

Alberta Transportation

## **Intersection Safety Device Program – Red-Light Camera Analysis**

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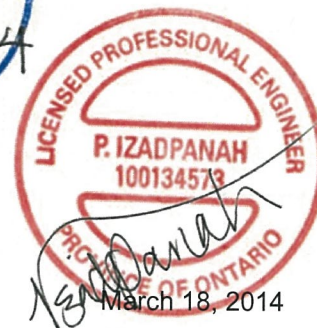
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## Executive Summary

Many jurisdictions throughout the world have implemented programs to improve intersection safety. Red-light violations are a contributing factor for severe collisions at signalized intersections. One of the programs that has been introduced to improve intersection safety and mitigate against motorists who run red lights is a system of automated enforcement using red-light cameras (RLCs).

Red-light cameras have been deployed by many jurisdictions in the world and their effectiveness has been evaluated by a number of researchers. Due to factors such as variations in enforcement practices, differing levels of detail in the record keeping for collision information, and the complexities of data collection and analysis, the results obtained from previous research into RLC impacts have varied.

In this study, data from multiple jurisdictions in the Province of Alberta were used to evaluate the various municipal red-light camera programs. For the purpose of this study, extensive data were collected for the following:

- 76 signalized intersections equipped with red-light cameras;
- 141 signalized intersections without red-light cameras; and
- 37 unsignalized intersections.

Before-and-after studies of the RLC safety program were conducted using the Empirical Bayes (EB) method. This method of assessment evaluates the changes in safety at intersections related to red-light camera enforcement, as well as quantifies the magnitude of “spillover”<sup>1</sup> effects of the cameras on intersections without cameras in place.

The study was to answer four specific questions, as taken from the Request for Proposals (RFP). Based on the completed before-and-after study, after implementation of RLC programs and related publicity initiatives, the answers to the four questions are as follows:

1. *How have red light cameras impacted the number of collisions at monitored intersections?*

Based on the completed before-and-after study, it was found that the total number of collisions has reduced. Table A below notes the percent reduction in total collisions as 8.4%.

2. *How have red light cameras impacted collision severity (fatal, injury, property damage) at monitored intersections?*

The before-and-after study indicates an overall reduction in severe (fatal and injury) collisions at monitored intersections (32.4% reduction), with an increase in the number of PDO collisions (1.4% increase). This information is shown in Table A below.

3. *How have red light cameras impacted the type of collision occurring at monitored intersections?*

The before-and-after study indicates that there is an overall reduction in angle collisions (37.7% reduction); however, the frequency of rear-end collisions was shown to increase after installation of red light cameras at monitored intersections (7.7% increase).

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1. “Spillover” effect is the expected effect of RLCs on intersections other than the ones actually treated because of jurisdiction-wide publicity and the general public’s lack of knowledge of where RLCs are installed.

**Table A. Collision Analysis Aggregated Results (Five Municipalities)**

Collision Category	Estimate of Percentage Change in Number of Collisions
<b>Total Collisions</b>	-8.4%
<b>Property Damage Only (PDO) Collisions</b>	+1.4%
<b>Severe Collisions</b>	-32.4%
<b>Angle Collisions</b>	-37.7%
<b>Rear-End Collisions</b>	+7.7%

4. *How have red light cameras impacted the number of red light violations occurring at monitored intersections?*

The time-series red-light violation analysis that was undertaken in this study was inconclusive with respect to determining the changes in number of red light violations that occurred at monitored intersections from an overall provincial perspective. Through this study, it was found that in order to draw conclusions from a broader perspective, definition and control of uniform data collection processes is needed to obtain consistent and complete data from all of the individual participating municipalities. In light of the study results, this report makes recommendations regarding modifications to the violation data collection task to improve future data collection and analysis efforts.

In addition to the above results, there were indications of relatively large “spillover” effects at signalized intersections that did not have RLC cameras in place.

Study analyses and results are highly dependent on the available data input. In this study, the collected data was sufficient to complete a statistically valid collision assessment. However, as noted in item 4 above, due to data limitations, a red-light violation assessment could not be completed from an overall provincial perspective. In general, through review of the individual municipalities that participated in the study, it appears that a Province-wide RLC program would have an overall positive net benefit and provide effective reduction in red-light violations which would subsequently result in fewer numbers of severe and angle collisions. However, it should be noted that not all intersections are likely to receive the same positive benefits of RLC program implementation, and that the number of rear-end collisions may increase at RLC equipped intersections.

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# 1. Introduction

Traffic signals and other traffic control devices are generally installed in order to reduce the number of “conflicts” at intersections. Reducing conflicts between two or more vehicles, and between vehicles and pedestrians, can improve safety and operation of the intersection by separating and controlling the movements of competing traffic and pedestrian movements. However, some motorists intentionally choose to disobey traffic signals and, in doing so, increase the risk of collisions at intersections. Of particular concern at signalized intersections is red-light violation, or “running the red-light”, which increases the potential for right-angle collisions. Right-angle collisions in particular can result in more severe damage to vehicles involved, and are more likely to result in injuries to vehicle occupants in comparison to other types of collision impacts, such as rear-end collisions.

There is currently no consistent approach to resolve red-light running issues. There have been safety programs created that include a wide range of engineering, educational, and enforcement measures that are either used individually or in combination in an attempt to reduce or stop red-light running occurrences. From a general engineering perspective, coordinated signal timing plans and improved visibility of traffic signal displays are two common red-light running treatments in North America. Many jurisdictions in the world have also deployed Red-Light Cameras (RLCs) to automate enforcement as a means of reducing the number of red-light running incidents.

At RLC-equipped intersections, an RLC is installed upstream of the intersection, most often on one approach, facing towards the intersection. Once a vehicle crosses the stop bar while the red signal indication is displayed, the RLC takes a photograph of the rear of the red-light running vehicle, from which the license plate can then be read and a ticket issued. Over the past two decades or so, road authorities in various jurisdictions around the world have been interested in quantifying the associated safety benefits of RLCs. Road authorities also question whether RLCs affect the safety performance only at the specific intersections at which RLCs are installed, or, if their presence at some intersections within a jurisdiction can influence the behaviour of drivers and therefore generally improve safety at other signalized intersections within the jurisdiction which are not equipped with RLCs. This type of behavioural influence is referred to as a “spillover” or “halo” effect.

Commencing on January 1, 1999, various municipalities across the Province of Alberta began using RLCs. In 2009, Alberta Transportation initiated this study to evaluate the RLC programs as implemented in multiple jurisdictions within the Province. This study was initiated almost 10 years after the commencement of the first RLC program in the Province, at a time when the program was mature and was thought to have reliable data available from which conclusive analysis results could be obtained.

The main objectives of this study, as noted in the RFP, were to answer the following four questions:

- How have red light cameras impacted the number of collisions at monitored intersections?
- How have red light cameras impacted collision severity (fatal, injury, property damage) at monitored intersections?
- How have red light cameras impacted the type of collision occurring at monitored intersections?
- How have red light cameras impacted the number of red light violations occurring at monitored intersections?

This document answers the above four questions, and is organized as follows:

- Section 2: A brief review of the past literature to better understand previous findings and efforts of other researchers

- Section 3: An overview of data collection and processing
- Section 4: Study methodology used for both collision and red-light violation analyses
- Section 5: Study results, including the safety effects of RLCs and the magnitude of the “spillover” effect, providing answers to the four questions that form the main study objective
- Section 6: The document concludes with a summary of findings and discussion
- Section 7: Provides a list of study reference material



## 2. Literature Review

A number of studies have been conducted by researchers to evaluate safety benefits of RLCs (1 – 9). Since the 1970s, jurisdictions in Europe, Australia, and North America have been using RLCs with the aim of reducing red-light violations and the resulting collisions. Evaluating the RLC programs and the resulting safety effects has generally been a challenging task, as the study findings tend to vary. As noted in one study (7), the challenges associated with RLC program evaluation include the following:

- There are a number of confounding and uncontrolled factors involved in the evaluations of RLCs such as changes in traffic volumes;
- It has been known that the RLC programs are potentially able to have “spillover” effects<sup>2</sup> and change behaviour of motorists at non-RLC-equipped signalized intersections; and
- The candidate intersections for installation of cameras are not often randomly selected. These locations often exhibit safety concerns and RLCs are installed with the intent to improve safety at these locations. As a result, these locations are prone to the “regression-to-the-mean” (RTM) phenomenon<sup>3</sup>.

Overall, RLC programs reduce the more severe, right-angle collisions but could increase less severe rear-end collisions; however, many studies that evaluate the effectiveness of RLC programs had challenges with the study methodology, and as a result there were questions regarding the study conclusions. These studies were based on best practices at the time, but evolving methodologies are now yielding more confident results. “RTM” and “spillover” effects are two major considerations that most of the previous studies did not take into account in assessing the effectiveness of RLC programs. Failure to account for the RTM phenomenon can exaggerate the positive effects of RLCs, while ignoring possible “spillover” effects to intersections that do not have RLCs will lead to an underestimation of the RLC benefits. “History”<sup>4</sup> and “maturation”<sup>5</sup> factors are two other factors that need to be controlled in the evaluation of RLC programs.

One study that addressed these two most common flaws (i.e., RTM and “spillover” effects) in study methodology was an evaluation of the Oxnard, California program by Retting and Kyrychenko (8). This study considered the city-wide effects based on only 29 months of before-and-after data.

In 2005, the U.S. Federal Highway Administration (FHWA) completed an evaluation of RLCs, and in an attempt to control for “RTM” and “spillover” effects, used data from seven jurisdictions across the United States. The FHWA-HRT-05-048 report on “Safety Evaluation of Red-Light Cameras” presented the findings of this statistically defensible evaluation study (1). The combined effect of the seven jurisdictions showed that the RLC programs resulted in a 25% decrease in right-angle collisions and a 15% increase in rear-end collisions; these results are somewhat lower than those reported in other earlier studies. Apart from illustrating the benefits of RLC programs, this study also identified other program components that might make RLC programs more beneficial in terms of collision reductions. As per this FHWA report, the greatest economic benefits obtained from use of RLC programs are associated with the intersections that have the following conditions:

- 
2. *“Spillover” effect is the expected effect of RLCs on intersections other than the ones actually treated because of jurisdiction-wide publicity of the RLC program and the general public’s lack of knowledge of where RLCs are installed. [Same concern as mentioned in the same footnote above, as it suggests that the general public doesn’t have much knowledge of where RLCs are installed.]*
  3. *“Regression to the mean” is a statistical phenomenon and a tendency to select locations with high collision histories for applying safety treatments (e.g. installation of RLCs). However, if the selection is made based on short-term high prevalence of collisions, a lower collision rate would be expected in subsequent years even if no treatment had been implemented.*
  4. *“History” is the possibility that factors other than an RLC may have caused all or part of the change in safety performance at a location.*
  5. *“Maturation” is the long-term collision trend effects that may contribute to changes in safety performance at sites treated with an RLC.*

- The highest total entering traffic volumes, based on Average Annual Daily Traffic (AADT);
- The largest ratios of right-angle to rear-end collisions;
- Higher proportions of entering AADT on major roads; and,
- The presence of protected left-turn phases.

The presence of warning signs and high publicity levels also appeared to be associated with greater benefits. Due to the observational retrospective nature of the FHWA study, and the fact that RLC installations took place over many years with no control over the “history” factor, it is very likely that other programs and treatments may have affected collision frequencies at the selected “spillover” study sites. However, this study managed to control for the RTM effect. The study concluded that a well-designed future study is required for the explicit purpose of addressing the “spillover” issue.

Using data from the State of Arizona, Washington and Shin (9) estimated the impact of the RLCs on safety at signalized intersections equipped with cameras, as well as at non-camera-equipped intersections, to assess the potential “spillover” effect of the RLCs. The authors concluded that there are considerable variations in the level of “spillover” effect between different locations. At intersections in Scottsdale, it appears that drivers modify their behaviour at non-RLC intersections, showing a “spillover” effect nearly equal in magnitude to the effects observed in signalized intersections equipped with cameras. In contrast, “spillover” effects in Phoenix were found to be not significant.

In 2006, adopting an Empirical Bayes (EB) approach, Tarek and de Leur (4) evaluated Edmonton’s RLC program by controlling for “history” and “maturation” factors through use of comparison group sites. The comparison group sites were subjected to the same traffic and environmental conditions as the RLC-treated sites, but they did not have an RLC. This study showed an estimated 11.1% reduction in total collisions. Overall, severe collisions were reduced by 6.1%, and Property Damage Only (PDO) collisions were reduced by 14.3%. Angle-type collisions were also reduced by 17.2%; however, contrary to most of the previously completed studies, the rear-end collisions were reduced by 12.4%. Due to the scattered positioning of the RLCs throughout the city, the investigation into potential “spillover” effects was ineffective<sup>6</sup>; the researchers found it difficult to select comparison sites that were not in close proximity to the treatment sites.

A study by Malone *et al.* (10) looked at collision rates in Calgary, for the five- to seven-year period after red-light cameras had been in place. The study found that right-angle collisions decreased by 48.2 % and rear-end collisions decreased by 8% (but the rear-end collision decrease was found to be not statistically significant).

On the basis of the literature review, it generally appears that RLCs are effective in reducing angle collisions but that they increase rear-end collisions; however, some studies have determined contrary results showing a decrease in the number of rear-end collisions. This literature review shows that effective evaluation of the safety implications of RLCs requires application of a before-and-after study methodology that is designed to account for changes in traffic volume, RTM, and potential “spillover” effects.

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6. *In this research, an attempt was made to differentiate between comparison group sites that were in close proximity to treatment sites and those that were not, so as to determine whether a spillover effect existed.*

### 3. Data Collection and Processing

Multiple municipalities in the Province of Alberta were contacted at the outset of this study and asked about the availability of relevant RLC-related intersection data for this study, including, but not limited to:

- Entering traffic volumes,
- Geometric characteristics and traffic control types (signals, stop-control, etc.),
- RLC-specific information (camera installation / activations dates, camera direction, etc.).

The final selection of the jurisdictions and intersections/sites to be included in the RLC safety and violation evaluations was based on a general assessment of each jurisdiction's ability to provide the reliable data with a sufficient sample size.

A total of seven jurisdictions were selected to participate in this study. Four jurisdictions participated in both the RLC safety evaluation and violation studies. Two jurisdictions were excluded for the RLC safety evaluation study and one was excluded from the violation study.

Once the jurisdiction/site selection task was completed, the municipalities collected and supplied the following required data:

- Intersection Description (Major Roadway / Minor Roadway);
- RLC Installation / Activation Dates;
- Direction of Camera;
- Type of Traffic Control;
- Traffic Signal Installation Date;
- Number of Intersection Approaches;
- Area Type (Urban versus Suburban);
- Intersecting Roadway Classification Type (e.g., Divided Arterial, Undivided Arterial);
- Entering AADT for major and minor roadways;
- Reported red-light running records.

Data were obtained for RLC-equipped and non-RLC-equipped signalized intersections as well as for two-way stop controlled (TWSC) intersections. Collision data were obtained directly from Alberta Transportation, whereas all other data were obtained from the participating municipalities. The data obtained for unsignalized TWSC intersections were used to control for “spillover” effect.

**Table 1** presents a summary of all data collected from the participating municipalities.

**Table 1. Summary of Data Collected from Participating Municipalities**

Municipality	Range of RLC Program Start Dates	No. of RLC-Equipped Sites	No. of Non-RLC-Equipped Sites	No. of Unsignalized Sites
City 'A'	2001 – 2004	42	92	30
City 'B'	1999 - 2005	19	25	0
City 'C'	2000 - 2005	7	14	1
City 'D'	2008	2	5	3
City 'E'	1998 - 2005	6	5	3
<b>Total</b>	-	<b>76</b>	<b>141</b>	<b>37</b>

Study analyses and results are highly dependent on the available data input. In this study, the collected data was sufficient to complete a statistically valid collision assessment. However, due to data limitations, a red-light violation assessment could not be completed from an overall provincial perspective.

Given the available data for use in the study, the study team proceeded with extensive data cleaning and data quality checks. The data cleaning tasks included the following major sub-tasks:

- Remove collision records for which the “collision location” field had been coded as something other than Code “2” (Code “2” collisions are those that report the collision location as “intersection/intersection-related”);
- Fix all inconsistencies with street names. There were some inconsistencies/variations in the way names of intersection streets were reported and input in the collision database for most of the municipalities. In addition, there were reported street names which were incomplete and/or with errors in names spelling. This task was required in order to complete the following task.
- Create a new field in the collision database (for all participating municipalities). This new field is called “intersection name”, and was created by combining the names of the intersecting roadways in a defined format: “Street A-Street B”. Street names were required to be consistent (as noted in the previous bullet) in order to complete this task, and provide a unique name in the database for any given intersection.
- Estimate missing AADT information, or convert AADTs as provided to a useable format. The entering AADT data for all years in the study period are required in order to conduct a before-and-after study using the EB method. The collected data lacked AADT details for all of the study period (from 1995 to 2008). As a result, the missing AADTs were estimated using either one of two methods. Where the available traffic count information was sufficient, a trending analysis (based on the least square linear methodology<sup>7</sup>) was implemented as the preferred method to generate missing AADT data. Where data was not sufficient to complete a trending analysis, missing AADT data were produced by using a fixed annual growth factor (assumed to be equal to 2% per annum). For three of the participating municipalities the AADT data were provided only for mid-block road sections, and not in the form of the “entering AADT volumes” at each intersection. As a result this AADT data had to be converted to a useable format.

7. “Least squares” is a standard approach in data fitting by minimizing the sum of squared residuals – the difference between an observed value and the fitted value provided by a model.

## 4. Study Methodology

### 4.1 RLC Program Analysis # 1 – Collision Analysis

#### 4.1.1 Overview of Evaluation Methodology

A before-and-after study using an Empirical Bayes (EB) approach was used to evaluate the safety performance of the selected RLC sites. The EB method is a statistical approach that accounts for the “regression to the mean bias”<sup>8</sup> that can occur during RLC site selection, and also takes into account the specific probability of collision occurrences (1).

The safety performance of an RLC-equipped intersection is evaluated by determining the difference between:

- a) The expected collision frequency that would have occurred in the “After Period”<sup>9</sup> without the RLC installation, for a given collision type, and
- b) The actual number of collisions observed in the “After Period”.

For the purposes of this study, Safety Performance Functions (SPFs) were developed and used to estimate what the collision frequency would have been had the RLC programs not been implemented in the participating municipalities. SPFs provide a benchmark used for comparison with the observed number of collisions at RLC-equipped intersections during the “After Period.” The SPFs are mathematical models to estimate yearly number of collisions for a road facility (e.g., for intersections, mid-block road sections, etc.) as a function of variables such as traffic volume, number of lanes, area type, etc. on that facility. A number of SPFs have already been developed by researchers and jurisdictions to estimate collision frequencies on different road facilities. The SPFs that were developed in this study are a function of the “entering AADT volumes” at each intersection (as further discussed in Section 4.1.2).

The first step in developing SPFs is to identify a reference group for the locations which have similar traits as the RLC-equipped intersections. In this study, the reference group is the non-RLC signalized intersections. SPF development also uses the data obtained at RLC-equipped signalized intersections from the “Before Period”<sup>10</sup>, when the RLCs were not present at the intersections. SPFs were developed using the collision, traffic volume, and intersection geometry data associated with the reference group.

Previous studies (3,8) have shown that initiation of RLC programs and the related jurisdiction-wide publicity are not only effective in reducing the number of collisions at RLC-equipped intersections, but are also effective at reducing collisions at non-RLC-equipped signalized intersections within that jurisdiction. This is known as the “spillover” effect and it is mainly due to jurisdiction-wide publicity of RLC programs, the general public’s lack of knowledge on where RLCs are installed and a subsequent conservative assumption by motorists that every signalized intersection is potentially equipped with a RLC.

Therefore, selecting non-equipped signalized intersections as the control (comparison) group and ignoring “spillover” effects of the RLC program at non-equipped signalized intersections in a before-and-after evaluation of RLC programs potentially leads to an underestimation of RLC benefits. In other words, without controlling for the “spillover” effect, comparing the expected number of collisions in non-equipped signalized intersections in the “After Period” with the observed number of collisions in RLC-equipped intersections in the “After Period” does not show the true benefits of RLC programs. This occurs because initiation of an RLC program and the related jurisdiction-wide

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<sup>8</sup> Specifically, the Empirical Bayes (EB) method accounts for Regression to the Mean (RTM) bias (refer to footnote 3 on p. 3).

<sup>9</sup> “After Period” refers to the period after the RLCs were installed at the intersections.

<sup>10</sup> “Before Period” refers to the period before the RLCs were installed at the intersections.

publicity results in reduced collision frequencies at both RLC and non RLC-equipped signalized intersection located in the same vicinity.

Therefore, an additional step is taken in developing SPFs: the identification of a control group. This step is taken to identify the true effect of RLC programs and acknowledge potential “spillover” effects. The control group, or comparison group, is formed of unsignalized intersections within the study area that have not undergone any improvements (e.g., geometric change, traffic control improvements, etc.) from the “Before Period” to the “After Period.” Separate SPFs were developed for the unsignalized intersections as the control group. The assumption (for analysis using unsignalized intersections as the control group) is that the RLC program might have changed the behaviour of motorists at all signalized intersections, with or without cameras, but that their behaviour at unsignalized intersections is not impacted. Other factors such as weather conditions, effects of educational programs, speed enforcement, changes in vehicle characteristics and other confounding factors are assumed to affect driver behavior at both signalized and unsignalized intersections in the same way.

**Appendix A** presents the basic algorithm used to evaluate the safety performance of the RLC program. This algorithm was developed to control for other potential influencing factors that may influence collision frequency beyond that of the RLC program initiation.

#### **4.1.2 Development of Safety Performance Functions**

The following section provides details on the development of the SPFs used to obtain expected number of collision frequency. **Appendix B** presents additional details on the methodology used for the development of SPFs.

In this assessment, SPFs were developed for both signalized and unsignalized intersections. The SPFs for signalized intersections were used for evaluating the safety performance of RLC-equipped intersections. The SPFs were applied to the EB analysis method to account for changes in (traffic) volumes and the RTM phenomenon. SPFs that were developed for unsignalized intersections were used to account for any potential “spillover” effect of RLCs by taking into account the temporal trends (trends over time) in the number of collisions that were not related to RLC installation.

All participating municipalities had similar collision reporting practices. As a result, data were combined to develop the SPFs. For signalized intersections, SPFs were developed for total, severe (i.e., fatal and injury), and property-damage-only (PDO) collisions. In terms of collision types, SPFs for right-angle and rear-end collisions were developed as the literature review found that RLCs mostly affect these two collision types. The literature review also identified these two collision types as the target for collision reductions through RLC program implementation. Similarly, for unsignalized intersections, separate SPFs were developed for total, severe, and PDO collisions as well as for right-angle and rear-end collisions.

The AADT volumes were considered as an independent variable for SPF development. Because all intersections in this study were four-legged intersections, the SPFs were developed only for four-legged signalized and unsignalized (TWSC) intersections. **Table 2** summarizes the resulting SPF model form and its parameters for signalized intersections for total, severe, PDO, angle, and rear-end collision categories, and, for unsignalized intersections for only total and PDO collision categories. For unsignalized intersections, it was only possible to develop statistically reliable SPFs for total and property-damage-only collisions, as summarized in Table 2.



**Table 2. Safety Performance Functions for 4-legged Intersections**

Traffic Control	Type	SPF Model Form	$\alpha$	$b$	$K$	mean Pearson's Chi-Square
Signalized	Total	$E(Y) = \alpha \times F_{tot}^b$	$1.7364 \times 10^{-4}$	1.0774	0.2503	1.0599
	Severe		$0.6794 \times 10^{-4}$	1.0344	0.4883	1.0667
	PDO		$0.1044 \times 10^{-4}$	1.0985	0.2329	1.0558
	Angle		$8.5563 \times 10^{-2}$	0.3182	0.6608	1.2510
	Rear-End		$1.2094 \times 10^{-7}$	1.6788	0.4074	1.2842
Unsignalized	Total		$1.9540 \times 10^{-2}$	0.5020	0.8056	1.0251
	PDO		$1.9359 \times 10^{-2}$	0.4752	0.7794	1.0383

- In the third column from the left,  $F_{tot}$ , denotes total entering AADT.
- 'a' and 'b' are model parameters (presented in fourth and fifth columns respectively) determined by AECOM through model development / calibration tasks using historic collision and traffic data.
- $E(Y)$  is the mean annual expected collision frequency for that intersection.
- The two last columns are the dispersion parameter (denoted by 'k') and mean Pearson's Chi-Square ( $X^2$ ) as two statistical measures to assess the goodness-of-fit of the SPF model. A more statistically reliable model is represented by a smaller model dispersion parameter and a mean Pearson's Chi-square value that is closer to 1.0000.
- All parameters are significant at a 95% confidence level, and present intuitive signs with an expected effect (increase or decrease) on the number of predicted collisions.

As a numerical example, and based on information provided in Table 2, for a signalized intersection with total entering AADT ( $F_{tot}$ ) of 25,000, the mean annual expected number of total collisions is calculated at 9.5058 (roughly equivalent to ten collisions per year), as follows:

$$\text{Mean annual expected total collision frequency: } E(Y) = 1.7364 \times 10^{-4} \times (25,000)^{1.0774} = 9.5058$$

For the same intersection, the mean annual expected number of rear-end collisions is calculated at 2.9230 (almost three collisions per year), as follows:

$$\text{Mean annual expected rear-end collision frequency: } E(Y) = 1.2094 \times 10^{-7} \times (25,000)^{1.6788} = 2.9230$$

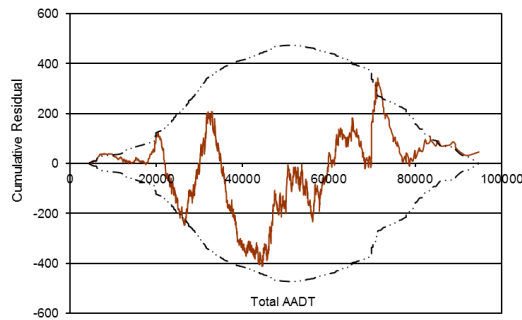
As shown by these examples, the development of SPFs provides a means to approximate expected numbers of collisions, as the benchmark used for comparison to the observed number of collisions in the "After Period". The results of the comparison are discussed in Section 5.1.

The performance of the above SPFs over a range of total AADT values entering intersections was also evaluated using CUMulative RESidual (CURE) plots. The CURE plots illustrate how well the model fits the observed collision data. In the CURE plots, the cumulative residuals (the difference between the observed and predicted values for each intersection) are plotted versus Total AADT. Graphs of the 95% confidence limits are also plotted. The plots can show if there is bias in the model. For example, if there is no bias in the model, the plot of cumulative residuals moves up and down around the x-axis with a random pattern, and ideally it should stay inside of the graphs of 95% confidence limits.

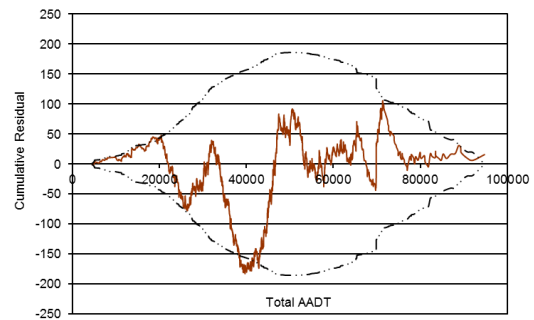
**Figure 1** illustrates CURE plots for the models developed for a range of Total AADT values. The indication is that the fit is very good for SPF models that were developed for the Total, Severe, and PDO collisions at signalized intersections (Figures 1-A, 1-B, and 1-C). The SPF models developed for Total and PDO collisions at unsignalized intersections are also a reasonable fit (Figures 1-F and 1-G).



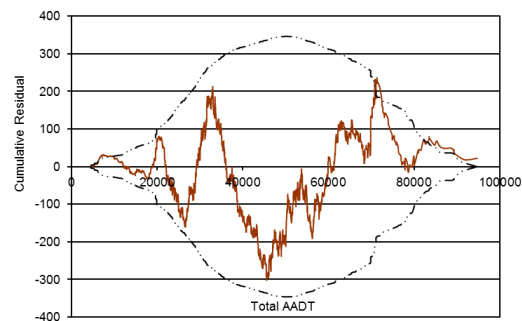
**Figure 1. CURE Plots for Safety Performance Functions (SPFs)**



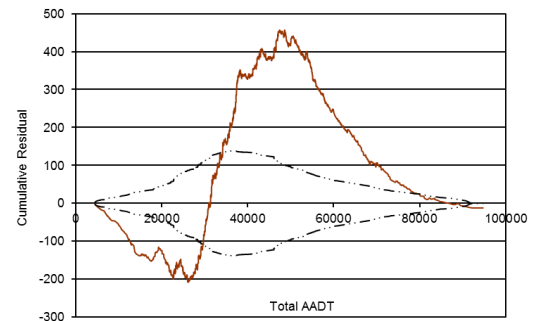
**A. CURE Graph For Signalized 4-Legged Intersections for Total Collisions**



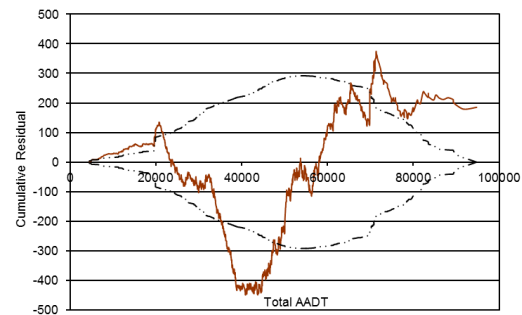
**B. CURE Graph For Signalized 4-Legged Intersections for Severe Collisions**



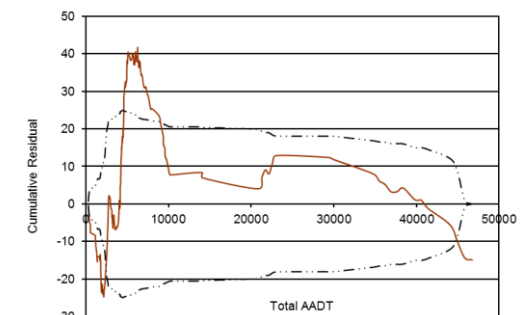
**C. CURE Graph For Signalized 4-Legged Intersections for PDO Collisions**



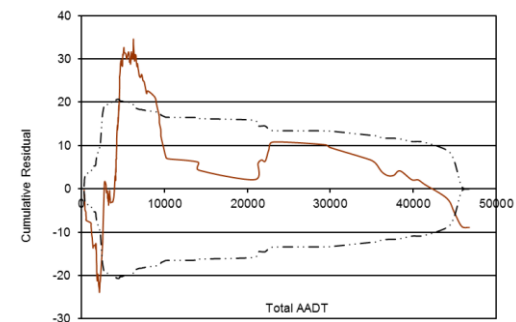
**D. CURE Graph For Signalized 4-Legged Intersections for Angle Collisions**



**E. CURE Graph For Signalized 4-Legged Intersections for Rear-End Collisions**



**F. CURE Graph For Unsignalized 4-Legged Intersections for Total Collisions**



**G. CURE Graph For Unsignalized 4-Legged Intersections for PDO Collisions**

**Legend:** — Cumulative Residual  
- - - ± 1.96 Standard Deviations

However, the fit is not as good for angle and rear-end SPF models developed for signalized intersections (Figures 1-D and 1-E). To address this deficiency in the SPF models pertaining to angle and rear-end collisions, the methodology used in the Highway Safety Manual (HSM) (11) and Safety Analyst (12) was applied. In this methodology, based on historical collision data for each specific collision impact type, a proportion of collisions by impact type (as a fraction of total collisions) is calculated and multiplied by the SPF developed for total collisions to obtain the SPF models for that specific impact type. In other words, it is assumed that for non-RLC-equipped signalized and unsignalized intersections, the proportions of rear-end and angle collisions remain unchanged from the “Before Period” to the “After Period”.

The proportions of angle and rear-end collisions for both signalized and unsignalized intersections were determined from the observed collisions for the “Before Period”, as summarized in **Table 3**. As can be seen in Table 3, rear-end collisions were reported as an impact type for 44% of collision records at signalized intersections and 14% of collision records at unsignalized intersections. In addition, angle collisions account for 16% of total collisions at signalized intersections and 53% of collisions at unsignalized intersections.

**Table 3. Proportions of Angle and Rear-End Collisions (Based on Observed Number of Collisions)**

	Angle	Rear End
Signalized Intersections	16%	44%
Unsignalized Intersections	53%	14%

## 4.2 RLC Program Analysis # 2 – Violation Analysis

In the absence of red-light violation data for periods before the installation of red-light cameras as a requirement for conducting before-and-after assessment, time series analyses were used to evaluate the occurrence of red-light violations within each participating municipality. Time-series analysis is a methodology to identify potential specific trends in number of red-light violations following the initiation of RLC programs. The results of the violation analysis are discussed in Section 5.2.

## 5. Results

### 5.1 RLC Program Analysis # 1 – Collision Analysis

#### 5.1.1 Safety Effects of RLC Program

The first component of the collision analysis considers the safety effects of installing RLCs. As per the analysis methodology explained in Section 4.1.1, unsignalized intersections were included in this analysis as a means to account for the potential for “spillover” effects. Data were provided by five municipalities (noted in Section 3).

**Table 4** shows the aggregated results of the RLC program safety evaluation and compares two items:

- 1) Expected collision data that would have occurred at RLC-equipped intersections if RLCs had not been installed, estimated through the EB method calculations (referred to as “EB Estimate of Collisions Expected in After Period without RLC”); and
- 2) Actual collision data that were collected in the field at the same intersection locations where RLCs were installed (referred to as “Observed Collisions in After Period”).

The comparison of these two items for each collision category gives the “Estimate of Percent Change in Collision Frequency”, which shows that the safety effects of installing RLCs is a significant reduction in the number (or frequency) of expected severe and angle-type collisions (32.4% and 37.7% reductions respectively), a lesser number (or frequency) of expected total collisions (8.4% reduction), and a greater number (or frequency) of expected PDO and rear-end collisions (1.4% and 7.7% increases respectively).

**Table 4. Collision Analysis Aggregated Results (Five Municipalities)**

	Total Collisions	PDO Collisions	Severe Collisions	Angle Collisions	Rear-End Collisions
<b>Comparison Items</b>					
1) EB Estimate of Collisions Expected in After Period without RLC – Spillover Effects Controlled	10854	7550	3391	1813	4785
2) Observed Collisions in After Period	9945	7654	2291	1129	5152
<b>Estimated RLC Program Safety Benefits and Associated Confidence Measures</b>					
Estimate of Percent Change in Collision Frequency $100 \times (2)/(1) - 100$	-8.4%	+1.4%	-32.4%	-37.7%	+7.7%
Estimate of Index of Effectiveness (2)/(1)	0.916	1.014	0.676	0.623	1.077
Lower Bound of the 95% Confidence Interval	0.897	0.989	0.646	0.584	1.044
Upper Bound of the 95% Confidence Interval	0.936	1.039	0.705	0.661	1.110

In Table 4, the “Estimate of Index of Effectiveness” is the measure of the reduction in collisions through the introduction of RLCs. The “Estimate of Index of Effectiveness” values lie between the calculated lower bound and the upper bound values of the 95% confidence interval, meaning the results in Table 4 are statistically significant at a 95% confidence level for all collision severity levels and impact types (refer to Appendix A for further discussion on “Index of Effectiveness”).

### 5.1.2 Magnitude of “Spillover” Effects

As stated in Section 4.1.1, previous studies (3,8) have shown that initiation of RLC programs and the related jurisdiction-wide publicity are not only effective in reducing the number of collisions at RLC-equipped intersections, but are also effective at non-equipped signalized intersections, within that jurisdiction.

In the analysis of the RLC programs described in Section 5.1.1, potential “spillover” effects at non-RLC-equipped signalized intersections were controlled through the use of an “annual spillover multiplier” (ASM) as described in Appendix A. The following analysis is undertaken to better understand and quantify the magnitude of the “spillover” effects.

This second analysis of the RLC programs is completed without controlling for the potential “spillover” effects. In other words, two similar analyses were conducted: one with and one without application of the ASM. The analysis in Section 5.1.1 used the ASM, while this section discusses the analysis without the application of ASM. **Table 5** shows the aggregated results of the second assessment. The “Observed Collisions in After Period” remain the same in both analyses as summarized in Tables 4 and 5.

**Table 5. Collision Analysis Aggregated Results (Five Municipalities)  
without Accounting for Spillover Effects**

	Total Collisions	PDO Collisions	Severe Collisions	Angle Collisions	Rear-End Collisions
<b>Comparison Items</b>					
1) EB Estimate of Collisions Expected in After Period without RLC – Spillover Effects <u>not</u> Controlled	9695	7053	2620	1769	4088
2) Observed Collisions in After Period	9945	7654	2291	1129	5152
<b>Estimated RLC Program Safety Benefits and Associated Confidence Measures</b>					
Estimate of Percent Change in Collision Frequency $100 \times (2)/(1) - 100$	+2.6%	+8.5%	-12.6%	-36.2%	+26.0%
Estimate of Index of Effectiveness (2)/(1)	1.026	1.085	0.874	0.638	1.260
Lower Bound of the 95% Confidence Interval	1.004	1.059	0.836	0.599	1.222
Upper Bound of the 95% Confidence Interval	1.048	1.112	0.913	0.677	1.298

As shown by “Estimate of Percent Change in Collision Frequency” in Table 5, when “spillover” effects are not controlled, the frequencies of total, PDO, and rear-end collisions have increased by 2.6%, 8.5%, and 26.0% respectively after implementation of RLC programs, while collisions have reduced by 12.6% for severe and 36.2% for angle types. This is consistent with findings of previous research (as presented in Section 2).

The “Estimate of ‘Spillover’ Effects” summarized in **Table 6** are the difference between respective numbers of collisions expected in the “After Period” (obtained by using EB method), shown in the first rows of Table 4 and Table 5 (repeated in the first two rows of Table 6), for each collision category (i.e. total, PDO, severe, angle, and rear-end). This comparison shows that there is an overall reduction in the expected number of collisions (calculated by the EB method) where “spillover” effects are not controlled, regardless of the collision type. The “Estimate of Percent Change in Collision Frequency” as well as “Estimate of Index of Effectiveness” values presented in Table 5 were underestimated in assessing RLC program safety benefits.

**Table 6. Estimated Spillover Effects**

	Total Collisions	PDO Collisions	Severe Collisions	Angle Collisions	Rear-End Collisions
EB Estimate of Collisions Expected in After Period without RLC – Spillover Effects Controlled (Item 1 from Table 4)	10854	7550	3391	1813	4785
EB Estimate of Collisions Expected in After Period without RLC – Spillover Effects <u>not</u> Controlled (Item 1 from Table 5)	9695	7053	2620	1769	4088
Difference in Collision Frequencies Attributed to Spillover Effects (Item 1 from Table 4 minus Item 1 from Table 5)	1159	497	771	44	697
Percent Change in Collision Frequencies Attributed to the Spillover Effect	10.7%	6.6%	22.7%	2.4%	14.6%

As an example, Table 6 shows that if “spillover” effects are not controlled, the expected number of total collisions is estimated at 9,695 in the “After Period”. However, when “spillover” effects are controlled in order to replicate a scenario with no RLC programs and no associated “spillover” effects, the expected number of total collisions is estimated to be 10,854 in the “After Period”. The difference between these two numbers is attributed to “spillover” effects and the resultant reduction in collisions in non-equipped signalized intersections in the “After Period” following the RLC program initiation. As noted in Section 4.1.1, this collision reduction is attributed to modified driver behaviour at non-RLC-equipped signalized intersections, which may result from jurisdiction-wide publicity of RLC programs and the negative results of red-light-running, the general public’s lack of knowledge with respect to where RLCs are installed, and a subsequent conservative assumption by motorists that every signalized intersection is potentially equipped with an RLC.

The challenge with this before-and-after study and estimating the magnitude of the “spillover” effect is that the RLC program has been in effect for a long period of time. As stated by Persaud et al. (15), other safety programs (“history” factors) may have contributed to a change in driver behaviour over the same data collection period, and it is important to note that the safety benefits of RLC installation and the results given in Table 4 (Section 5.1.1) may be overstated by this assessment.

Despite the potential for overstated results, it is recommended that the values in Table 4, Section 5.1.1 be used as the final RLC program assessment results.

## 5.2 RLC Program Analysis # 2 – Violation Analysis

In this study, the collected data was sufficient to complete a statistically valid collision assessment which, as presented in the preceding section, shows reductions in angle and other severe collisions with the implementation of RLCs at signalized intersections, though PDO and rear-end collisions increased. This conclusion was based on the aggregation of data and analysis across multiple representative municipalities, and hence can be considered a “provincial perspective” on the safety benefits of RLC programs. Given that many angle and other severe collisions involve vehicles running through red lights, and that the analysis shows that these collisions can be reduced with RLC enforcement, one might infer that red-light violations at intersections should also be reduced with RLC programs. Comparable broad-based violation analysis to confirm (or not confirm) this inference would be beneficial.

Ideally, there would be sufficient data available from multiple municipal agencies regarding red-light violations, both before and after implementation of RLCs, to allow for the same degree of analysis of RLC benefits with respect to reducing the number of violations as is possible for a collision-based analysis. While record keeping practices with respect to collisions appear to be fairly consistent amongst municipalities and the province, there are variations from one municipality to another in terms of how red-light violation data are processed and stored. Considering the limitations of the available data, the red-light violation analysis could not be completed on a provincial level.

In order to be able to draw conclusions regarding red-light violations from a broad perspective, more consistent and complete data would be needed for future studies. For example, storing and reporting on critical data for each individual red-light violation as a discrete event (as is done with collision records) would provide a good base of data. Maintaining detailed records of when RLCs are or are not present and/or active at each intersection would also be beneficial.

The available red-light violation data used in this study shows decreases in violations in some communities believed to be related to the implementation of RLCs, increases in violations in some other communities, and no definitive results for others.

## 6. Summary of Findings and Discussion

### 6.1 RLC Program Analysis # 1 – Collision Analysis

One of the important characteristics of this study was that it was initiated in 2009, almost 10 years after the 1999 commencement of the first RLC program in the Province, at a time when the program was mature and could provide enough data. A second characteristic that differentiates this study from other previous studies is that in the evaluation of the RLC program the potential “spillover” effects of RLCs were controlled by using data from unsignalized intersections. The literature review revealed that little of the previous completed research had been able to account for the “spillover” effects. Therefore, this study, through use of the Empirical Bayes (EB) before-and-after study methodology, was designed to effectively evaluate the safety implications of RLC programs by accounting for changes in traffic volume, RTM, and potential “spillover” effects.

The results of the before-and-after study were found to be consistent with previous research. Taking spillover effects into account, it was found that angle collisions decreased 37.7% and severe collisions decreased 32.4%, while PDO collisions increased 1.4%, and rear-end collisions increased 7.7% with the implementation of RLCs at signalized intersections. These results are consistent with other research, although this study estimated a larger reduction in angle collisions and a smaller increase in rear-end collisions than had been identified previously. The variation in results between this and previous studies may be attributed to either maturity of the RLC program in Alberta, or the inclusion of “spillover” effects in this study analysis.

This study also assessed the magnitude of the “spillover” effect of RLCs. Using data associated with both signalized and unsignalized intersections, this study identified a rather significant “spillover” effect. The analysis showed an additional 10.7% reduction in the total expected number of collisions at non-RLC equipped signalized intersections due to “spillover” effect. In other words, the initiation of RLC programs within municipalities, and the related jurisdiction-wide publicity campaigns, are effective at reducing the number of collisions at RLC-equipped intersections as well as at non-RLC-equipped signalized intersections. However, it should be noted that the actual “spillover” effect might be smaller than the findings of this study. The main reason, as stated by Persaud et al. (15), is that the RLC installations occurred over a 10-year period in Alberta, and many other safety-related programs might have affected driver behaviour during that same time period.

### 6.2 RLC Program Analysis # 2 – Violation Analysis

For all of the municipalities that participated in this study, details/data related to red-light violations prior to installation of RLCs were not collected and are unknown, eliminating the possibility of “before-and-after” analysis. As this information was not available for assessment, an analysis of the data trends after RLC installation was undertaken to explore the impacts of RLC programs on the number of red-light running violations, in place of a “before-and-after” study.

Considering the limitations of the available data, including variations from one municipality to another in terms of how violation data are processed and stored, the red-light violation analysis could not be completed on a provincial level. Aggregation of the data and analysis results to provide an overall assessment of RLC impacts on violations was not possible.

Study analyses and results, or output, are highly dependent on the available data input. At this time, collision records are recorded and reported in a consistent manner, while there is currently no consistency in the quality and quantity of red-light violation data available for use in studies such as this. As a general observation, more consistent recording of information such as times of camera activity/inactivity would be very helpful as would consistent



recording of details of each individual event captured by enforcement cameras (e.g., location/intersection, date, time, direction of travel, etc., along with a record of whether or not a ticket was issued).

### **6.3 Conclusion**

Study analyses and results are highly dependent on the available data input. In this study, the collected data was sufficient to complete a statistically valid collision assessment. However, due to data limitations, a red-light violation assessment could not be completed from an overall provincial perspective.

In general, through review of the individual municipalities that participated in the study, it appears that a Province-wide RLC program would have an overall positive net benefit and provide for a reduction in red-light violations, which subsequently may contribute to reduced numbers of severe and angle collisions. However, it should be noted that not all intersections are likely to receive the same positive benefits of program implementation, and that the number of rear-end collisions may increase at RLC-equipped intersections. From the collision analysis conducted with respect to the RLC program, taking spillover effects into account, it was found that angle collisions decreased 37.7% and severe collisions decreased 32.4%, while PDO collisions increased 1.4%, and rear-end collisions increased 7.7% with the implementation of RLCs at signalized intersections.

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# Appendix A

Detailed Algorithm to Evaluate  
Safety Performance of RLC  
Programs

## Appendix A. Detailed Algorithm to Evaluate Safety Performance of RLC Programs

This appendix presents the algorithm used to evaluate the safety performance of RLC programs. The evaluation of an RLC program involves finding the expected number of collisions in the “After Period” and comparing it with the observed number of collisions in the “After Period”. The Empirical Bayes (EB) approach was utilized to estimate this quantity.

The first step is to estimate the mean annual expected number of collisions using Safety Performance Functions (SPFs) developed for the “Before Period”. The estimate of the mean annual expected number of collisions would not incorporate some other determinants of the safety such as traffic, weather, and vehicle mix, which generally change from year to year. The effect of such changes must be controlled using the EB approach suggested by Hauer (13). The mean annual expected numbers of collisions obtained directly from SPFs for all years are used to calculate multipliers for every single year (the “Before and After Periods”) to account for temporal variations in these factors using the following equation:

$$C_{i,y} = E_{i,y}/E_{i,1} \quad (\text{A-1})$$

Where  $C_{i,y}$  = annual multiplier for location  $i$  for year  $y$ ,  
 $E_{i,y}$  = mean annual expected number of collisions for location  $i$  for year  $y$ , and  
 $E_{i,1}$  = mean annual expected number of collisions for location  $i$  for year 1.

The above multipliers were then used to compute the expected number of collisions and variances for each of the treated sites and for each of the years in the “After Period” using the EB method. This was achieved by using the following equations. In these equations, the assumption is that the “Before Period” consists of  $y = 1, \dots, Y$  and the “After Period” includes  $y = Y + 1, Y + 2, \dots, Z$ .

$$m_{i,1} = (k + x) / \left[ \frac{k}{E_{i,1}} + \sum_{y=1}^{Y-1} C_{i,y} \right] \quad (\text{A-2})$$

$$\text{Var}(m_{i,1}) = m_{i,1} / \left[ \frac{k}{E_{i,1}} + \sum_{y=1}^{Y-1} C_{i,y} \right] \quad (\text{A-3})$$

$$m_{i,y} = C_{i,y}(m_{i,1}) \quad (\text{A-4})$$

$$\text{Var}(m_{i,y}) = (C_{i,y})^2 \text{Var}(m_{i,1}) \quad (\text{A-5})$$

Where,  $m_{i,1}$  = Expected number of collisions at treated location (RLC intersection)  $i$  in year 1,  
 $m_{i,y}$  = Expected number of collisions at treated location (RLC intersection)  $i$  in year  $y$ ,  
 $\text{Var}(m_{i,1})$  = Variance of expected number of collisions at treated location (RLC intersection)  $i$  in year 1,  
 $\text{Var}(m_{i,y})$  = Variance of expected number of collisions at treated location (RLC intersection)  $i$  in year  $y$ ,  
 $k$  = Over dispersion parameter, and  
 $x$  = Sum of observed number of collisions at location  $i$  during the “Before Period”.

The aggregate of the expected number of collisions that would have occurred in the “After Period” without the treatment ( $\pi$ ) is then obtained by summing over all RLC-equipped intersections and comparing with observed collisions for the same intersections in the “After Period” ( $\lambda$ ). The variance of  $\pi$  was also computed by summing over variances of all intersections in the treatment group. The index of effectiveness ( $\theta$ ) is then determined using the following equations (13).

$$\pi = \sum_{y=1}^y m_{i,y} \quad (A-6)$$

$$\theta = \frac{\frac{\lambda}{\pi}}{\left[1 + \frac{Var(\pi)}{\pi^2}\right]} \quad (A-7)$$

$$Var(\theta) = \theta^2 \frac{\frac{Var(\lambda)}{\lambda^2} + \frac{Var(\pi)}{\pi^2}}{\left[1 + \frac{Var(\pi)}{\pi^2}\right]^2} \quad (A-8)$$

To determine, whether  $\theta$  is significant or not, the lower and upper bounds of the 95% confidence interval for  $\theta$  is calculated as follows if the number of RLC-equipped locations are larger than 30 based on the central limit theorem:

$$\theta \pm 1.96\sqrt{var(\theta)} \quad (A-9)$$

In the above equations, the “spillover” effect has not been considered. Therefore, an additional step is taken in developing SPFs, specifically the identification of a control group. This step is taken to identify the true effect of RLC programs and acknowledge potential “spillover” effects. The control group, or comparison group, is formed of unsignalized intersections within the study area that have not undergone any improvements (e.g. geometric change, traffic control improvements, etc.) from the “Before Period” to the “After Period”. Separate SPFs were developed for the unsignalized intersections in the control group. The assumption (for using unsignalized intersections as the control group) is that the RLC program might have changed the behaviour of motorists at all signalized intersections, with or without cameras, but that their behaviour at unsignalized intersections is not impacted. Other factors such as weather conditions, effects of educational programs, speed enforcement, change in vehicle characteristics, and other confounding factors are assumed to affect driver behavior at both signalized and unsignalized intersections in the same way

The SPF for unsignalized intersections is developed based on the data prior to the installation of the first RLC in each jurisdiction in this study. Annual spillover multipliers (ASM) for each year, after the year of the first RLC installation, are calculated as the ratio of the observed collisions to the predicted collisions for unsignalized intersections. Then, these multipliers are applied to the mean expected number of collisions,  $E_{i,y}$ , before they are used in equation (A-1).

# Appendix B

## Methodology to Develop Safety Performance Functions

## Appendix B. Methodology to Develop Safety Performance Functions

The SPF models were developed using a Full Bayes approach and Markov Chain Monte Carlo (MCMC) simulation techniques assuming a negative binomial error structure (14, 15). The BayesX software package (16) was used as a tool in the development of the SPFs. For each of the dependent variables (i.e., frequency of collision severity levels and frequency of collision impact types described before), SPFs with different model forms were calibrated. The candidate SPF model forms considered in this study were those that most often had appeared in the literature for signalized and unsignalized intersections with similar traffic and environment characteristics. These SPF model forms were evaluated using various criteria. The first criterion was the presence of a counter-intuitive sign for variable coefficients (' $\alpha$ ' and ' $\beta$ '), which immediately resulted in the rejection of the model. The second criterion was the statistical significance of the coefficients. Only models for which all coefficients were statistically significant at a 95% confidence level were accepted. The over-dispersion parameter (' $k$ ') was also used as an overall goodness-of-fit measure. A lower value of the over-dispersion parameter (' $k$ ') represents a better fit of the model. Finally, the fourth criterion was the mean Pearson's Chi-Square ( $X^2$ ) statistical measure. This measure is calculated using the following equations, where  $df$  represents the degrees of freedom of the model:

$$X^2 = \sum_{i=1}^n \sum_{t=1}^T \frac{[Y_{it} - E(Y)]^2}{Var(Y)} \quad (B-1)$$

$$X^2_{mean} = \frac{X^2}{df} \quad (B-2)$$

where,  $Y_{it}$  denotes observed collision frequency for intersection  $i$  in year  $t$ ,  
 $E(Y)$  denotes the expected value of collision frequency corresponding to  $Y_{it}$  obtained from the SPF model,  
 $Var(Y)$  represents the variance of collision frequency,  
 $n$  is the number of intersections, and  
 $T$  is the study period.

A value of  $X^2_{mean}$  closer to 1 indicates a better goodness-of-fit of the model.

The third and fourth criteria were jointly used to assess the overall goodness-of-fit of the model. In this assignment, if the first two criteria for goodness-of-fit were satisfied (i.e., the signs for the model coefficients were all intuitive and coefficients were statistically significant) then the SPF model form with the smallest over-dispersion parameter (' $k$ ') and  $X^2_{mean}$  statistics smaller than 1.5 was selected. The selected SPF model form in this study was as follows:

$$E(Y) = \alpha \times F_{tot}^b \quad (B-3)$$

Where,  $F_{tot}$ , denotes total entering AADT, and  
' $\alpha$ ' and ' $\beta$ ' are model parameters