the curve. The discontinuity is very noticeable when viewed from the Pritchard Road overpass. **Figure 15** provides an illustrative example of this issue.

Figure 16 - View of Discontinuity in Horizontal Curve on the Mainline (View West from Pritchard Road Overpass)

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Many drivers were observed traversing or closely approaching the inside (median) edge line of the highway. Some vehicles were observed driving over the rumble strips and then overcorrecting to position themselves back into their travel lane. Overcorrection actions were observed less often during the peak hours, possibly due to lower speeds. **Figure 16** provides illustrative examples of this case.

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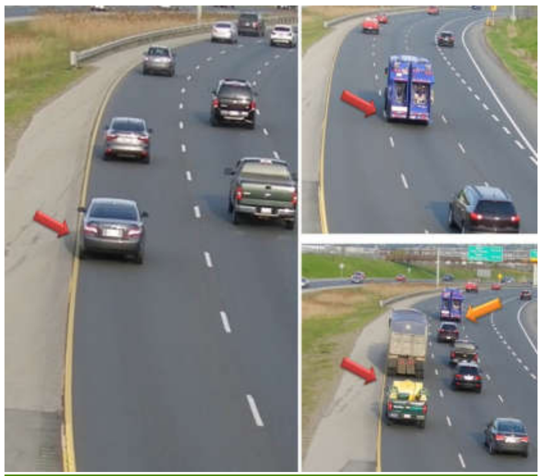

Figure 17 - Observed Cases of Swerve- and Overcorrection-Manoeuvers (View West from Pritchard Road Overpass)

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In the figure, the photos illustrate drivers approaching the edge lines (emphasized with the red-coloured arrow). The picture on the right illustrates the overcorrection manoeuver made by the driver in the garbage truck in the center lane of the mainline. Subsequent to the initial correction manoeuver and as a result of overcorrection, the driver had veered close to the right outer side of the lane (emphasized with the orange-coloured arrow).

It is important to note that no collisions were attributable to this issue, nor does this issue appear as significant in the northbound lanes.

RHVP Northbound Mainline

OBSCURED INFORMATION SIGN (DARTNALL 4)

The information sign for Stone Church Road / Mud Street located approximately 500 metres upstream of the Stone Church Road / Mud Street off-ramp is marginally eclipsed by the Deer Crossing warning sign immediately in advance. **Figure 20** provides an illustrative example of this case.

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Figure 18 - Deer Crossing Warning Sign Obscuring Information Sign (View North from the Mainline)

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POTENTIALLY RESTRICTED SIGHTLINES FOR MERGING TRAFFIC (DARTNALL 4)

The on-ramp merge lane is located within a horizontal curve in the mainline. Vehicles northbound on the mainline and upstream of the ramp may not be easily visible by a merging driver given the curvature of the road and the angle of approach. Many drivers were observed merging onto the mainline immediately downstream of the gore area, even where short gaps were available, which could lead to sideswipe collisions, rear-end collisions or SMV collisions if evasive manoeuvres are undertaken. **Figure 21** provides an illustrative example.

Figure 19 - Potentially Restricted Sightlines for Merging Traffic

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UNEVEN TERRAIN IN FRONT OF GUIDE RAIL (MUD 1)

The terrain is uneven immediately in front of the steel beam guide rail system in the median downstream of the Stone Church Road / Mud Street diverge point. The purpose of the guide rail system is to shield arrant vehicles from the columns of the Stone Church Road / Mud Street overpass structure. If an errant vehicle were to run off the road in this location, they would ride up on the uneven grassy terrain in front of the barrier causing the vehicle to strike the system at a higher point than it is designed for. This could lead to the overturning of a vehicle, and possibly continuation into the column being shielded. **Figure 22** provides and illustrative example.

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Figure 20 - Uneven Terrain Immediately In Front of the Steel Beam Guide Rail System (View North from the Mainline)

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CLOSELY SPACED SIGNAGE (MUD 5)

A "PLEASE AVOID USE OF ENGINE BRAKES" Regulatory sign located downstream of the Mud Street on-ramp between a Lane Drop and Bridge Ices warning sign. These signs are closely spaced and within the vicinity of a complex merging area where drivers from Mud Street are required to perform two consecutive merging maneuvers; one from the Stone Church on-ramp and then another onto the mainline of the RHVP. Given the nature of the location, the warning signs are the highest priority and require the immediate attention of drivers. In its current configuration, the signage in this area could potentially lead to driver-overload and possible conflicts. **Figure 23** provides an illustrative example.

Deleted: A curve warning sign also exists on the left side of the road in this area. Given the nature of the location

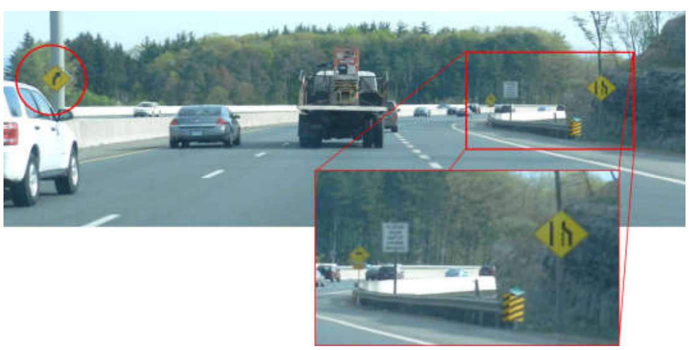

Figure 21 - Closely Spaced Signs within the Vicinity of a Complex Merging Area (View North from the Mainline)

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Dartnall Road W-E Off-Ramp (Ramp 1)

POORLY DESIGNED AND DAMAGED GUIDE RAIL END TREATMENT

The Eccentric Loader steel beam guide rail end treatment on the outer edge of the Dartnall Road off-ramp is damaged, does not contain a sufficient flat run-out area behind the system, and the system itself on the approach end is leaning out and is not vertically plumb. A vehicle striking this system may not be shielded from the slope as intended. **Figure 24** provides and illustrative example.

Figure 22 - Damaged and Poorly Designed Guide Rail End Treatment

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Dartnall Road S-E On-Ramp (Ramp 2)

LUMINAIRE WITHIN DEFLECTION AREA OF APPROACH ECCENTRIC LOADER END TREATMENT

The luminaire pole adjacent to the guide rail system at the beginning of the Dartnall Road on-ramp is within the run-out area of the Eccentric Loader approach end treatment. If the end treatment is stuck, it is possible that the vehicle will also come into contact with the luminaire. **Figure 25** provides and illustrative example.

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Figure 23 - Pole within Deflection Area of Approach Eccentric Loader End Treatment (View North from Beginning of Off-Ramp)

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Mud Street W-E Off-Ramp (Ramp 5)

The outside (right) lane ends within the horizontal curve downstream of the mainline. The taper ending the lane is fairly short and exists along the length of the curve. This lane essentially ends at the beginning of the curve, forcing traffic to merge within the curve which requires a driver to perform two workload intensive maneuvers at the same time. **Figure 26** provides an illustrative example.

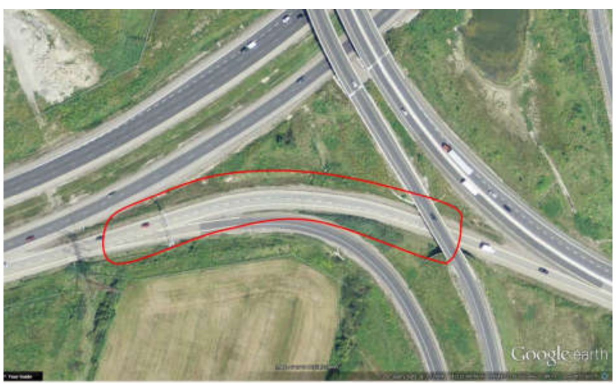

Figure 24 - Outside Lane Ends within Horizontal Curve

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Mud Street E-W On-Ramp (Ramp 6)

CLOSELY-SPACED AND ECLIPSING SIGNAGE

A group of closely-spaced signage exists in the ramp gore area (near Winterberry Drive). Many of the signs eclipse each other on approach, most notably the information sign for the Linc and the Lane Drop warning sign are not clearly visible to drivers but provide valuable information that needs to be legible. **Figure 27** provides illustrative examples of this signage configuration from two vantage points.

Figure 25 - Closely-Spaced and Eclipsing Signage (View West from Beginning of On-Ramps)

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EVIDENCE OF LANE DEPARTURES

Evidence of vehicles departing the travel lane was identified on the outside of the ramp. In this case, if a vehicle were to leave the traveled portion of the road, it would likely result in damage to a vehicle and possibly injury to its occupants. **Figure 28** provides an illustrative example.

Figure 26 - Evidence of Lane Departures

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Mud Street E-N On-Ramp (Ramp 7a)

CLOSELY-SPACED AND "BACK-DROPPED" SIGNAGE

As noted for the Mud Street E-W on-ramp, a group of closely-spaced signage exists in the ramp gore area. The 40 km/h advisory signage for this ramp is placed amongst signage for the Mud Street E-W on-ramp and is easily lost in the jumble. Although sign-eclipsing isn't an issue here, the signs are back-dropped by the information sign for the Linc. Also, the Lane Ends warning sign for the Mud Street E-W on-ramp is located between the Freeway Exit sign and the Mud Street E-W on-ramp information sign, which could cause further confusion. **Figure 29** provides an illustrative example.

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Figure 27 - Closely-Spaced and Eclipsing Signage (View West from Beginning of On-Ramp)

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INAPPROPRIATE WARNING SIGN FOR CONFIGURATION

The Merge warning sign on approach to the Stone Church Road East S-N on-ramp is inappropriate for the configuration. The driver on the E-N ramp is the one who is merging onto the S-N ramp. This sign indicates that another lane is joining from the right and could cause driver confusion. A Lane Ends warning sign is required, as opposed to the Merge warning sign. **Figure 30** provides an illustrative example.

Figure 28 – Inappropriate Merge Warning Sign (View North from On-Ramp)

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OBJECT MARKERS, AND POST-MOUNTED DELINEATORS

The Object Marker warning sign immediately in advance of the Extruder guide rail end treatment downstream of the Stone Church Road / Mud Street merge lane is damaged and not vertically plumb. **Figure 31** provides and illustrative example.

Figure 29 - Object Marker Damaged and Not Vertically Plumb (View North from the Mainline)

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DAMAGED POST-MOUNTED DELINEATORS

A number of post-mounted delineators on the outside of the ramp curves appear to have been struck by vehicles and are not vertically plumb. **Figure 32** provides an illustrative example.

Figure 30 - Damaged Post-Mounted Delineators

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Stone Church Road East N-S Off-Ramp & Mud Street N-E Off-Ramp (Ramp 8)

LOCATION OF INFORMATION SIGNS

The information and lane designation signs at the diverge point from RHVP indicates both ramp lanes to lead to Mud Street and Stone Church Road. Small information signs indicating that the left lane leads to Mud Street and the right lane leads to Stone Church Road are located approximately 160 metres upstream of the forced diverge point for Mud Street and Stone Church Road, are directly behind curve warning signs and immediately before a curve. Since the information signs are small there is a good chance that a driver will not detect them. Also, due to the horizontal curvature of the ramp, the signs are not visible very far in advance (they fall outside the driver's cone of vision through the curve), and as a result, sudden lane changes and potentially related conflicts, may occur in this area.

If the small information signs are missed the next available signage to inform road users of the appropriate lane decision are located at the diverge point. However, similar to the previous information signs, given the horizontal curvature of the ramp, the signs are not visible in advance of their placement and sudden lane changes, and potentially related conflicts, may occur in this area. **Figure 33** provides illustrative examples of the drivers' approach to the diverge area.

Figure 31 - Information Signs Leading to Mud Street and Stone Church Road (View South Successively Traveling South)

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INCONSISTENT CURVE WARNING SIGNS ON THE RAMP

The curve warning signs on either side of the road on the off-ramp provide inconsistent information regarding the severity of the curve. It is important that consistent and appropriate warning the severity of a curve be provided to a driver in order to assist them in making the appropriate decisions to safety navigate through the curve. **Figure 34** provides an illustrative example of this case.

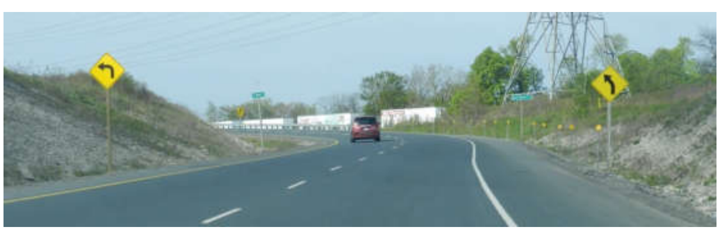

Figure 32 - Conflicting Curve Warning Signs on the Ramp

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5. Summary of Findings

This section summarizes the findings from the collision, ISATe and field reviews. Where possible, road sections have been grouped by similar characteristics and findings, similar to the more aggregated sections shown in **Figure 2** earlier in the report.

Overall, it was found that the RHVP is operating safely with the calculated expected number of collisions being lower than the predicted number of collisions for a roadway with similar characteristics in most segments. During the study period, no collisions were observed on Ramps 2, 3 and 4, and just two collisions were observed on Ramp 8 and one collision on Ramp 10. However, it is important to note that half of the ramps collisions were observed on Ramp 6 (from Mud Street westbound to the Linc westbound).

For mainline, the segment that experienced the highest proportion of collisions (43%) was between Mud Street and 0.8 km South of Greenhill Avenue, which also represents the longest segment with a total length of 1.5 kilometres. The next highest segment was between Dartnall Road and Mud Street which experienced 28% of the mainline collisions.

The output of the ISATe tool indicated that freeway segment Mud 4 and ramps 5, 6, 7b 9 and 10 have an excess number of collisions as indicated by a positive difference between the expected and predicted number of collisions. This is indicative of a a potential for a safety improvement (PSI). In other words, these locations stand out as performing worse than a typical location of the same facility type with similar traffic volume.

It is also noteworthy that the collisions that are occurring on the RHVP show an atypically high proportion of SMV, wet road surface and non-daylight collisions when compared to the Provincial average.

The TAC illumination warrants were examined as part of this study and it was determine that the the Mud Street interchange would meet the justification for interchange illumination. However, it must also be noted that just because a warrant has been achieved does not mean that illumination must or can be implemented. Environmental constraints and approvals must be considered before pursing the recommendation to illuminate.

Table 5 summarizes the road segment findings and **Table 6** summarizes the ramp findings.

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Table 5 - Summary of Road Segment Findings

Road Segment	Collisions				Field
	Obs.	Pred.	Exp.	Pattern	
Dartnall 1 & 2	15	32.5	21.4	+ None	+ No major findings
Dartnall 3, 4 & 5	19	63.1	32.8	+ 48% SMV	+ Potentially restricted sightlines for merging traffic from Dartnall onto NB RHVP + Placement of exit information sign potentially confusing NB RHVP + Exit information sign partially obscured NB RHVP + Alignment discontinuity in SB direction
Mud 1, 2 & 3	26	32.5	29.6	+ 60% SMV + 50% non-daylight	+ Unshielded hazard SB + Uneven terrain in front of guiderail NB
Mud 4, 5 & 6	29	66.6	31.6	+ **Exp. >. Pred. @ Mud 4** + Primarily SMV + High proportion of non-daylight & wet surface	+ Closely spaced & obscured signage at critical decision points NB & SB + Potentially confusing "keep right" sign SB
Greenhill 1 to 4	23	96.2	53.8	+ None	+ No major findings

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Table 6 - Summary of Ramp Findings

Ramp	Collisions				Field
	Obs.	Pred.	Exp.	Pattern	
Ramp 1 & 2	n/a	n/a	n/a	+ n/a	+ Poorly designed and damaged guiderail end treatment (Ramp 1) + Luminaire within deflection area of approach eccentric loader end treatment (Ramp 2)
Ramp 3	1	40.1	7.6	+ n/a	+ No major findings
Ramp 4	n/a	n/a	n/a	+ n/a	+ No major findings
Ramp 5	5	2.0	2.6	+ n/a	+ Lane ends within curve
Ramp 6	40	23.3	37.1	+ **Exp. > Pred.** + 65% of all ramp collisions + High proportion & frequency of SMV, non-daylight & wet surface	+ Closely spaced / eclipsing signage at diverge point + Evidence of lane departures
Ramp 7a 7 7b	10	8.3	8.8	+ **Exp. > Pred.** + 80% of collisions SMV + High proportion of non-daylight & wet surface	+ Closely spaced & back dropped signage at diverge + Inappropriate merge sign + Damaged object markers and delineators
Ramp 8	1	0.9	1	+ **Exp. > Pred.,** however very low # of collisions	+ Location and size of information signs + Inconsistent curve warning signs

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Ramp 9	4	1.4	1.8	+ **Exp. > Pred.,** however very low # of collisions	+ No major findings
Ramp 10	1	0.9	1.0	+ **Exp. > Pred.,** however very low # of collisions	+ No major findings

6. Potential Countermeasures and Benefit-Cost Analysis

A list of potential countermeasures was developed to address the issues that were found in the previous sections. In keeping within the limitations of this study, the countermeasures that were developed do not propose to alter the geometry of the lanes and curves on the RHVP.

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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[11] and the MTO SafetyAnalyst project. 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. There are a number of countermeasures for which CMFs were not available. The CMF values are applicable to all collision types that occur at a site, unless the CMF is specific to the related collision impact type(s) (e.g., single-vehicle collision with fixed object).

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. A comparison between the B/C ratios of the alternative countermeasures proposed for a site leads to the most economically efficient countermeasure. The alternative countermeasure with a higher B/C is considered as the preferred alternative. For the purposes of calculating the societal costs of collisions, MTO costs were utilized and projected to 2013 dollars. The resultant costs are summarized in **Table 7**.

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[11] http://www.cmfclearinghouse.org/

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Table 7 - Annual Societal Costs of Collisions

Annual Societal Costs of Collisions (inflated from 2004)	2013	Proportion of Collisions
Fatal	$1,308,127	0.5%
Injury	$31,599	34%
PDO	$9,654	65.5%

6.1 Overall Study Area Countermeasures

The following potential countermeasures should be installed as an overall measure due to the need to create consistency throughout the RHVP.

6.1.1

Moved down [2]: Illumination
The outcome of the TAC illumination warrant indicated that full illumination of the corridor and ramps is justified. Illumination increases a drivers' preview area and increases safety by providing drivers with improved nighttime visibility of roadway conditions and potential hazards. However, sporadic installation of illumination should be avoided as it creates dark spots that require drivers' eyes to readjust to the low-light levels, temporarily reducing their visibility even further.
Benefit-Cost Ratio
The CMF used for this assessment was 0.6 and is related to all types of nighttime collisions. The calculated benefit would be a reduction of 48.5 collisions over a five-year period. The expected service life for this countermeasure is 20 years, for a total benefit of $4,692,624. The costs associated with this countermeasure are expected to be $1,100,000. The B/C ratio is expected to be 4.27.

6.1.2 Permanent Raised Pavement Markings (PRPM)

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 roadway condition and non-daylight 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.

Benefit-Cost Ratio

The CMF used for this assessment was 0.94 and is related to all collision types. The calculated benefit would be a reduction of 10.2 collisions over a five-year period. The expected service life for this countermeasure is 5 years, for a total benefit of $245,593. The costs associated with this countermeasure are expected to be $74,700. The B/C ratio is expected to be 3.29.

6.1.3 Wide Pavement Markings (102 mm to 150 mm)

Wide pavement markings can be used to improve preview distances and guidance for drivers in inclement weather and low-light conditions. Given the wet roadway condition and non-daylight trend in collisions along the RHVP, combined with the curvilinear geometry of the roadway, wide pavement markings have the potential to positively affect the collision experience on the roadway as well as increase driver security.

Benefit-Cost Ratio

The CMF used for this assessment was 0.96 and is related to fatal and injury collision types. The calculated benefit would be a reduction of 2.6 collisions over a five-year period. The expected service life for this countermeasure is 5 years, for a total benefit of $135,537. The costs associated with this countermeasure are expected to be $40,000. The B/C ratio is expected to be 3.39.

6.1.4 Perform Friction Testing

Pavement friction plays a vital role in keeping vehicles on the road by enabling the drivers to control/maneuver 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 of texture: 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.

Cost-Benefit Ratio

There is no specific CMF for friction testing, however the costs to undertake these tests are not expected to exceed $20,000. For this price, the City would receive valuable information regarding the dry friction values on the asphalt. Based on the results, the City may be in a better position to determine if further action is required.

6.1.5 Install Wc-105 Slippery When Wet 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 expectantly low level. Given the high proportion of wet surface collisions, it may be determined through friction testing that the skid resistance of the roadway surface is lower than normally encountered in some areas. If this is determined, the City could examine the installation of the Wc-105 sign for the northbound and southbound directions in relation to any areas identified through friction testing.

Cost-Benefit Ratio

There is no specific CMF for the installation of these signs. However the costs to install signs are not likely to exceed $5,000.

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Water films develop on the pavement surface during natural rainfall and tend to increase in thickness along the water drainage or flow path. At the onset of rainfall, the water first occupies the macrotexture of the pavement surface and is contained within the macrotexture of the pavement surface or is drained from the surface through grooves or internal drainage. With increasing rainfall, a film of water forms above the macrotexture. The flow of water on the pavement surface is called sheet flow; the depth of the sheet flow tends to increase in the direction of the drainage path. The depth of the sheet flow is critically important because the depth of this flow controls the skid resistance of the pavement and the tendency for hydroplaning. Given the high proportion of wet surface collisions, the City could examine the undertaking of a drainage review to determine the adequacy of the surface drainage of the pavement.¶
Cost-Benefit Ratio¶
There is no specific CMF for a drainage review; however the costs to undertake this review are not expected to exceed $20,000. For this price, the City would receive valuable information regarding the drainage conditions on the surface of the asphalt. Based on the results, the City may be in a better position to determine if further action is required.¶

6.1.6 Enforcement of Travel Speeds

The exact relation between speed and crashes depends on many factors. However, in a general sense the relation is very clear: if on a road the driven speeds become higher, the crash rate will also increase. Therefore, targeted enforcement of known high crash areas can be an effective means to reduce the crash rate.

Benefit-Cost Ratio

There is no CMF or cost for this countermeasure. Speed enforcement is a regular activity undertaken by the Police, therefore targeting specific areas should not increase costs.

6.1.7 Rationalization of Trailblazer Signs

The trailblazer information sign displays for the RHVP and the Linc contain a lot of information for an approaching road user to read, process, and make an appropriate decision. The displays contain varying colours, shapes, text sizes, and individual signs separated by boarders and copy faces. Each display contains a number of individual pieces of information, and in some, a number of different physical signs. The City could examine reducing the complexity of the trailblazer signs and possibly adding the QEW and 403 signs to each of the markers as well to assist unfamiliar drivers to determine if they should be taking the RHVP or the Linc to reach their intended destination.

Benefit-Cost Ratio

These trailblazer signs cannot be directly linked to any specific collisions, nor is there a corresponding CMF. However, the costs to replace or add signs would not be expected to exceed $2,000, and because they are not on the mainline, special traffic protection would not be required to install the signs.

6.1.8 Remove Lane Exits Signs from Ramps

The Lane Exits sign exists in several locations on ramps where its use is not intended. The City could examine the potential to remove these signs.

Cost-Benefit Ratio

These Lane Exists signs cannot be directly linked to any specific collisions, nor is there a corresponding CMF. However, the costs to remove the sign would not be expected to exceed $1,000, and because they are not on the mainline, special traffic protection would not be required to install the signs.

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6.2 Mud Street Interchange

6.2.1 Illumination

The outcome of the TAC illumination warrant indicated that illumination of the interchange is justified. Illumination increases a drivers' preview area and increases safety by providing drivers with

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improved nighttime visibility of roadway conditions and potential hazards. However, sporadic installation of illumination should be avoided as it creates dark spots that require drivers' eyes to readjust to the low-light levels, temporarily reducing their visibility even further.

Benefit-Cost Ratio

The CMF used for this assessment was 0.6 and is related to all types of nighttime collisions. The expected service life for this countermeasure is 20 years. Although the TAC warrant examines the entire interchange, the benefit-cost ratio was calculated for the interchange as a whole as well as each of the ramps. The results of this are:

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A total benefit of $1,400,816 and costs of $150,000 for a B/C ratio of 9.34.

RAMP #5

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A total benefit of $19,954 and costs of $30,000 for a B/C ratio of 0.67.

RAMP #6

A total benefit of $1,040,193 and costs of $30,000 for a B/C ratio of 34.67.

RAMP #7A & 7B

A total benefit of $107,010 and costs of $60,000 for a B/C ratio of 1.78.

RAMP #8

A total benefit of $233,663 and costs of $30,000 for a B/C ratio of 7.79.

6.3 Site Specific Countermeasures

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6.3.1 Dartnall Segments 1 & 2

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There were no major collision or field findings in this segment.

6.3.2 Dartnall Segments 3, 4 & 5

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The main collision finding through these segments was the high proportion SMV type collisions, at 48%, as well as a significant number of wet road condition collisions. In the field, sightline challenges as well as the placement of several signs were the primary findings, as well as the alignment discontinuity in the southbound mainline. The following improvements could be considered for implementation.

Extend Solid White Line from Gore Area on Dartnall S-E Ramp

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Due to the angle of approach between the northbound mainline drivers and the drivers merging from the Dartnall Road S-E ramp, it can be challenging for the merging drivers to properly detect a safe gap in traffic. It was observed in the field that drivers tended to enter the through lane abruptly at the

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beginning of the broken line. If the solid line were extended further from the gore area, it would encourage drivers to utilize more of the speed change lane, which would have the effect of bringing their speed up more in line with the through vehicles (reducing the speed variance), as well as improving their chances of detecting a safe gap in traffic in which to merge.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however the costs are not expected to exceed $500 so we recommend implementing this countermeasure.

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Relocate Deer Warning Sign

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The Stone Church Road / Mud Street exit information sign located within the taper for the Dartnall S-E on-ramp is partially obscured by a Deer Warning sign. The City could consider removing (there were no animal related collisions in five years) or relocating the Deer Warning sign to a point beyond the information sign.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however the costs are not expected to exceed $500 so we recommend implementing this countermeasure.

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Correct Alignment Discontinuity in Southbound Direction

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In the southbound direction there is an alignment discontinuity that occurs wherein there is a tangent section of roadway between two curves, but within an intended smooth curve. We are unsure why the roadway was built this way as the design drawings do not show this occurring. It is difficult to attribute any collisions to this geometric aspect, however, it is clear that it catches drivers off-guard and leads to wandering in the lanes. The City could consider smoothing out the alignment through the use of pavement markings by shifting the flat area by approximately 1.6 metres, as shown in **Figure 35**. This would allow the outside yellow line to fall within the existing roadway platform, although it would be on the current paved shoulder and would require filling and regrinding of the existing edgeline rumblestrips. Final recommendations for this countermeasure would require additional examination of the road design that was not possible with the data provided for this study.

Figure 33 - Potential Pavement Marking Adjustment

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COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $4,000.

6.3.3 Mud Segments 1, 2 & 3

The main collision finding through these segments was the high proportion SMV type collisions as well as non-daylight collisions. The field investigation revealed minor deficiencies relating primarily to a guiderail installation in the northbound direction.

Flatten Slope or Raise Guiderail in Northbound Direction

In the northbound direction within the median downstream of the Stone Church Road / Mud Street diverge point there is a guiderail system with a mound of terrain immediately adjacent to the front of the system. If an errant vehicle were to run off the road in this location, they would ride up on the uneven grassy terrain in front of the barrier causing the vehicle to strike the system at a higher point than it is designed for. This could lead to the overturning of a vehicle, and possibly continuation into the column being shielded. The City could examine the possibility to either lower the terrain or raise the guiderail system.

COST-BENEFIT RATIO

There have not been any collisions associated with this guiderail, nor are there any CMFs directly related to regarding the terrain adjacent to a guiderail. However, this could be considered maintenance of the system and the costs are expected to be low.

6.3.4 Mud Segments 4, 5 & 6

Similar to other segments, the main collision finding through these segments was the high proportion SMV type as well as wet surface and non-daylight collisions. Of additional note, the segment Mud 4 shows a positive PSI. The field review found issues with closely spaced and potentially confusing signage installations.

Relocate "ENGINE BRAKES" Sign (Northbound)

A "PLEASE AVOID USE OF ENGINE BRAKES" Regulatory sign located downstream of the Mud Street on-ramp between a Lane Drop and Bridge Ices warning sign. These signs are closely spaced and within the vicinity of a complex merging area where drivers from Mud Street are required to perform two consecutive merging maneuvers. Given the nature of the location, the warning signs are the highest priority and require the immediate attention of drivers. In its current configuration, the signage in this area could potentially lead to driver-overload and possible conflicts. The City could consider relocating the "ENGINE BRAKES" sign further north beyond the end of the taper.

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COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $500 so we recommend implementing this countermeasure.Remove "Slower Traffic Keep Right" Sign at Stone Church / Mud Diverge (Southbound)

There are a number of Slower Traffic Keep Right signs in the northbound direction through the study area. While this is generally good advice, there is one sign posted immediately before the Stone Church Road / Mud Street diverge point where the right lane becomes a dedicated exit lane for the freeway exit. Providing this message at this point may be confusing to road users, and could possibly lead to weaving conflicts. This sign is also part of a group of closely spaced signs in the area. The City could consider removing the sign located immediately upstream of the Stone Church Road / Mud Street diverge.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $500 so we recommend implementing this countermeasure.

Relocate Object Marker Sign (Southbound)

The Freeway Exit sign in the gore area of the Stone Church Road / Mud Street off-ramp is partially eclipsed by the Object Marker warning sign on approach. The City could consider relocating the object marker sign to the post of the exit sign.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $500 so we recommend implementing this countermeasure.

6.3.5 Greenhill Segments 1 to 4

There were no major collision or field findings in this segment.

6.3.6 Ramps 1 & 2

There were no major collision findings for these ramps, however, during the field review it was noted that there are a couple of minor issues with roadside elements.

Redesign / Replace Guiderail End Treatment (Ramp 1)

The Eccentric Loader steel beam guide rail end treatment on the outer edge of the Dartnall Road off-ramp is damaged, does not contain a sufficient flat run-out area behind the system, and the system itself on the approach end is leaning out and is not vertically plumb. A vehicle striking this system may not be shielded from the slope as intended. The City could consider replacing the existing damaged end treatment with an extruder end treatment and ensure that the there is sufficient run-out for the particular anchoring and deflection properties of the system.

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COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $5,000.

Redesign End Treatment on Guiderail (Ramp 2)

The luminaire pole adjacent to the guide rail system at the beginning of the Dartnall Road on-ramp is within the run-out area of the Eccentric Loader approach end treatment. If the end treatment is stuck, it is possible that the vehicle will also come into contact with the luminaire. An extruder end treatment demands less adjacent deflection area upon impact than the Eccentric Loader, preventing an impacted vehicle from traveling through the breakaway area of the system. The City could consider replacing the eccentric loader with an extruder end treatment.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $11,000.

6.3.7 Ramps 3 & 4

There were no major collision or field findings for these ramps.

6.3.8 Ramp 5

There were no major collision findings for this ramp; however it was noted during the field investigation that the two lane off-ramp diverges into one lane for Stone Church Road and two lanes that merge to one lane for Mud Street. This merge on the Mud Street section of the ramp occurs within a curve immediately downstream of the diverge point of the ramps. The City could consider restriping the entire ramp to have one lane exit to Stone Church Road and one lane exit to Mud Street thereby eliminating the need for the merge on the curve on approach to Mud Street.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $4,000.

6.3.9 Ramp 6

This ramp was found to be the poorest performing segment of the RHVP that was reviewed for this assignment and was noted as having a positive PSI. This ramp has experienced 65% of all collisions occurring on ramps, and like other areas, has a high proportion of SMV, wet surface and non-daylight collisions. The field review noted evidence of run off the road collisions, as well as some closely spaced and eclipsing signage at the diverge point from Ramp 7a.

It must be noted that the City has installed improved signage on the ramp in the recent past. Because this signage was installed after the period for which collisions were available for this review, any effect that this improved signage may have on collisions on the ramp cannot be quantified in this review.

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Install High Friction Pavement on Approach to and through Curve

In locations where drivers may brake excessively; for example, when going around curves; the road surface can become prematurely polished, reducing the pavement friction and allowing vehicles to skid when drivers brake. Drivers may also be speeding or distracted, contributing to the high-collision rates in this location. Wet road surfaces can also reduce pavement friction and cause skidding or hydroplaning. High friction surface (HFS) treatment is an emerging technology that dramatically and immediately reduces crashes. With friction demands far exceeding conventional pavement friction, high-quality aggregate is applied to existing or potential high-crash areas to help motorists maintain better control in dry and wet driving conditions. While the initial costs are higher than conventional pavement, however, the long-lasting durability of HFS treatment and limited use in critical locations makes the product a low-cost option over its life cycle. The City could consider installed a HFS treatment on approach to and through the curve at the end of the ramp.

COST-BENEFIT RATIO

The CMF used for this assessment was 0.76 and is related to all collision types. The calculated benefit would be a reduction of 8.9 collisions over a five-year period. The expected service life for this countermeasure is 5 years, for a total benefit of $215,212. The costs associated with this countermeasure are expected to be $92,900. The B/C ratio is expected to be 2.32.

Install Progressively Larger Chevron Signs

Inappropriate speeds are expected to be the major cause of the run-off-the-road type collisions occurring at this ramp. Since driving is a task with a substantial contribution from vision, the use of lighting and visual information such as signage can assist in providing appropriate cues to encourage appropriate driving speeds. Modifying the use of chevrons to employ progressively-increasing sizes throughout a curve, and adjusting the spacing of them to provide an appearance consistent with a smaller radius curve (about two-thirds the radius of the original curve) can increase perceptions of sharpness by drivers, and can result in greater speed reductions. The City could consider installing modified chevron signs along the curve.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $4,000.

Install Retroreflective Strips on Chevron Signs

To assist in increasing the conspicuity of the chevron signs, the City could consider adding retroreflective tape (or other) to the chevron signs.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $500 so we recommend implementing this countermeasure.

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Install Pavement Marking Text

A pavement marking placed on the roadway indicating that the driver should reduce speed for an upcoming curve is being promoted in the U.S. on sections of roads or corridors with higher than average numbers of crashes having roadway curvature as a contributing factor. The pavement marking consists of a "SLOW" legend and an arrow indicating the direction of the upcoming curve. The overall objective is to reduce the upper percentile speed, thus reducing the number of vehicles leaving the roadway and being involved in a collision. The City could consider installing these pavement markings to reinforce to drivers that they must reduce their speed for the curve.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $1,500.

Install Dynamic / Variable Warning Sign

Dynamic or variable warning signs are widely used to convey all manners of information to drivers. In order to reinforce the need for drivers to slow their vehicles for the curve, these warning signs could be used to:

+ Display the vehicle's speed versus the posted warning speed;
+ Display a message "SLOW DOWN" "TOO FAST" (or other) to vehicles travelling over a set speed threshold;
+ Etc.

These signs have proven to be effective in reducing the speed of vehicles. The City could consider installing a dynamic / variable warning sign on approach to the curve in the ramp.

COST-BENEFIT RATIO

There is no CMF for this countermeasure, however costs are not expected to exceed $7,000 including solar power option, wiring, installation, etc.

Install Flashing Amber Beacons on Signs

Using flashing beacons with a warning sign is another way to gain motorists' attention. The beacons are typically used with one of the advance Horizontal Alignment signs for a horizontal curve. One factor limiting their use is the availability of an accessible power source, although solar power panel systems can be used as well. The beacons can be flashed either alternately or simultaneously. The safety effectiveness of this particular treatment is yet to be established, but a 1970s study evaluated

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Moved up [1]: Install Retroreflective Strips on Chevron Signs¶
To assist in increasing the conspicuity of the chevron signs, the City could consider adding retroreflective tape (or other) to the chevron signs.¶
COST-BENEFIT RATIO¶
There is no CMF for this countermeasure; however, costs are not expected to exceed $500.¶

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the effects of signing to warn drivers of wet weather skidding hazards at horizontal curves. The study concluded that agencies could significantly reduce vehicle speed by adding flashing beacons on curve warning signs. The City could consider adding flashing beacons to the warning signs and/or the chevron signs, similar to what the MTO has implemented on a ramp at the north end of the RHVP.

COST-BENEFIT RATIO

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There is no CMF for this countermeasure on its own; however, in combination with advance intersection warning signs and chevron signs, CMFs for the devices installed collectively show a positive reduction in collisions at a curve. Costs per beacon are not expected to exceed $3,000.

Relocate Signs

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There are several signs located within the gore area at the diverge between ramps 6 & 7a. Some of these signs are related to ramp 6 while other are related to ramp 7a. The City could consider making the following adjustments as illustrated in **Figure 36**:

- Relocate the merge sign from the wood post to the luminaire pole (it is related to ramp 6, not important for ramp 7a);
- Relocate the exit sign closer to the area where the grass begins; and
- Relocate the Linc sign further down the ramp or combine with the upstream RHVP sign.

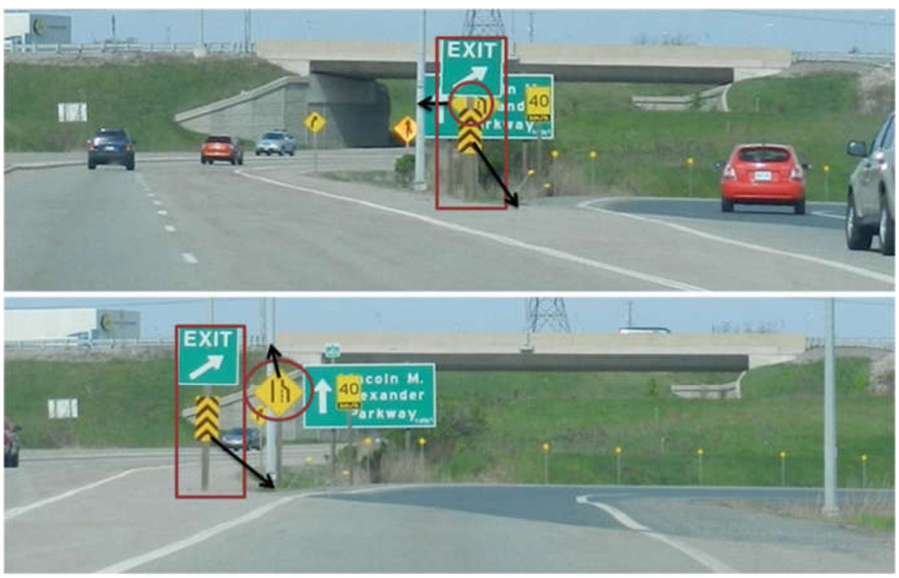

Figure 34 - Possible Signage Adjustments

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COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $2,000.

6.3.10 Ramp 7a & 7b

Similar to other sites, this ramp was has a very high proportion of SMV (80%), wet surface and non-daylight collisions, and was found to have a PSI. The field review noted evidence of run off the road collisions, as well as some closely spaced and backdropped signage at the diverge point from Ramp 6 and an inappropriate merge sign.

Relocate Signs as per Ramp 6

The changes to the signage discussed for ramp 6 are directly applicable to ramp 7a.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $2,000, but would only need to be done once (i.e. through ramp 6).

Replace Merge Sign with Lane Ends Sign

The Merge warning sign on approach to the Stone Church Road East S-N on-ramp is inappropriate for the configuration. The driver on the E-N ramp is the one who is merging onto the S-N ramp. This sign indicates that another lane is joining from the right and could cause driver confusion. A Lane Ends warning sign is required, as opposed to the Merge warning sign. The City could consider replacing the merge sign with a Wa-123 Lane Ends sign.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $500 so we recommend implementing this countermeasure.

Replace Object Markers and Delineators

Many of the signs on this ramp have been damaged through collisions with them. The City could consider replacing damaged markers and delineators.

COST-BENEFIT RATIO

The cost is variable and could be done as maintenance.

6.3.11 Ramp 8

The collision review indicated a PSI for this ramp, however the actual number of observed collisions is low. The field review highlighted the need for some sign rationalization throughout the ramp.

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Replace Road Name Signs with Advance Diagrammatic Sign

Small information signs indicating that the left lane leads to Mud Street and the right lane leads to Stone Church Road are located approximately 160 metres upstream of the forced diverge point for Mud Street and Stone Church Road, are directly behind curve warning signs and immediately before a curve. Since the information signs are small there is a good chance that a driver will not detect them. If the small information signs are missed the next available signage to inform road users of the appropriate lane decision are located at the diverge point. However, similar to the previous information signs, given the horizontal curvature of the ramp, the signs are not visible in advance of their placement and sudden lane changes, and potentially related conflicts, may occur in this area. To assist drivers, the City could consider installing a ground mounted advance diagrammatic sign (similar to example in **Figure 37**) on the right side of the road in the location of the existing small signs.

Figure 35 - Example of Diagrammatic Sign

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $2,000.

Install Consistent Curve Warning Signage

The curve warning signs on either side of the road on the off-ramp provide inconsistent information regarding the severity of the curve. It is important that consistent and appropriate warning the severity of a curve be provided to a driver in order to assist them in making the appropriate decisions to safety navigate through the curve. It appears that the sign on the left is attempting to indicate that the left lane has a tighter radius than the right lane. The City could installing consistent and appropriate curve warning signs.

COST-BENEFIT RATIO

There is no CMF for this countermeasure; however, costs are not expected to exceed $1,000.

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Figure 37 - Example of Diagrammatic Sign¶

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6.3.12 Ramps 9 & 10

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There were no major collision or field findings for these ramps, although they indicate a PSI, the number of collisions is very low.

6.4 Summary of Potential Countermeasures and B/C Ratios

Table 8 summarizes the countermeasures and b/c ratios for the overall study area, **Table 9** summarizes the same information for road segments and **Table 10** summarizes the same information for ramps.

Table 8 - Summary of Countermeasures & B/C for Overall Study Area

Countermeasure	B/C Ratio [Cost]
PRPM	3.29
Wide Markings	3.39
Friction Testing	[$10,000]
Slippery When Wet Signs	[$5,000]
Enforcement of Travel Speeds	n/a
Trailblazer Signage	[$2,000]
Remove Lane Exit Signs	[$1,000]
Illumination of Mud St. Interchange	9.34
Illumination of Ramp #5	0.67
Illumination of Ramp #6	34.67
Illumination of Ramp #7a & 7b	1.78
Illumination of Ramp #8	7.79

Table 9 - Summary of Countermeasures & B/C for Road Segments

Road Segment	Collisions	Field	Countermeasure	B/C

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Road Segment	Collisions	Field	Countermeasure	B/C
Dartnall 1 & 2	None	No major findings	n/a	n/a
Dartnall 3, 4 & 5	48% SMV	Potentially restricted sightlines for merging traffic from Dartnall onto NB RHVP	Extend solid white line from gore	[$500]
		Exit information sign partially obscured NB RHVP	Relocate Deer Warning sign	[$500]
		Alignment discontinuity in SB direction	Alter SB alignment with pavement markings	[$4,000]
Mud 1, 2 & 3	60% SMV 50% non-daylight	Uneven terrain in front of guiderail NB	Flatten terrain or raise guiderail NB	n/a
Mud 4, 5 & 6	**Exp. >. Pred. @ Mud 4** Primarily SMV High proportion of non-daylight & wet surface	Closely spaced & obscured signage at critical decision points SB	Relocate "ENGINE BRAKES" sign NB	[$500]
		Potentially confusing "keep right" sign NB	Remove "Slower Traffic" sign SB	[$500]
		Closely spaced & obscured signage at critical decision points NB	Place "Object Marker" sign on same post as "Exit" sign SB	[$500]
Greenhill 1 to 4	None	No major findings	n/a	n/a

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Table 10 - Summary of Countermeasures & B/C for Ramps

Ramp	Collisions	Field	Countermeasure	B/C
Ramp 1 & 2	+ n/a	+ Poorly designed and damaged guiderail end treatment (Ramp 1)	+ Change guiderail end treatment	+ [$5,000]
		+ Luminaire within deflection area of approach eccentric loader end treatment (Ramp 2)	+ End guiderail and change end treatment	+ [$11,000]
Ramp 3	+ n/a	+ No major findings	+ n/a	+ n/a
Ramp 4	+ n/a	+ No major findings	+ n/a	+ n/a
Ramp 5	+ n/a	+ Lane ends within curve	+ Restripe to one lane for each ramp	+ [$4,000]
Ramp 6	+ **Exp. > Pred.** + 65% of all ramp collisions + High proportion & frequency of SMV, non-daylight & wet surface	+ Closely spaced / eclipsing signage at diverge point + Evidence of lane departures	+ Install high-friction pavement approaching and through curve	+ 2.32
			+ Install progressively larger chevrons	+ [$4,000]
			+ Install pavement marking text	+ [$1,500]
			+ Install dynamic / variable speed warning sign	+ [$7,000]
			+ Install retrorefelective strips on chevron signs	+ [$500]
			+ Install flashing amber beacons on signs	+ [$3,000]
			+ Relocate signs	+ [$2,000]

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Ramp	Collisions	Field	Countermeasure	B/C
Ramp 7a 7b	+ **Exp. > Pred.** + 80% of collisions SMV + High proportion of non-daylight & wet surface	+ Closely spaced & back dropped signage at diverge	+ Relocate signs	+ [$2,000]
		+ Inappropriate merge sign	+ Replace merge sign with Wa-123 Lane Ends sign	+ [$500]
		+ Damaged object markers and delineators	+ Replace object markers and delineators	+ n/a
Ramp 8	+ **Exp. > Pred.,** however very low # of collisions	+ Size of information signs	+ Replace road name information signs with advance diagrammatic sign	+ [$2,000]
		+ Inconsistent curve warning signs	+ Install consistent curve warning signage	+ [$1,000]
Ramp 9	+ **Exp. > Pred.,** however very low # of collisions	+ No major findings	+ n/a	+ n/a
Ramp 10	+ **Exp. > Pred.,** however very low # of collisions	+ No major findings	+ n/a	+ n/a

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