Safety Evaluation of Intersection Safety Camera Program in Edmonton

by

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ABSTRACT

This thesis evaluates the safety effects of intersection safety devices (ISD). The purpose of ISD cameras is to reduce the number of collisions that result from red-light running and speeding at intersections. Typically, ISD cameras are placed at one or more approaches of an intersection and identify drivers who either speed or run red-lights at that approach. Currently, the City of Edmonton has a total of 50 ISD cameras installed at 30 intersections. The goal of this thesis is to evaluate the collision reductions that occur as a result of ISD camera installation and to identify factors which contributed to the successful application of ISD cameras. The effectiveness of several site selection criteria is also evaluated, and potential new site selection criteria are identified. The collision reductions are determined using the before-and-after Empirical Bayes (EB) methodology. The EB method controls for many potential sources of bias, and is identified in the literature as the preferred method for safety evaluations. The results showed significant reductions in total collisions as well as angle and rear-end collisions. The reduction in total collisions ranged from 13% to 25%. The reduction in angle collisions ranged from 13% to 27%. The impact of site selection criteria on collision reduction was also evaluated. Greater reduction were found at sites that had higher collision frequency. Additionally, the impact of intersection characteristics on collision reduction was investigated. It was found that lane width, speed limits, and the number of lanes had an impact on ISD collision reduction. From the results it could be concluded that ISD cameras were effective at improving the safety of the evaluated intersections. Finally, the intersection characteristics associated with greater ISD collision reductions can be used to aid in determining locations for future ISD installation.

PREFACE

The work in Chapter 3 & 4 is currently under review as L. Contini and K. El-Basyouny "Before-After Empirical Bayes Evaluation of Intersection Safety Camera Program in Edmonton". I was responsible for the data collection, analysis and manuscript composition. Dr. Karim El-Basyouny contributed to concept formation and manuscript edits.

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1 INTRODUCTION

1.1 Background

In Canada there were 1,923 fatalities and 10,315 serious injuries resulting from collisions in 2013 (Transport Canada, 2015). In addition to the loss of life and health consequences, collisions also result in heavy economic consequences. It is estimated that across Canada the societal cost of collisions is approximately 5% of the GDP, or $63 billion (Transport Canada, 2007). The cost of collisions consists of several components such as the loss of life, medical treatment and rehabilitation, loss of productivity and property loss. Traffic safety continues to be a major issue on the provincial and municipal levels. For example, in Alberta the fatality rate for 2013 was 8.9 per 100,000 people and the injury rate was 465 per 100,000 people (Transport Canada, 2015). In 2014 there were nearly 25,000 collisions in the city of Edmonton including over 2,900 injuries and 23 fatalities (Motor Vehicle Collisions, 2014). These statistics demonstrate that the traffic safety problem has a far reaching social and economic effect on our society, affecting the lives and welfare of millions of Canadians. If current (unsafe) trends continue unchanged, the number of people killed and injured on our roads is projected to increase. Consequently, the importance of reducing the social and economic costs of road collisions cannot be overstated. There are several approaches to address the traffic safety problem with engineering and enforcement initiatives being recognized as the most sustainable and cost effective.

In 2014 collisions at intersections accounted for 55% of the total number of collisions and 68% of injury collisions in the city of Edmonton (Motor Vehicle Collisions, 2014). Red-light running is a common problem at intersections; Retting et al. (1996) observed at least one instance of red-light running in 30% of all intersection phase cycles. Angle collisions and rear-end collisions are the commonly identified collisions related to red light running (Retting et al. 2003). Angle collisions occur when a vehicle enters the intersection after the onset of the red phase and collides with a vehicle with the right-of-way entering from a perpendicular roadway.

In order to reduce collisions at intersections several jurisdictions in Canada and around the globe have used intersections safety cameras. There are two main types of intersection safety cameras. Firstly, there are red-light cameras (RLC), which target red-light running by ticketing vehicles which enter the intersection after the red phase. The second type of intersection safety camera are similar to RLC but also include speed enforcement. There has not been a consistent name for these types of cameras in the literature, in this thesis the combined cameras are referred to as intersection safety devices (ISD).

The City of Edmonton began their intersection camera program in 1998 with the installation of red light cameras (RLC). They have since introduced Intersection Safety Devices (ISD) which combine red-light running enforcement and speed enforcement at intersections. The continuation/discontinuation, or expansion of the program hinges on its ability to achieve its desired objective which is to improve safety by reducing the frequency of collisions that occur at ISD intersections. Consequently, the primary goal of this thesis is to apply the latest state-of-the-art techniques to evaluate the safety effects of the ISD program in order to demonstrate the success of the program in improving safety while help inform policy decision on the expansion or refinement of the current program or similar programs. Ultimately, the goal is to share information with other researchers and practitioners about the effectiveness of the ISD programs.

1.2 Objectives of Thesis

Currently there are 50 ISD cameras installed at 30 intersections throughout the City of Edmonton. The general objective of this thesis is to evaluate the safety effectiveness of the ISD camera program in the city of Edmonton at the intersection level and the approach level.

The first objective of this thesis is to estimate the safety effectiveness of ISD cameras at the intersection level. This means that the unit of analysis is the entire intersection which is usually composed of four approaches. The changes in collisions across at all intersection approaches is included. It is important to note that ISD cameras could be installed on one or more approaches of the intersection. However, it is difficult to say how the presence of that ISD is affecting the driver behaviour on all other approaches. Hence, the first analysis focuses on the changes in safety for the entire intersection. The safety effectiveness of RLC has been thoroughly studied in the literature, however there has been few studies evaluating ISD cameras. The before-and-after Empirical Bayes (EB) methodology will be used to estimate the collisions reductions at ISD intersections.

The second objective of this thesis is to estimate the safety effectiveness of ISD cameras at the approach level. The approach level analysis concerns the changes in collisions that occur on each approach. This analysis has four sub-objectives. The first objective is to estimate the approach level collision reductions using the before-and-after EB method. The second objective is to estimate the spillover effects at the untreated approaches at the ISD intersections. The third objective is to investigate the effects of various site selection criteria and their relationship to changes in collision. This should provide valuable information for future ISD site selection. The fourth and final objective is to identify factors that contribute to the successful application of ISD technologies. It is expected that ISD performance will not be the same for all sites since different intersections typically have varying traffic and geometrical configurations.

1.3 Thesis Structure

The remainder of this thesis is organized into the following chapters:

Chapter 2 provides a literature review in two sections related to the topics of this thesis. The first section describes an overview of intersection safety. Focus is given to the effects of speeding and red-light running. The second section details current methods of safety evaluation analysis specifically focusing on the rational for choosing the Empirical Bayes before-and-after methodology.

Chapter 3 presents the data, methodology and results of the intersection level analysis. Attention is given to detailing the process of developing safety performance functions and yearly calibration factors as well as the Empirical Bayes methodology.

Chapter 4 presents the data, methodology and results of the approach level analysis. Spillover effects and various site selection criteria for ISD treatment sites is also evaluated. Recommendations are made for future site selection criteria.

2 LITERATURE REVIEW

2.1 Intersection Safety

In 2014 there were nearly 25,000 collisions in the city of Edmonton including over 2,900 injuries and 23 fatalities. Collisions at intersections accounted for 55% of the total number of collisions and 68% of injury collisions (Motor Vehicle Collisions, 2014). The two main causes of injury collisions at intersections were rear-end collisions and left-turn cross path collisions.

2.2 Red-light Running

Red-light running RLR is known to be a major contributor to intersection collisions. Retting et al. (1995) found RLR was the most common type of intersection collisions, accounting for 22% of urban intersection collisions, and 27% of all urban injury crashes based on a study of four jurisdictions in the United States. In Edmonton left-turn-across-path and failure to observe traffic signals where the second and thirds largest contributor to intersection collisions (Motor Vehicle Collisions, 2014). When a driver approaches a yellow light at an intersection they are faced with the decision to stop, or to continue through the intersection. When driving at the appropriate speed, drivers should have enough time to safely stop if they are too far away to safely clear the intersection, or they are able to clear the intersection before the signal changes to red. A dilemma zone is created when the driver must either come to a sudden stop or cross through the intersection during the red phase. Both rear-end collisions and RLR violation occur as a result of the dilemma zone.

Retting et al. (1999) discussed the characteristics of RLR collisions and identified common trends. They found that a difference in the characteristics of drivers involved in RLR collisions that occurred during the day, versus those that occurred at night. It was found that drivers involved in night time RLR collisions were younger, have previous violations or to have suspended licenses. They also found that two thirds of fatality collisions reported some degree of alcohol involvement.

The frequency of RLR events have been studied in the literature. Retting et al. (1996), collected driver behaviour information at Arlington County, Virginia. The found that RLR violators were more likely to be under 30 years of age and have poorer driving histories. Their observations also indicated that there were as up to two instances of RLR per hour. Porter and England (2000) observed 6 intersections from 3 cities in Virginia. They collect data for the last entering vehicle for each phase cycle. They found that 35% of the light cycles there was at least one RLR occurrence; Retting and Williams (1996) found 33% of the cycles had a RLR occurrence. Both studies also found that seat belt usage was lower among RLR occurrences.

Elmitiny et al. (2010) modeled the driver decisions making behaviour at intersections related to RLR. Collected data regarding drivers stop/go decision making at intersections at the on-set of the yellow phase. They found that drivers in the following position were more likely to run red-lights than if they were in the leading position. Therefor if the leading vehicle makes the decision to stop conservatively, they are more likely to be involved in a rear end collision. They found that RLR increased the closer a vehicle was to the intersection at the time of the yellow on-set. Also vehicles travelling at higher speeds where more likely to continue through the intersection, thinking they can beat the light changing. The study recommends that lowering drivers speeds would reduce RLR.

2.2.1 Impact of Speed on Traffic Safety

Driving at higher speeds is associated with both an increased risk of being involved in a collisions but also an increased risk for a more severe collision. Driving at higher speeds increases a driver's reaction time, making it difficult to avoid potential collision situations. Higher speeds also make the road user more vulnerable to injury or fatality. Both average speed and speed variance have been shown to impact safety.

There is very strong evidence to support the idea that speed affects crash risk. Specifically, as speed increases, so does the risk of being involved in a collision (Aarts and van Schagen, 2006; OECD, 2006). Driving at higher speeds contributes to collisions in several ways. Firstly at a higher speed the distance covered by a normal reaction time is greater. Secondly breaking distance also increases as speed increases. Therefore at a higher speed, drivers have less time available to observe a situation, react and execute a maneuver (OECD, 2006) Speed differentials have also been shown to increase collision risk. Taylor et al. (2000) showed that it is not just the average speed of a roadway that impacts safety. When the variation in traffic speed is larger, collisions are more common. They suggested that reducing the speeds of the fastest drivers had the greatest effect on collisions reductions.

Finally speeding also impacts the severity of collisions. Even if speed is not the direct cause of a collision, collision severity is related to the speed at time of collision. This is due to the kinetic energy released during a collision. The relationship between speed and collision severity was modeled by Nilsson (1982) and is referred to as the power model. It was found that a 10% increase in mean speed leads to a 21 % increase in all injury accidents, a 33% increase in fatal and severe injury accidents and a 46% increase in fatal accidents. The Nilsson model describes the general rule of thumb between speed and collisions, however the exact effect will vary for different road conditions (Aarts and van Schagen, 2006).

2.3 Safety Evaluations

Safety Evaluations are used to assess the effectiveness of treatments. Safety evaluation methods fall into two categories: longitudinal evaluation and cross-sectional evaluation. Longitudinal evaluations are also known as before-and-after evaluations and they evaluate the change in collisions from the periods before and after implementation of a treatment. Cross-sectional evaluations focus on the collisions data only in the period after the treatment is applied; the difference in collision frequency between treated and non-treated sites are compared to each other.

Traffic safety studies generally follow a quasi-experimental design. Treatment sites are intentional chosen due to a history of high collision frequencies or some other safety concern and are not randomly assigned. Therefore there can be significant differences between the treated and untreated sites in terms of collision patterns making it difficult to adequately assess safety initiatives using a cross-sectional evaluation. For cross sectional evaluations it is important that sites are as similar as possible; it can often be difficult to gather a large enough sample size while still maintaining similarities in the groups. Therefore before-and-after evaluations are the preferable method for conducting safety evaluations. There are three kinds of before-and-after evaluations:

- Naïve before-and-after evaluation
- Before-and-after evaluation with comparison group
- Before-and-after evaluation with Empirical Bayes method

These three types of evaluations follow the same general format. The study period is broken down into the time before the treatment is applied (before period) and the period after the treatment is applied (after period). Collisions in the before period are compared to the predicted number of collisions that would have occurred in the absence of the treatment in the after period. The three methods differ in how the after period collisions are predicted. The different methods are discussed in more detail in the following sections.

2.3.1 Naïve Before-and-After Evaluation

Naïve before-and-after evaluations are conducted by using the collision frequency in the before period to predict the collision frequency in the after period had the treatment not been applied. This erroneously assumes that the collision frequency would have remained constant if there was no treatment. The formula for the naïve method is shown in Equation (2-1).

$$collision\ reduction = \frac{N_b - N_a}{N_b} \tag{2-1}$$

where

N_b = Number of collisions in the before period

N_a = Number of collisions in the after period

By assuming that the collision frequency is constant several factors are ignored including regression-to-the-mean effects, collision migration, maturation and confounding factors.

Regression-to-the-mean or “bias by selection” is the statistical phenomenon that collision frequency will naturally fluctuate at a location; location with high collision numbers in the before period tend to be followed by low collision numbers in the after period regardless of a treatment being applied. If the regression to the mean effect is ignored, this natural fluctuation may be mistaken for a safety improvement due to the treatment. Council et al. (1980) show an example of regression-to-the-mean effect illustrated in figure 1-1. In the example the collision frequency ranges from 8 to 32, with an average of 20. If a treatment is applied in 1973 to mitigate the high collision frequency in 1972 it would appear that there was a reduction in collisions due to the treatment. It can be seen that any collision reductions observed at the location would be partially attributed to the regression-to-the-mean. Thus the treatment effectiveness would be overestimated in this example. Therefor it can be seen that failing to account for regression to the mean can lead to overestimations of treatment effectiveness. In order to mitigate possible regression-to-the-mean effects using a longer study period for the before period is recommended.

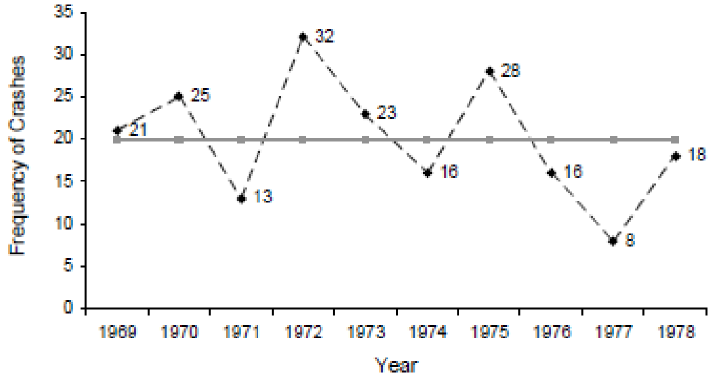

FIGURE 2-1 Regression-to-the-mean example (Council et al. 1980)

The second factor is collision migration. Collision migration is the transfer of collisions from the treatment site to the surrounding area due to the treatment. For example if road surface conditions are improved in one locations drivers may become less cautious resulting in collisions at other locations. Similarly if speed limits are reduced in one location drivers may chose alternative routes with higher speed limits. When drivers change their travel patterns traffic will increase at surrounding areas and decrease for the treatment site, likely resulting in a decrease in collisions at the treatment sites due to the lower traffic volumes. Crash migration can also refer to a shift in the severity of collisions due to a treatment. For example adding a median my decrease head-on collisions but increase fixed-object collisions.

Maturation is the third issue faced by the naïve before-and-after method. Over time there are general changes in traffic volumes, infrastructure, etc. which will impact collision frequency. Traffic volumes generally follow the increase or decrease in population, which is likely to affect the number of collisions. Similarly changes to infrastructure levels can impact collision frequency as well. If road conditions are deteriorating, collisions will likely increase as a consequence. On the other hand increases in education or enforcement of traffic safety initiatives will cause a trend of collisions decreasing over time. These changes in collision frequency are not captured by the naïve before-and-after method and thus the impact of the trends will be misattributed to the treatment.

Finally external factors that would impact collision frequencies are not accounted for. Similar to maturation trends, external factors are temporary conditions or onetime events that influence collision frequencies. Some examples of external factors include varying weather conditions, changes in collision reporting thresholds, or the implementation of new safety countermeasures.

Of the three types of evaluations naïve before-and-after evaluations have the least intensive data requirements and is the simplest to apply. However the naive method fails to account for several key factors the impact the reliability of the evaluation and therefore is the inferior evaluation method.

2.3.2 Before-and-After Evaluation with a Comparison Group

Unlike the naïve before-and-after method, the comparison group method is able to control from maturation and external factors. A comparison group is a group of control sites that are used to estimate the collisions that would have occurred in the after period. The ratio of collisions in the before period to the after period at the comparison sites is assumed to be the same for the treatment sites if the treatment had not occurred. The reduction in collisions is expressed as the odds ratio, a value less than one indicates a reduction in collision.

$$Odds\ ratio = \frac{Comparison_{before}/Comparison_{after}}{Treatment_{before}/Treatment_{after}} \tag{2-2}$$

There are two main assumptions made by this method as identified by (Hauer, 1997). The first is that trends in collision frequencies would be the same for both groups. The accuracy of this method is greatly impact by the choice of comparison group. Similarity between the treatment group and comparison group is important to ensure that the comparison group sufficiently represents what would have happened at the treatment group. Criteria such as collision frequency, traffic volumes, road geometry, and geographic location can all be used to assure similarity between the treatment group and the comparison group. The second assumption is that the comparison group will respond to maturation effects and external factors in the same way as the treatment sites, and therefore the evaluation will be corrected for these factors. In order to use the comparison group to predict the collisions in the after period it is necessary to assume that the treatment does not have an effect at the comparison group sites. This is not always the case, in some instances a treatment may cause an increase in collisions in the surrounding locations if drivers change their behavior in response to the treatment. It is therefore important to use comparison sites that are not likely to be influenced by the treatments. Hauer (1997) suggests 4 requirements for a comparison group:

- The before-and-after periods should be the same length for the treatment group and the comparison group
- The number of collisions should be sufficiently large compared to with the treatment group
- Changes in external factors should be the same for both groups
- The collision history in the before period should be comparable for the treatment and comparison groups

Additionally Pendleton (1991) recommends that the comparison group should be at least five times larger than the number of treatment sites.

2.3.3 Before-and-After Evaluation with Empirical Bayes

Both the naïve method and comparison group method fail to account for regression-to-the-mean effects. Since treatment sites are generally chosen due to high collision frequency the collisions in the before period is likely to suffer from regression-to-the-mean bias. The EB method accounts for this by using an expected value of collisions in the before period. The goal of the EB method is to predict the number of collisions that would have been expected had the treatment not been implemented. This is accomplished by two main steps. First the expected number of collisions in the before period is estimated. Next predict how the expected number of collisions would have changed due to changes in traffic volumes and other external factors.

The EB method is described by Hauer (1997). The method uses the collision history from the treatment site as well as at a group of reference sites which consists of location similar to the treatment. From this information K denotes the number of collision in the before period and the reference group has a mean of $E\{\theta\}$ and a variance of $Var\{\theta\}$. Thus the estimate of the expected number of collisions at the treatment sites is expressed as $E\{\theta|K\}$ with a variance $Var\{\theta|K\}$. Bayes' theorem for probability distributions links these two clues using two assumptions. First it is assumed the distribution of θ's in the reference group follows a Gamma probability density function. The second assumption is that the collision frequency of the treatment sites (*K*) follows a Poisson distribution, meaning that collisions are rare, discrete, random and non-negative. Thus the posterior distribution $p(\theta|K)$ also follows a Gamma distribution shown in below.

$$p(\theta|K) = \frac{p(K|\theta) \cdot p(\theta)}{p(K)} \tag{2-3}$$

where, $p(K)$

$$E\{\theta|K\} = w \cdot E\{\theta\} + (1 - w)K \tag{2-4}$$

$$w = \frac{1}{1 + \frac{Var\{\theta\}}{E\{\theta\}}} \tag{2-5}$$

where $0 \leq w \leq 1$

As shown in Equations (1-4) and (1-5) the expected number of collisions at the treated sites ($E\{\theta|K\}$) is equal to the weight average (*w*) of the expected collisions at the references sites ($E\{\theta\}$) and the observed collisions at the treatment sites (*K*).

$E\{\theta\}$ and $Var\{\theta\}$ can be calculated two ways as recommended by Hauer (1997). Firstly the method of sample moments can be used or safety performance functions (SPF) can be developed using negative binomial (NB) regression analysis.

Persaud and Lyon (2007) compare the study results obtained using EB methodology to those of similar before-and-after methodologies. Data for stop controlled intersections in California from 1994-1999 was used for the comparison. By comparing the collision frequencies in 1994-1996 to the collision frequencies in 1997-1999 it was observed that locations with higher than average collision frequencies was followed by lower collision frequencies and vice versa.

These changes were attributed to regression-to-the-mean effects since there had been no changes at the locations. Furthermore when the accuracy of the comparison group predictions and EB predictions were compared it was evident that the comparison group consistently under-predicted when the before period collision frequency were low and over-predicted when collision frequencies in the before period were high.

2.3.4 Summary of Safety Evaluation Methods

There are four key issues that affect the accuracy of before-and-after evaluations:

- Regression-to-the-mean
- Collision Migration
- Maturation
- External Factors

The EB method is the preferred safety evaluation method because of its ability to account for regression-to-the-mean bias. The EB method also requires the most extensive data in order to develop SPFs. Based on evidence from several studies EB method is the most valid procedure for evaluating safety performance, however it still need to be applied with care (Hauer, 1997; Persaud and Lyon, 2007).

2.4 Previous Works on Intersection Safety Cameras

This section provides information regarding previous safety evaluation results of intersection safety camera studies. The literature review is divided into two groups; studies which focus on red light cameras (RLC) only and studies which evaluate combined speed and red light running cameras (ISD). A table summarizing the results is included in section 2.4.4.

2.4.1 Intersection Safety Cameras Targeting Red Light Running

Red light cameras are used to target red-light running at intersections. Red-light running (RLR) occurs when a vehicle enters the intersection after the signal turns red. RLC target collisions which occur when a vehicle continues through the intersection after the onset of the red light phase and collides with a vehicle traveling in the perpendicular direction. RLR behaviour typically result in angle and head on collisions. Rear-end collisions are also affected by RLC, this is thought to be due to changes in decision making at the end of the green light cycle. Knowledge of RLR enforcement at an intersection may cause a driver to be more conservative when deciding to slow down or stop in anticipation of the yellow/red cycle while the following vehicle expects to proceed through the intersection.

A study by Persaud et al. (2005) presented a multijurisdictional before-and-after evaluation of 132 treatment sites across 7 jurisdictions in the USA. The study used an Empirical Bayes methodology and SPF were developed using comparison sites. At the disaggregate level the reductions in angle collisions were found in 6 of the 7 jurisdictions and ranged from a 1% increase to a 40% decrease. Rear-end collisions were found to increase in jurisdictions ranging from 7% to 38%. At the aggregate level the change for total collisions as well as injury collisions was reported. The overall change in angle collisions was 25% for total collisions and 16% for injury collisions. Rear-end collisions increased by 15% for total collisions and 24% for injury collisions. Spillover effects to untreated signalized intersections was also were also studied; a 9% decrease in angle collisions and a 2% increase in rear-end collisions were observed. A companion paper by Council et al. (2005) evaluated the economic net benefit considering the opposing changes in angle collisions and rear-end collisions. The study found that the positive impact of reduced angle collisions was able to offset the increase in rear-end collisions. It was estimated that the economic benefit was between \$39,000 and \$50,000 per treated site.

A study by Shin and Washington (2007) estimated the safety impact of RLC for two cities in Arizona. 24 RLC enforced intersections in Phoenix and Scottsdale were included in the study. Several before and after study methodologies were applied including a simple before and after, before and after with comparison group and an Empirical Bayes before and after methodology. The EB methodology was the preferred methodology however the comparison group method was used to describe the collision reductions in Phoenix due to data availability. Collision reduction were found in both cities for angle collisions (20% and 40%) and left turn collisions (10% and 45%). Rear-end collisions were found to increase between 20% and 45%. In addition to intersection level reductions, changes in collisions at the enforced approaches was also evaluated. Angle collisions were decrease 20-42% and left turn collisions were reduced 10% to 45%. However the increase in rear-end collisions was much larger (41%-51%). In order to estimate spillover effects the change in collisions for enforced versus non enforced approaches were compared. The analysis suggested spillover effects occurred in Scottsdale but no spillover effects were evident in Phoenix. Finally the study also considered the economic benefit of RLC at the two cities. Using the KABCO scale the changes for each collision severities level was combined with the associated cost for that severity level. It was found that in both cities there was a net benefit, however the benefit was much greater in Scottsdale which had a larger reduction in fatality and injury collisions compared to Phoenix.

A meta-analysis of 21 RLC evaluation studies conducted by Erke (2009) provides an overview of RLC effectiveness and examines the impact of study methodology on results. The meta-analysis suggests that studies that controlled for both the RTM and spillover effect generally showed unfavourable or insignificant results. The meta-analysis of results from studies that controlled for both these factors suggest a 10% decrease in right angle collisions but a 15% increase in all collisions and a 43% increase in rear-end collisions. Criticism of the meta-analysis by Lund et al. (2009) argues that although the statistical process used to conduct the meta-analysis is thorough, the appropriateness of the included studies is questionable

A follow up meta-analysis by Høye (2013) used a larger sample of studies and addresses some of the issues raised with the original analysis. The new study found improved estimated effects of RLC comparted to the previous study. The new meta-analysis included the 19 studies from the original study plus 9 additional studies. The summery effects of RLC were computed based on four categories describing the control for spillover effects and RTM. The four categories of studies where those that controlled for spillover effects but not RTM, RTM but not spillover effects, both RTM and spillover effects and studies that did not control for either RTM or spillover effects. Studies that use a before and after with comparison groups may be affected by both spillover effects and RTM if the comparison groups are not matched with respect to collision frequency and if the potential impact of RLC spillover effects on comparison groups is not accounted for. Although the new study still suggests an increase in overall collisions the magnitude decreased (non-significant 6% increase compared to 15%) and the right angle collisions for all unspecified severity and injury collisions of 13% and 33% respectively.

2.4.2 RLC in Canada

Sayed and de Leur (2007) evaluated the safety impact of the City of Edmonton's RLC program using a before-and-after EB method. The study controlled for confounding factors that affect the reliability of RLC safety evaluations by using comparison group sites. Comparison sites were chosen which had similar traffic conditions as the RLC sites. The RLC sites were scattered throughout the city making it too difficult to identify a group of intersections suitable for examining spillover effects. The study estimated an 11.1% reduction in total collisions, a 6.1% reduction in severe collisions, 14.3% reduction in PDO collisions. Angle collisions were reduced by 17.2% and rear-end collisions were also found to be reduced (12.4%).

An Alberta Transportation study, *Intersection Safety Device Program- Red-light Camera Analysis* (2014), evaluated the safety performance of 76 RLC equipped intersections in five cities in Alberta. A before-and-after evaluation was conducted using the EB method. The aim of the study was to determine the change in the number of collisions as well as changes in collision severity. The study period spanned from 1998-2008, however the implementation dates and study length varied for different cities. A comparison group of 141 non-RLC equipped sites was used to develop SPF. Additionally a group of un-signalized intersections were used to investigate spillover effects. Overall the study found an 8% reduction in total collisions. The largest reductions were in severe and angle collisions (32% and 38% respectively). The study also found increases in the number of PDO and rear-end collisions (1% and 8%).

2.4.3 Combined RLC and Speeding

A study of ISD cameras in Victoria Australia was conducted by Budd et al. (2011). Their study included 77 intersection locations in Victoria. Warning signs were posted at all intersection approaches however cameras were limited to only 1 or 2 approaches per intersection. A 44% reduction was found in target collisions (right angle as well as right turn collisions) and no significant change in rear-end collisions. The study also found there was a strong effect on the targeted approaches; there was a 26% reduction in fatality collisions at intersections and a 47% reduction at target approaches.

A study of Winnipeg's intersection photo enforcement program was conducted by Vanlarr et al. (2014). The study looked at both the changes in collisions as well as speeding and red-light running violations. There was a drop in both speed and red-light running violations, however the reduction in speeding violations were greatest for less severe violations (1-13% over the speed limit) and less effective at reduction serious speeding violations (more 13% over the speed limit). Right angle collisions were found to decrease 46% but there was no change in collisions relating to speeding. Rear-end collisions were found to increase by 42% however time series analysis suggested that rear-end collisions may decrease over time.

Alberta Transportation study, *Intersection Safety Device Program- Red-light Camera Analysis* (2014), evaluated the safety performance of 54 ISD equipped intersections in four municipalities in Alberta. A before-and-after evaluation was conducted using the EB method. The study investigated the change in collisions and collision severity following ISD installation. Overall the study found a 1% increase in total collisions. The largest reductions were in severe and angle collisions (32% and 31% respectively). The study also found increases in the number of PDO and rear-end collisions (11% and 9%).

A De Pauw et al. (2014) study analysed the change in injury collisions after the installation of ISD cameras in Flanders Belgium using a before and after Empirical Bayes methodology. The study included 253 intersections and a comparison group which included all collisions in Flanders. The total injury collisions increased 5% to 9% after the installation of the cameras. The results also indicated a 14% to 18% reduction in severe side angle collisions and a 44% increase in rear-end collisions. The increase in rear-end collisions was much greater in urban areas than rural areas. The study also found that the proximity of ISD cameras impact the safety effectiveness; when there were 2 or more ISD cameras within 1500 meters the collisions reductions were smaller.

2.4.4 Summary of Intersection Safety Camera Results

A summary of the literature is presented in Table 2-1 and Table 2-2 with a brief description of the type of camera, methodology, data and major findings. In addition to the studies mentioned above several other relevant studies are included.

TABLE 2-1 Summary of RLC Evaluation Studies

Study	Camera Type	Method	Data and Study Period	Major Findings
Alberta Transportation (2014), Canada	RLC	Before and after with Empirical Bayes	76 intersections	8% reduction in total collision 37.7% reduction in angle collisions 7.7% increase in rear-end collisions
Council et al. (2005) USA	RLC	Before and after with Empirical Bayes	132 sites (7 jurisdictions)	25% reduction in angle collisions 15% increase in rear-end collisions
Hu et. al. (2011), USA	RLC	Before and after with comparison group	14 Cities (treated) Study Period 1992-2008	35% reduction in fatality collisions
Retting and Kyrychenko (2002), USA	RLC	Before and after with comparison group	11 sites Before Period 1995-1997 After Period 1997-1999	7% reductions in total collisions 32% reduction in angle collisions 3% increase in rear-end collisions
Shin and Washington (2007), USA	RLC	Before and after with Empirical Bayes	24 sites	20%-42% reduction in angle collisions 10%-45% reduction in Left turn collisions 41%-51% increase in rear-end collisions
Sayed and de Leur (2007), Canada	RLC	Before and after with Empirical Bayes	25 sites Before Period: 3 years After Period: 2-3 years	11% reduction in total collisions 17% reduction in angle collisions 12% reduction in rear end collisions 6% reduction in severe collisions 14% reduction in PDO collisions
Ko et al. (2013), USA	RLC	Before and after with Empirical Bayes	245 intersections	20% reduction in total collisions 24% reduction in angle collisions 37% increase in rear-end collisions

TABLE 2-2 Summary of ISD Evaluation Studies

Study	Camera Type	Method	Data and Study Period	Major Findings
Alberta Transportation (2014), Canada	ISD	Before and after with Empirical Bayes	46 intersections (4 cities)	1% increase in total collisions 31.3% reduction in angle collisions 9.4% increase in rear-end collisions
Budd et al. (2011), Australia	ISD	Before and after with comparison group	77 sites Study Period: 2000-2009	44% reduction in angle collisions 26% reduction in fatality collisions
De Pauw et al. (2014), Flanders	ISD	Before and after with Empirical Bayes	253 sites Study Period 2000-2008	6% reduction in angle collisions 24% reduction in severe angle collision 44% increase in rear-end collisions 5% increase in injury collisions
Vanlaar et al. (2014), Canada	ISD	ARIMA time series analysis	48 sites Study Period 1994-2008	46% reduction in angle collisions 42% increase in rear-end collisions

The reported efficacy of RLC and ISD varies widely in the literature. The magnitude of the changes in collisions and the impacted collisions types varies by report. All studies found a reduction in angle collisions (6%-46%) and the change in total collisions varied but generally showed a reduction. However studies commonly show some level of increase in rear-end collisions.

Accounting for regression to the mean (RTM) or for spillover effects has an impact on the results of RLC and ISD studies. RTM is the statistical tendency for treatment locations that are chosen due to high collision in previous years to have lower collision frequencies in following years regardless of treatment being applied. Spillover effects refers to the change in collision frequency at surrounding untreated locations due to the treatment. For example if drivers are aware that cameras are installed in a certain area they may modify their behavior at all intersections, not just the treated locations. Neglecting to account for RTM may result in studies over estimating the effectiveness of the cameras. Neglecting to account for spillover effects may cause a study to underestimate the impact of the cameras.

Spillover effects in RLC and ISD safety evaluations have be accounted for in several ways. Some studies which have specifically evaluated spillover effects found that the results were statistically insignificant and therefore concluded the evaluate results are not impacted by spillover effects. Other studies attempt to control for spillover effect by the selection of a comparison group that is either sufficient far away from the treatment locations, or are un-signalized. Council et al. (2005) argues that spillover effects are less likely to occur at un-signalized intersections making them appropriate as a comparison group. Other studies have used collision types that are not considered to be associated with the target collisions as a comparison group. Shin and Washington (2007) compared the collision rates at the approach level (for target approaches) to the collision rates at the intersection level to test for spillover effects. It was found that spillover effects were only evident in one of the two cities studied. Hu et al. (2011) make the argument that spillover effects are part of the benefit of an ISC program, (assuming that spillover effects will be beneficial) and compare the RLC effects at the city level compared to cities without RLC. Other studies use comparison groups that are taken from other cities that do not have an ISC program; this makes the assumption that safety effects do not spillover to other cities (Hu et al., 2011). Høye (2013) compared the results from RLC studies that had attempted to control for spillover effects to those that had not controlled for spillover effects. The analysis did not support the assumption that spillover effects have an impact on RLC studies.

Using an EB methodology is the most common method for controlling for regression-to-the-mean. Using control groups that have been carefully matched with respect to collision frequency and other intersection characteristics is another way to control for RTM (Budd et. al., 2011). Other studies use larger control groups to control for RTM following the argument that RTM is not likely to be a factor when the analysis is at a city wide level, and it is unlikely that there are city wide higher collision rates that lead to RLC program being implemented (Hu et al., 2011).

3 INTERSECTION LEVEL EVALUATION

This chapter evaluates the intersection level safety effects of ISD cameras. The work from this chapter is currently under review as L. Contini and K. El-Basyouny “Before-After Empirical Bayes Evaluation of Intersection Safety Camera Program in Edmonton”.

3.1 Data Description

The evaluation period spanned from January 2006 to December 2013. The data set includes arterial intersections within the city of Edmonton, Alberta, Canada. The data collection effort consisted of three key requirements:

- Historical traffic volumes
- Collision history
- Intersection characteristics

Availability of traffic volume data was a limiting factor in identifying a potential reference group. The analysis required an estimated average annual daily traffic (AADT) for each year at each site. In the case were a location had multiple counts completed in the same year the average of each approach was used. Only the locations with at least two traffic counts were included in the study. A total of 235 intersections met this criteria and were considered as potential reference sites. Traffic counts were not available for every year at each site. For location that were missing turning movement counts for certain years the Highway Safety Manual (2010) recommendations were used to complete the missing temporal data as follows:

- If AADT data is missing for years between available AADT counts, the intervening years are computed by interpolation.
- The AADTs for years preceding the first available traffic count, or following the last available count are assumed to be equal to the count of the closest available year.

For the years 2006 to 2008 there were no available turning movement counts. In order to provide a more accurate prediction of AADT for this period it was assumed that the AADT for this period would follow similar growth as the population. The population values for the City of Edmonton census was used to predicted the change in AADT for the missing years. For 10 out of the 50 ISD locations there was no available traffic data.

Collision data was collected for all intersections with available AADT data. Variables provided in the collision data included location code, data, collision severity, primary object travel direction, collision cause, vehicle type, injury type, etc. Collision data was aggregated at a yearly basis for each location. In order to better understand the effects of ISD cameras, several collision categories were created to analyze different target collision types. The following is a description of the 7 collisions categories used in the analysis:

- *Severe Collisions* – sum of fatal and injury collisions
- *Property Damage Only (PDO) Collisions* – collisions which do not result in an injury or fatality
- *Total Collisions* – sum of PDO collisions and Severe collisions
- *Angle Collisions* – collisions involving at least two vehicles traveling in perpendicular directions
- *Left-Turn Across Path Collisions* – collisions in which the vehicle making a left turn is struck by an oncoming vehicle with the right of way
- *Rear-End Collisions* – collisions in which a leading vehicle is stuck by the following vehicle
- *Failed to Observe Traffic Signal Collisions* – collisions which occur when a driver fails to obey a signal and collides with another vehicle with the right of way

The collision categories are not mutually exclusive; for example a single collision event could be included in multiple categories. Using the different collision categories helps create a clearer picture of how ISD cameras impact collisions.

Geometric data was also collected for each of the intersections. Geometric data collected for intersection included the following:

- Right turn separation
- Number of Approaches (3 leg or 4 leg intersection)

A statistical summary of the treated locations is shown in Table 3-1.

TABLE 3-1 Treatment Site Data Summary

	Average	**Standard Deviation**	**Minimum**	**Maximum**
Average Yearly Major Approach AADT	31,513	12,419	10,206	61,981
Average Yearly Minor Approach AADT	19,874	6,076	4,806	27,850
Average Yearly Total Collisions	41.7	17.9	11.0	103.0
Average Yearly Severe Collisions	8.4	4.6	0.0	21.0
Average Yearly PDO Collisions	33.2	15.0	8.0	93.0
Average Yearly Rear End Collisions	28.0	16.3	3.0	76.0
Average Yearly Angle Collisions	7.4	4.8	0.0	25.0
Average Yearly Left Turn Across Path Collisions	5.6	4.8	0.0	23.0
Average Yearly Failed to Observe Traffic Signal Collisions	4.2	2.9	0.0	16.0

3.2 Methodology

3.2.1 Safety Performance Functions

Safety performance functions (SPF) are used as a collision prediction model to relate the collision frequencies to the traffic volumes and other explanatory variables. SPF are used to predict the collision frequency at treated locations, which is a key component of the before-after evaluation process. In this evaluation, the generalized linear model (GLM) was used to examine the relationship between collisions and the explanatory variables. Consistent with state-of-the-art methods, a negative binomial (NB) model is used since the negative binomial error structure is able to capture the over-dispersion in the collision data. The specification of the NB model are shown below (El-Basyouny & Sayed, 2010).

Let Y_i denote the number of collisions at site i (i=1,2,3,…,n) which has a mean of θ_i. It can be assumed that the collisions at each site are independent and that

$$Y_i|\theta_i \sim Poisson\ (\theta_i) \tag{3-1}$$

overdispersion for unobserved/unmeasured heterogeneity is addressed by assuming that

$$\theta_i = \mu_i \exp(u_i) \tag{3-2}$$

where μ_i is determined by a set of covariates representing site-specific attributes and a corresponding set of regression parameters to be estimated.

The term $\exp(u_i)$ represents a multiplicative random effect. The negative binomial (Poisson–gamma) model is obtained by the assumption

$$\exp(u_i)|\kappa \sim \mathrm{Gamma}(\kappa, \kappa) \tag{3-3}$$

$$E(\theta_i) = \mu_i \cdot E(e^{u_i}) = \mu \cdot \frac{\kappa}{\kappa} = \mu \tag{3-4}$$

$$Var(\theta_i) = {\mu_i}^2 \cdot Var(e^{u_i}) = \mu^2 \frac{\kappa}{\kappa^2} = \frac{\mu^2}{\kappa} \tag{3-5}$$

where κ is the inverse dispersion parameter. The probability function, mean and variance of the negative binomial distribution are given by

$$P(Y_i = y_i|\mu_i, \kappa) = \frac{\Gamma(y_i+\kappa)}{y_i!\Gamma(\kappa)} \left(\frac{\kappa}{\kappa+\mu_i}\right)^{\mathrm{K}} \left(\frac{\mu_i}{\kappa+\mu_i}\right)^{y_i} \tag{3-6}$$

$$E(Y_i) = \mu_i \tag{3-7}$$

$$Var(Y_i) = \mu_i + \frac{{\mu_i}^2}{\kappa} \tag{3-8}$$

where y_i is the number of observed collisions.

A standard SPF model form for intersection was selected. In the model the predicted yearly average number of collisions is the dependent variable and the independent variables are traffic volumes on the major and minor approach as well as intersection characteristics. A number of independent intersection-related variables were included in the analysis and only significant variables were included in the final model. The variable selection was conducted a backward stepwise elimination process.

$$\mu = AADT_{major}^{\beta_1} * AADT_{minor}^{\beta_2} * \exp^{(\beta_0 + \beta_3 * X_1 + \beta_4 * X_2 \cdots)} \tag{3-9}$$

where;

$AADT_{major}$ is the AADT on the major road

$AADT_{minor}$ is the AADT on the minor road

X_i is the various geometric independent variables

β_i is the parameter estimates from SAS

SPFs are developed using the data for a group of reference sites. In order for the SPF to accurately represent the conditions at the treatment sites it is important that the reference group is as similar as possible to the treatment sites. In this study the reference group was chosen from non-ISD enforced signal controlled arterial intersections within the City of Edmonton. The main criteria for selecting reference group sites was collision frequency; reference sites were chosen that were as similar as possible to the treatment sites. The availability of traffic volume data was a limiting factor in the selection of reference group sites

The model parameters were estimated using the SAS GENMOD procedure (SAS Institute Inc., 2012), which uses the maximum likelihood estimation. The scaled deviance (SD) and Pearson χ^2 were used to assess the model's goodness of fit. SPF functions were developed for each of the collision classifications at the intersection level.

3.2.2 Yearly Calibration Factors

Confounding factors such as weather patterns, engineering initiatives and general traffic safety lead to annual fluctuations in collision frequency that cannot be entirely captured by SPFs. Yearly Calibration Factors (YCF) are used to address the annual fluctuations that are not attributed to the variables in the SPFs. The YCF are calculated as a ratio between the number of observed collisions and the number of predicted collisions for each year at the reference sites as shown below. The yearly collision frequency predicted by the SPF are adjusted by multiplying the SPF predicted collision frequency by the corresponding YCF. This assumes that the impact of the confounding factors are similar across all sites in both the reference and treatment sites, therefore the variations that occur in the reference sites can be assumed to occur at the treatment sites as well.

$$C_i = \frac{\sum_{ref} N_i}{\sum_{ref} \mu_i} \tag{3-10}$$

where

C = yearly calibration factor

N = observed number of collisions

μ = predicted average number of collisions

i = year

3.2.3 Before-After Evaluation

In order to account for regression-to-the-mean (RTM) bias the before-and-after Empirical Bayes (EB) analysis method is used. The EB method uses collision information from a reference group to address the problem of RTM. The EB method also incorporates yearly changes in traffic volume and can accommodate varying lengths for the before and after periods. Traffic safety treatment sites are generally chosen by prioritizing sites with high collision frequency. Therefore it is important to consider the impact of RTM bias. RTM refers to the random fluctuation in collision frequency, specifically the tendency for sites with a high collision frequency in one time period to be followed by a lower collision frequency in the following time period and vice-versa. The safety effectiveness is determined by the ratio of the observed number of collisions to the expected number of collisions. The first step of the EB method is to calculate the expected number of collisions in the before period for each site. The expected number of collisions is calculated as a weighted combination of the predicted number of collisions (from the SPF) and the observed number of collisions in the before period shown in Equation (3-11). The weighted adjustment factor is established using the over-dispersion parameter from the SPF as shown in Equation (3-12).

$$N_{Expected,B} = (w)N_{\text{Predicted,B}} + (1-w)N_{Observed,B} \tag{3-11}$$

$$w = \frac{1}{1+\dfrac{N_{\text{Predicted,B}}}{k}} \tag{3-12}$$

where:

w = weighted adjustment factor (between 0 and 1)

$N_{Expected,B}$ = expected number of collisions in the before period

$N_{Predicted,B}$ = predicted number of collisions in the before period

$N_{Observed,B}$ = observed number of collisions in the before period

k = negative binomial over-dispersion parameter (estimated from SPF).

In order to account for variations in traffic volume and difference period length a ratio of the predicted before collisions to after collisions is used as a multiplier. The expected number of collisions in the after period is then determined as the product of the multiplier and the expected number of collisions in the before period. Finally the overall odds ratio of collision reduction and the associated standard error are calculated shown in Equations (3-13), (3-14) and (3-15). The percent reduction is then calculated from the odds ratio. The ratio of the percent reduction and its standard error is used to test significance.

$$\theta = \frac{\sum_{Allsites} N_{Observed,A} \Big/ \sum_{Allsites} N_{Expected,A}}{1+Var(\sum_{Allsites} N_{Expected,A}) \Big/ (\sum_{Allsites} N_{Expected,A})^2} \tag{3-13}$$

$$Var(\sum_{AllSites} N_{Expected,A}) = \sum_{AllSites}\left[\left(\frac{N_{\Pr edicted,A}}{N_{\Pr edicted,B}}\right)^2 \times N_{Expected,B} \times (1-\omega)\right] \tag{3-14}$$

$$SE(\theta)=\sqrt{\frac{(\sum_{Allsites} N_{Obsesrved,A} \Big/ \sum_{Allsites} N_{Expected,A})^2[\frac{1}{\sum_{Allsites} N_{Observed,A}}+Var(\sum_{Allsites} N_{Expected,A}) \Big/ (\sum_{Allsites} N_{Expected,A})^2]}{[1+Var(\sum_{Allsites} N_{Expected,A}) \Big/ (\sum_{Allsites} N_{Expexted,A})^2]}} \tag{3-15}$$

Where;

$N_{Expected,A}$ = expected number of collisions in the after period

$N_{Predicted,A}$ = predicted number of collisions in the after period

$N_{Observed,A}$ = observed number of collisions in the after period

The percent reduction is then calculated from the odds ratio as follows

Collision reduction = $100 \cdot (1-\theta)$ with a standard error of $100 \cdot \mathrm{SE}(\theta)$

Positive values indicate a reduction in collisions, and a negative number indicates an increase in collisions. The ratio of the percent reduction and its standard error is used to test significance. If the ratio is higher than 2.0 the collision reduction percentage is significant at the 95% level. If the value is greater than 1.65 the collision reduction is significant at the 90% confidence level.

3.3 Results and Discussions

3.3.1 SPF and YCF

The SPF were developed using the methodology described above. A unique SPF model was developed for the seven collision types defined above using a reference group of 125 intersections. The yearly calibration factors for the 7 collision types are shown in Table 3-2. Table 3-3 show the parameters values for the 7 SPF developed. The goodness-of-fit measures is also shown on the tables. The critical values of χ^2 with degrees of freedom of 122 and 123 are 148.78 and 149.88, respectively. The SD and Pearson χ^2 for each model are smaller than the critical values, indicating good model fit. The presence of a separated right turn bay is a significant variable in the SPF for total, PDO and rear-end collisions. The number of intersection approaches is a significant variable in the SPF for severe and left turn across path collisions. The parameter estimates make intuitive sense for each SPF. The positive parameter values for both the major and minor approaches indicates that collisions increase as traffic volumes increase which is expected.

TABLE 3-2 Intersection Level Yearly Calibration Factors

Year	Total	Severe	PDO	Rear-End	Left Turn Across Path	Failed to Observe Traffic Signal	Angle
2006	1.091	1.560	0.964	1.109	1.338	1.134	1.263
2007	1.177	1.388	1.121	1.188	1.267	1.273	1.270
2008	1.108	1.115	1.107	1.056	1.219	1.095	1.175
2009	1.033	0.935	1.060	1.007	1.028	1.111	1.017
2010	1.001	0.920	1.022	1.010	0.919	0.958	0.904
2011	0.846	0.762	0.868	0.796	0.954	0.871	0.864
2012	0.852	0.730	0.884	0.854	0.833	0.752	0.750
2013	0.894	0.674	0.951	0.906	0.813	0.829	0.692

TABLE 3-3 Intersection Level SPF Parameter Estimates and Goodness of Fit

		Total Collisions	**Severe Collisions**	**PDO collisions**	**Rear-End Collisions**	**Left Turn Across Path Collisions**	**Failed To Observe Collisions**	**Angle Collisions**
Parameter Estimates	Intercept	-8.73 (<0.001)	-11.57 (<0.001)	-9.39 (<0.001)	-13.17 (<0.001)	-16.84 (<0.001)	-5.07 (<0.001)	-8.26 (<0.0001)
	Major ADDT	0.63 (<0.001)	0.51 (<0.001)	0.67 (<0.001)	0.98 (<0.001)	0.68 (<0.001)	0.25 (0.015)	0.44 (<0.0001)
	Minor ADDT	0.54 (<0.001)	0.62 (<0.001)	0.54 (<0.001)	0.57 (<0.001)	0.74(<0.001)	0.36 (<0.001)	0.57 (<0.0001)
	Right Turn Separation	0.29 (0.002)	-	0.32 (0.001)	0.58 (<0.001)	-	-	-
	Approaches	-	0.52 (<0.001)	-	-	1.08 (<0.001)	-	-
	Dispersion parameter	0.16	0.15	0.16	0.23	0.41	0.27	0.31
Goodness of Fit	Degrees of Freedom	122	122	122	122	122	123	123
	$\chi^2_{0.05}$	148.78	148.78	148.78	148.78	148.78	149.88	149.88
	Pearson χ^2	132.89	127.48	135.50	147.78	138.24	122.35	120.38
	Scaled Deviance	129.20	135.70	128.32	130.43	140.98	136.93	135.97

All parameters are significant at 99% level

(Parameter Significance)

3.3.2 Before-and-After Evaluation

The overall collision reduction percentages were established for the intersection level using the EB methodology described in the previous section. In total 23 ISD equipped intersections were included in the analysis. The adjusted yearly average predicted number of collisions was calculated for each intersection using the yearly calibration factors and the SPF discussed above. The reductions determined for each of the seven collision are summarised in Table 3-4.

TABLE 3-4 Overall Before-and-After Evaluation Results

	Total Collisions	**Severe Collisions**	**PDO collisions**	**Rear-End Collisions**	**Left Turn Across Path Collisions**	**Failed To Observe Collisions**	**Angle Collisions**
Collision Reduction (%)	25.3	2.6	6.5	10.7	7.6	27.5	12.9
Statistical Test Ratio	12.3*	0.4	2.2*	3.4*	1.0	4.0*	2.2*

* Significant at 95% level

There were significant reductions in all the collision categories with the exception of severe and left turn across path collisions. For the severe collision category and left turn across path collisions there were non-significant reductions of 2.6% and 7.6%, respectively. There was a 25.3% reduction in the total number of collisions as well as a 12.9% reduction in the angle collisions. The largest reduction was in failed-to-observe collisions (27.5%). The reductions in angle collisions is on lower end of the range when compared to other ISD studies. It is also interesting to note there was a significant 10.7% reduction in rear-end collisions. Previous studies typically found an increase in rear-end collision frequency, however the results from Sayed and de Leur (2007) found a similar reduction in read-end collisions attributed to red-light cameras. The difference in rear-end collision reduction rates may be due to the difference in collision reporting threshold for Edmonton compared to other cities. The reporting threshold for the City of Edmonton is CAD$2000, whereas the threshold in the study by Shin & Washington (2007) was US$1000.

Collisions resulting in damages below a determined threshold are not reported, and minor-rear end collisions are likely to be lower amount of property damage. Therefore it is possible there is a change in collisions which are not reported.

4 APPROACH LEVEL EVALUATION

This chapter evaluates the intersection level safety effects of ISD cameras. The work from this chapter is currently under review as L. Contini and K. El-Basyouny "Before-After Empirical Bayes Evaluation of Intersection Safety Camera Program in Edmonton". There are four sub-objectives to this evaluation. The first objective is the estimate the approach level collision reductions using the before-and-after EB method. The second objective is to estimate the spillover effects at the untreated approaches at the ISD intersections. The third objective is to explore the use of various site selection criteria on evaluating ISD sites. Finally, the fourth objective is to identify factors that contribute to successful ISD performance

4.1 Data Description

The approach level analysis covered the same study period from January 2006 to December 2013. The data set involves the same set of arterial intersections disaggregated to the approach level. Again the three data components include:

- Historical traffic volumes
- Collision history
- Intersection characteristics

Collisions were assigned to approaches based on the reported 'primary object travel direction'. However for roughly 20% of entries the 'primary object travel direction' was unknown. The collisions with unknown approaches were included in the data. At each location the number of unknown collision were assigned to approaches based on the proportion of known collisions at each approach, at a yearly basis.

The approach level analysis used the same set of collision types as the intersection analysis.

- *Severe Collisions* – sum of fatal and injury collisions
- Property Damage Only (PDO) Collisions – collisions which do not result in an injury or fatality
- *Total Collisions* – sum of PDO collisions and Severe collisions
- *Angle Collisions* – collisions involving at least two vehicles traveling in perpendicular directions

- *Left-Turn Across Path Collisions* – collisions in which the vehicle making a left turn is struck by an oncoming vehicle with the right of way
- *Rear-End Collisions* – collisions in which a leading vehicle is stuck by the following vehicle
- *Failed to Observe Traffic Signal Collisions* – collisions which occur when a driver fails to obey a signal and collides with another vehicle with the right of way

Geometric data was also collected for the approach level including the following

- Number of lanes and lane use – total number of lanes for each intersection approach, including a breakdown of the number of through lanes and turning lanes
- Lane width – The lane width of each lane of each approach
- Median presence

In total there were 40 ISD enforced approaches

4.2 Methodology

The methodology for the approach analysis followed the same procedure as the intersection level analysis. First SPF and YCF were established based on the reference group data. Next the EB before-and-after method was used to estimate collision reductions for the ISD approaches.

4.3 Results

4.3.1 SPF and YCF

The SPF approach models were developed for the seven collision types using a reference group of 460 approaches. Yearly calibration factors for the approach level analysis are shown in Table 4-1. Table 4-2 shows the model's parameters are highly significant. The presence of a separated right turn bay, presence of median separation and average lane width were significant variables in the approach level SPF. The positive parameter values for AADT indicates an increase in collisions as traffic volume increases, which is intuitive. For the angle collision SPF, the AADT was the only significant variable. The SD and Pearson χ^2 for each model are similar to the critical values.

TABLE 4-1 Approach Level Yearly Calibration Factors

Year	Total	Severe	PDO	Rear-End	Left Turn Across Path	Failed to Observe Traffic Signal	Angle
2006	1.08	1.56	0.96	1.08	1.09	1.14	1.12
2007	1.18	1.39	1.13	1.17	1.18	1.27	1.18
2008	1.10	1.11	1.10	1.03	1.12	1.11	1.16
2009	1.04	0.94	1.07	0.99	1.05	1.12	1.07
2010	1.00	0.93	1.02	0.99	0.91	0.97	0.97
2011	0.85	0.77	0.87	0.79	0.80	0.86	0.85
2012	0.86	0.75	0.89	0.85	0.85	0.76	0.83
2013	0.90	0.69	0.96	0.90	0.75	0.83	0.81

TABLE 4-2 Approach Level SPF Parameter Estimates and Goodness of Fit

		Total Collisions	Severe Collisions	PDO collisions	Rear-End Collisions	Left Turn Across Path Collisions	Failed To Observe Collisions	Angle Collisions
Parameter Estimates	Intercept	-9.66 (<0.001)	-10.85 (<0.001)	10.17(<0.001)	-13.11 (<0.001)	-11.92 (<0.001)	-7.31 (<0.001)	-8.93 (<0.001)
	Major ADDT	0.79 (<0.001)	0.76 (<0.001)	0.81 (<0.0001)	1.04 (<0.001)	0.88 (<0.001)	0.39 (<0.001)	0.66 (<0.001)
	Minor ADDT	0.33 (<0.001)	0.34 (<0.001)	0.34 (<0.001)	0.34 (<0.0001)	0.37 (<0.001)	0.32 (<0.001)	0.29 (<0.001)
	Right Turn Separation	0.17 (<0.001)	-	0.19 (<0.001)	0.36 (<0.001)	-	-0.13 (<0.001)	-
	Median	0.13 (0.042)	0.16 (0.040)	0.14 (0.037)	0.20 (0.016)	0.56 (<0.001)	-	-
	Average Lane Width	-	-	-	-	-0.21 (<0.001)	-	-
	Dispersion Parameter	0.27	0.32	0.28	0.43	0.97	0.36	0.46
Goodness of Fit	Degrees of Freedom	455	456	455	455	455	456	457
	$\chi^2_{0.5}$	505.73	506.78	505.73	505.73	505.73	506.78	507.84
	Pearson χ^2	545.18	454.01	560.94	573.16	534.79	505.27	479.73
	Scaled Deviance	480.56	530.23	492.54	519.57	496.09	489.79	509.33

(Parameter Significance)

All parameters are significant at 95% level

4.3.2 Before-and-After Evaluation

The EB analysis was repeated at the approach level. Table 4-3 shows the reductions for the ISD approaches. For ISD approaches there are reductions in all the collision categories except for severe collisions. A small increase in severe collisions was observed, however was not statistically significant. Reductions were observed for the failed-to-observe collisions however they were not statistically significant. There was an 11.7% reduction in total collisions as well as a 27.3% reduction in angle collisions. The largest collision reductions were found in the left-turn-across-path collisions. Furthermore, there is a significant reduction in rear-end collisions of 13%.

TABLE 4-3 Approach Level Collision Reductions

	Total Collisions	**Severe Collisions**	**PDO collisions**	**Rear-End Collisions**	**Left Turn Across Path Collisions**	**Failed to Observe Collisions**	**Angle Collisions**
Collision Reduction (%)	11.7	-3.8	11.7	13.1	30.5	11.4	27.3
Statistical Test Ratio	3.3*	-0.4	3.0*	3.1*	3.6*	0.8	3.9*

* Significant at 95% level

A total of 23 ISD approaches had been upgraded from previous RLCs. The safety evaluation was repeated for both groups in order to see if there was a difference in collision reductions for sites that previously had been RLCs. The results of the EB analysis is shown in Table 4-4 for the approaches that were upgraded from RLC and for the new ISD sites. Generally the reductions in collisions at sites that had previously been RLC were greater than sites that were new cameras. The biggest difference was seen in the failed-to-observe collisions which had large significant reduction at the sites that were previous RLC but an insignificant increase at new ISD locations. The reductions in rear-end collisions was slightly greater at the new sites however the difference was marginal (13% vs. 14%).

TABLE 4-4 Before-and-After Evaluation of Upgraded RLC Sites

	Previous RLC		**New ISD Locations**	
	Statistical Test Ratio	**Collision Reduction (%)**	**Statistical Test Ratio**	**Collision Reduction (%)**
Total Collisions	2.6*	12.1	2.1*	11.2
Severe Collisions	-0.3	-3.2	-0.3	-4.2
PDO Collisions	2.4*	12.4	1.8**	10.9
Rear-End Collisions	2.3*	12.6	2.2*	14.1
Left Turn Across Path Collisions	2.4*	26.5	3.0*	38.8
Failed to Observe Collisions	2.3*	36.3	-0.5	-10.2
Angle Collisions	3.4*	29.7	2.1*	23.8

* Significant at 95% level ** Significant at 90% level

4.3.3 Spillover Effects

Spillover effects refer to changes in collision frequency at untreated locations that are close to locations that have had a safety measure applied. In this instance effects from ISD cameras may 'spill over' to unequipped approaches at ISD intersections or to neighboring intersections without ISD cameras. Indication of spillover effects for intersection safety cameras has not been conclusive. Some previous studies of RLC and ISD cameras have attempted to estimate the spillover effect to surrounding intersections. A meta-analysis by Hoye (2013) suggests that there are generally not strong spillover effects from RLC, only mild indication of spillover of right angle collision reduction. Vanlaar et al. (2014) found evidence of spillover in rear-end collisions, but not significant spillover in target collisions. In this study it was not possible to evaluate the impact of spillover effects at other intersections; however it is possible to consider the spillover effects to other approaches at ISD enforced intersections. Shin and Washington (2007) investigated the spillover effect to non-approaches at intersections that have at least one ISD. By separately evaluating the collision reductions for ISD equipped approaches and non-equipped approaches the spillover effect can be observed. If the non-equipped approaches have collision reduction similar to the ISD equipped locations it can be suggested that a spillover effect might have occurred. The results in Table 4-5 show significant reductions were found at the ISD approaches, however for the non-ISD approaches only the angle collisions showed a significant reduction. From these results it seems that there may be spillover effects observed for the angle collision category. However overall the reductions are much greater at the ISD equipped locations suggesting that spillover to other approaches may not occur at the approach level. Significant rear-end collision reductions were only found for the ISD-approaches suggesting that there was no spillover for rear-end collisions.

TABLE 4-5 Collision Reductions for ISD and Non-ISD Approaches

	ISD Approaches		**Non-ISD Approaches**	
	Statistical Test Ratio	**Collision Reduction (%)**	**Statistical Test Ratio**	**Collision Reduction (%)**
Total Collisions	3.3*	11.7	-1.0	-4.4
Severe Collisions	-0.4	-3.8	-1.6	-16.9
PDO collisions	3.0*	11.7	-1.0	-4.8
Rear-End Collisions	3.1*	13.1	0.0	-0.1
Left Turn Across Path Collisions	3.6*	30.5	1.0	9.2
Failed to Observe Collisions	0.8	11.4	-0.7	-6.5
Angle Collisions	3.9*	27.3	2.3*	17.4

* Significant at 95% level

4.3.4 Site Selection Criteria

Current ISD sites were selected based on collision history and local expertise. In order to assist in identifying potential future locations for ISD cameras, it is of interest to appraise the current selection criteria as well as recommend new ones for the future. For the literature it is clear the reported effectiveness of ISD cameras is quite varied. It is therefore useful to identify factors that contribute to the success of ISD projects. Site selection criteria were evaluated in two ways. Firstly, the current treatment sites were reclassified into groups according to three site selection criteria, namely; collision frequency, collision rate, and average AADT. Secondly using regression analysis, the influence of various intersection characteristics was considered.

In order to evaluate the success of conventional site selection criteria the 40 treatment approaches were divided into groups. For each criterion the approaches were categorized into three groups based on a high, medium and low threshold. The threshold for each group was chosen to allow for sufficient samples within each group. The EB analysis is repeated for each group. The results are shown in Table 4-6.

TABLE 4-6 Evaluation Results for Site Selection Criteria – Collision Reductions

	Collision Frequency			Collision Rate			AADT		
Threshold	≤ 10	(10, 15]	> 15	≤ 1.1	(1.1, 1.6]	> 1.6	≤25,000	(25-30]	> 30,000
Group Size	14	15	11	13	17	10	16	12	12
Total	-10.1	17.1*	26.3*	-6.3	19.0*	22.9*	25.3*	-2.3	9.9*
Severe	-33.4	-10.2	28.6*	-38.3	4.9	19.1	4.4	-32.2	12.7*
PDO	-8.0	15.9*	8.8*	-2.3	18.6*	20.1*	26.7*	0.8	6.0
Rear-End	-3.8	24.2*	14.5	-2.3	27	10.1	33.8*	-6.5	8.0*
Left Turn Across Path	-66.1	11.3	66.0*	7.4	0.3	65.5*	30.0*	6.5	70.3*
Failed to Observe Traffic Signal	3.1	3.2	30.9	2.5	18.3	-7.4	-3.5	-0.1	51.8*
Angle	-7.8	19.0	57.5*	13.0	12.9	51.7	27.1*	11.3	47.6*

* Significant at 95% level

The results show that generally when the collision frequency or collision rate is high, there is a larger reduction in collisions. For example, there was a significant 26% reduction in total collisions when the collision frequency was greater than 15 collisions per year in the before period. The influence of AADT on ISD performance is less consistent. There does not appear to be an obvious trend between sites with higher AADT numbers and collision reduction. This suggests that AADT should not be considered as an appropriate site selection criterion for future ISD placement. Similar results for RLC have been observed in the literature; Ko et al. (2013) evaluated the effectiveness of both collision history and AADT as site selection criteria and found that there was no identifiable trends relating changes in AADT to RLC safety effectiveness.

In addition to collisions history and AADT, the impact of various intersection characteristics on collision reductions was considered. Maximum likelihood linear regression models were fitted with the index of effectiveness (θ) from the EB analysis as the dependent variable which was assumed to have a lognormal distribution (using SAS GENMOD procedure). The functional form of the model is shown in Equation (4-1).

$$\theta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon \qquad (4\text{-}1)$$

where $X_1, X_2, \ldots, X_n$ are the independent variables related to approach characteristics such as number of lanes, speed limit, average lane width, etc. The speed limits for the ISD sites were either 50, 60, or 70 km/h. Insignificant variables were removed in a backwards stepwise process to find the model with the best fit. The regression analysis was repeated for all the collision categories and the results are summarized in Table 4-7.

TABLE 4-7 Results of Regression Analysis of Intersection Characteristics

	Total	Severe	PDO	Rear-End	Left Turn Across Path	Failed To Observe Traffic Signals	Angle
Intercept	-1.94 (-0.009)	-2.62 (-0.039)	-1.40 (-0.059)	-2.79 (-0.002)	6.38 (0.001)	-5.55 (0.014)	-0.05 (-0.784)
Number of Through Lanes	-0.14 (-0.008)	-	-0.14 (-0.011)	-0.19 (-0.003)	-	-0.384 (<.001)	-
Speed Limit	0.04 (-0.001)	0.04 (-0.03)	0.03 (-0.011)	0.06 (<.001)	-	-	-
Lane Width	-	-	-	-	-1.72 (0.002)	1.89 (0.002)	-0.66 (-0.071)
Median	-	-	-	-	-	-0.93 (0.002)	-

(Parameter significance)

Four variables were significantly related to an increase in the safety effectiveness of the ISD, namely; speed limit, number of lanes, average lane width, and median presence. For the total collisions the variable parameters suggest that reductions were greater for approaches with more through lanes, and for approaches with lower speed limits. The study by De Pauw et al. (2014) also found that collision reductions were highest at sites where ISD cameras were installed with other measures such as lowering speed limits. Median presence was a significant variable for failed-to-observe collisions; sites that have did not have median separation had greater reductions. The lane width variables was found to be significant for the model representing left turn cross path collisions, failed to observe traffic signal collisions and angle collisions. The sign for the parameter estimates related to lane width was not consistent for each collision type; the value was positive (indicating that sites with narrower lanes experienced greater reductions) for the left-turn-across path collisions and angle collisions but was positive for the failed to observe traffic signal collisions.

In order to further explore these trends the treatment sites were classified into groups based on four intersection characteristics found to be significant from the regression analysis. The EB analysis was repeated for these four criteria using all the collision types. For the average lane width and speed limit, three threshold classifications were created. The threshold levels were used to observe the changes in collision reductions for the different characteristics. The results of the analysis are shown in Table 4-8. For the average lane width category, reductions were greatest at locations that had narrower lanes (threshold <3.9m). For example sites with narrower lanes showed a 26.8% reduction in collisions, the sites with wider lanes only showed a non-significant 3.9% reduction. From the regression analysis, the lane width variable was only significant for three of the collisions types, however by examining the collision classifications reductions were greatest at sites that had narrower lane widths across all collision types. The number of through lanes are also shown to impact the effectiveness of ISD cameras. Sites with 5-7 through lanes had greater collisions reduction for almost all collision types. Sites which did not have median separation had significant reductions in collisions. Finally sites with lower speed limits (50km/hr or 60 km/hr) had greater reductions that sites with a speed limit of 70km/hr.

Overall, it is clear that there can be significant collision reductions obtained by installing ISD cameras. Additionally the careful use of site selection criteria such as collision history, speed limits and intersection characteristics such as lane with, number of through lanes and median presence can impact the effectiveness of ISD cameras.

TABLE 4-8 Site Selection Criteria

	Average Lane Width			**Speed Limit**			**Median**		**Number of Through Lanes**	
Threshold	≤ 3.9	(3.9, 4.1)	≥ 4.1	50 km/hr	60 km/hr	70 km/hr	Yes	No	2 - 4	5 -7
Group Size	11	14	15	7	25	8	10	30	19	21
Total	26.81 *	8.12	3.88	1.93	20.7 *	-12.6	-0.12	14.5	10.73**	12.26 *
Severe	8.05	-18.27	-5.06	14.56	3.5	-29.4	-38.88	3.11	7.77	-10.68
PDO	26.82 *	9.75	3.26	-3.76	20.94 *	-11	0.43	11.93 *	7.02	14.30 *
Rear-End	34.34 *	9.87	0.61	14.75	23.32 *	-18.4 **	6	13.50 *	8.26	15.47 *
Left Turn Across Path	64.25 *	-17.06	38.07 *	-26.86	38.45 *	36.1 **	-10.89	30.80 *	17.52	41.4 *
Failed to Observe Traffic Signal	26.4	0.57	24.08	10.76	17.58 *	21.88	-7.76	25.13 **	22.37	3.69
Angle	53.15 *	-6.81	34.14 *	-7.12	33.28 *	30.8 **	-1.85	33.80 *	12.56	39.06 *

* Significant at 95% level ** Significant at 90% level

5 CONCLUSIONS AND FUTURE RESEARCH

5.1 Summary and Conclusion

For the intersection level analysis, a before-and-after evaluation with the Empirical Bayes method was used to examine the safety effects of ISD cameras at arterial intersections in the city of Edmonton. Local safety performance functions and yearly calibration factors were developed for 7 collision types in order to accurately predict the collision frequency at the ISD equipped intersections. With the exception of severe collisions, significant reductions were found for almost all collision types. There was a 25% reduction in the total number of collisions as well as a 13% reduction in the angle collisions. These results are consistent with those found in the literature. A significant decrease in the number of rear-end collisions was also found. In the literature, rear-end collisions are usually found to increase after installation of ISD or RLC.

The approach level analysis examined the effect of ISD cameras at the specific approaches that were targeted by the ISD camera. Similarly to the intersection level analysis, a before and after evaluation with the Empirical Bayes method was performed in order to establish collision reductions. Safety performance functions and yearly calibration factors were developed to represent the collision frequency at the approach level. For ISD approaches there are significant reductions in all the collision categories except for severe collisions and failed-to-observe collisions. There was a 12% reduction in total collisions as well as a 27% reduction in angle collisions. The results also indicated a statistically significant reduction in rear-end collisions.

In order to assess the spillover effect, the collision reduction at non-targeted approaches of ISD intersections was compared to the collision reduction at ISD enforced intersections. There was a slight indication of spillover effects for angle collisions, however overall the results suggest that spillover to other approaches may not occur at the approach level. These results are in accordance to what has been published in the literature.

- The evaluation based on site criteria showed that generally when the collision frequency or collision rate is high, there is a larger reduction in collisions. There does not appear to be an obvious trend between varying ranges of AADT and collision reduction. This suggests that AADT is not reliable as a site selection criteria for ISD sites. Significant reductions in severe collisions were observed for locations that had greater than 15 yearly collisions in the before period. Furthermore, a regression analysis was used to identify four additional characteristics that impact the safety effectiveness of ISD cameras. Speed limit, number of lanes, average lane width and median presence were all found to be significant contributors to ISD effectiveness. Collisions were greater at sites with a speed limit of 50 or 60km/hr. Sites with a higher number of through lanes had greater reductions, specifically sites with 5-7 through lanes had greatest reductions. Narrower lane width was associated with greater collision reductions, sites with average lane width of less than 3.9m had the greatest reductions. Finally sites that did not have median separation had greater reductions in collisions compared to sites with median separation.

In summary, the primary finding in this thesis can be summarized as follows:

- At the intersection level there were significant reductions in total collisions, angle collisions and rear-end collisions (25%, 13% and 11%)
- At the approach level there were significant reduction in total collision, angle collisions and rear-end collisions (12%, 13%, and 27%)
- Significant reductions in severe collisions was observed for locations with greater than 15 yearly collisions in the before period (28.6%).
- Small spillover effects were evident for angle collisions, but no spillover effects were observed for other collision types
- Collision frequency and collision rate were found to be successful as site selection indicators, however AADT was not found to be a successful site selection criteria for ISD selection.
- The four intersection characteristics were found to have an impact on ISD collision reduction include: number of through lanes, median presence, speed limit and average lane width.

5.2 Research Contributions

From the results of the before-and-after EB analysis it is clear that ISD cameras have been effective at reducing intersection collisions in the city of Edmonton. This thesis was also able to pinpoint intersection characteristics that are associated with successful ISD implementation. The results of this analysis can be used to aid in future ISD site selection.

This study confirmed that collision frequency and collision rate are successful site selection criteria. Sites with higher collision frequency/rate in the period before ISD installation had the greatest reductions in collisions. Specifically when the collision frequency was greater than 15 total collisions per year significant reductions were observed in almost all collision types. Additionally it was found that AADT was not effective as a site selection criteria; no trends were observed in collision reductions for different levels of AADT. Currently there has been no other evaluations of ISD site selection criteria in the literature. The results from this thesis are similar to those found for RLC (Ko et al., 2013).

Presently there have been no other studies that have been able to relate intersection characteristics with ISD effectiveness. This thesis found that there were four intersection characteristics that can be used to evaluate future ISD site selection; the four characteristics are as follows:

- Number of through lanes – sites with 5-7 through lanes had greater reductions
- Median Presence – sites without median separation had greater reductions
- Speed limit – reductions were greatest at sites which had a 60km/hr speed limit
- Average lane width – sites with narrower average lane width had greater reductions

5.3 Study Limitations

There are several limitations to this research. As discussed in section 2, the selection of reference sites that are as similar as possible to the treatment sites is important to ensure the accuracy of the before and after evaluation. In this thesis the selection of reference sites was limited by the availability of traffic data. The reference sites with the most similar collision histories were chosen, however given the limited number of sites to use, the overall collision frequency at the reference sites were lower than those at the treatment sites. This was most apparent in the case on severe collisions, as a result the results of the EB analysis for the severe collisions were not significant at the intersection level or the approach level.

Secondly, it was not possible to account for spillover to surrounding intersections. In this thesis the estimation of spillover effects were limited to the spillover to un-enforced approaches at ISD intersections. However, it is also possible that the impact of ISD cameras might spillover to other surrounding intersections.

5.4 Future Research

Although this thesis demonstrates the safety effectiveness of ISD cameras and makes recommendations for site selection criteria there is still further questions that need to be addressed. Future research may explore such topics as: spillover effects, ISD target collisions, changes in violations and the impact of signal timing on the effectiveness of ISD.

Firstly, the extent of spillover effects for ISD cameras have not been fully determined. Current literature suggests that spillover effects for RLC are limited to small decreases for angle collisions, and spillover effects have not been consistently observed for other collision types (Hoye, 2013). Current ISD studies have not deeply studied spillover effects. At this time the only ISD study to consider spillover effects was in Winnipeg, Manitoba (Vanlaar et al., 2014), which only looked at changes in intersection collisions for the city as a whole, not to neighbouring intersections. The evaluation of spillover effects in this thesis was also limited; only the spillover to approaches within the same intersection was considered. A more focused research of spillover effects would be of value in understanding the full impact of ISD cameras.

The changes in speeding and RLR violations as a result of ISD installation is another potential area for future study. Few studies have looked at the change in violations for RLC or ISD cameras. The study by Vanlaar et al. (2014) attempted to evaluate the change in violations. However in their study data was only collected for a few weeks immediately following camera installation. Future research may conduct a more thorough investigation into the changes in violations at ISD camera sites. Additionally the use of violations as a potential site selection criteria needs to be evaluated.

Another area which may benefit from further research is the effect of ISD cameras on rear-end collisions. Previous research on RLC and ISD cameras in other cities and municipalities have consistently shown at best no change in rear-end collisions, or in most cases, a significant increase. However, the results of this thesis have shown a significant decrease in rear-end collisions. The study by (Sayed et al., 2006) of RLC in Edmonton showed a similar reduction in collisions. Further exploration of the differences between other ISD programs and the city of Edmonton RLC and ISD programs may be able to identify why this difference occurs, and how increases in rear-end collisions may be avoided.

Finally the impact of signal timing on ISD performance is another area for future research. In this study the impact of various intersection geometric characteristics on ISD performance were considered, however the impact of signal timings was not evaluated. The length of the yellow signal has been shown to impact RLR; shorter yellow phases lead to an increase in RLR and RLR collisions (Retting et al., 1999). Therefor it might be possible for signal timings, particularly the length of the yellow phase, to impact ISD performance.

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