IMPROVING INTERSECTION SAFETY: REDUCING CASUALTIES AT HIGH-RISK INTERSECTIONS IN SURREY, RICHMOND AND VANCOUVER

by

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The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

Intersection safety is a growing concern for cities worldwide. In British Columbia (BC), over 20,000 injuries and almost 400 fatalities occurred at intersections each year between 2000 and 2004. The objective of this study is to identify which physical factors and intersection characteristics play a role in determining intersection safety. This study uses Ordinary Least Squares regression analysis to test the effect of 12 independent variables on the dependent variable: casualty count. Using data from 19 intersections from Surrey, Richmond and Vancouver from the years 2000 to 2004, the findings reveal that traffic volume, restricted left-turns, permissive left-turns and right-turn lanes are statistically significant and positive predictors of intersection casualties. Based on the findings, this study proposes five policy alternatives: 1) status quo, 2) reducing traffic volume, 3) eliminating the use of restricted left-turns, 4) using protected over permissive left-turns and 5) prohibiting right-turn on red. These five policy options are evaluated using three criteria 1) cost, 2) reduced casualty and 3) time delay. Based on the evaluation, status quo emerges as the most effective recommendation for reducing intersection casualties and improving intersection safety. It is also suggested that further studies be conducted to determine what would work best for individual municipalities.

Keywords: Intersection Safety; Traffic Volume; Restricted Left-Turns; Right-Turns on Red; Permissive Left-Turns; Casualty Reduction; Traffic Safety

Executive Summary

Over a million people each year lose their lives to motor vehicle accidents (Mohan, 2006), the majority of which occur at intersections (FHWA, 2005). Between 2000 and 2004, 41,825 casualties occurred at intersections in British Columbia (BC), accounting for 41 percent of accident related injuries and 22 percent of accident related fatalities (ICBC, 2000, 2001, 2002, 2003a and 2004). In attempting to reduce intersection related casualties, this study examines 19 intersections in Surrey, Richmond and Vancouver to determine which physical factors or intersection characteristics play a role in determining intersection safety. Data is collected from the period of 2000 to 2004, treating each intersection as an individual case, with a total sample size of 95.

Casualty count is the dependent variable and is a measure of intersection safety in this study. Data for casualty count was retrieved from ICBC from the periods of 2000 to 2004. Twelve independent variables are used to test variations in casualty counts: red light cameras, posted speed, traffic volume, through lanes, left-turn lanes, left-turn arrows, permissive left-turns, right-turn lanes, phasing/signal changes, gas stations and vanpool/bus lanes. Data for the 12 independent variables were collected manually from the 3 local municipalities.

Ordinary Least Squares regression (OLS) is utilized to test the effect of the independent variables on casualty count. Of the 12 independent variables, only 4 are statistically significant: traffic volume (LTV), permissive left-turns (PLT), restricted left-turns (RLFT) and right turn lanes (RT). All are found to have a positive effect on casualty count. These four significant independent variables account for 77 percent of the variations in the dependent variable. In this study, a one percent increase in traffic volume increases casualties by 0.73 percent. The presence of a restricted left-turn increases casualties by .20 percent. Permissive left-turns increases casualties by .087 percent and right-turn lanes increases casualties by .085 percent.

Based on the statistical findings, five policy alternatives are proposed: 1) maintaining status quo, 2) reducing traffic volume through traffic calming 3) eliminating restricted left-turns, 4) using protected as opposed to permissive left-turns, and 5) prohibiting right-turns on red. Three set criteria are used to evaluate the proposed policy alternatives:

1) Cost: monetary cost of implementing the policy

2) Casualty reduction: percent reduction in the number of casualties

3) Time delay: time delays caused to traffic flow

Each policy alternative is rated between 1 and 3 for a maximum score of 12. Status quo scored the highest among all options with a total score of seven. A score of five is given to reducing traffic volume, which ranked second and eliminating the use of restricted left-turns scored a four. Using protected left-turn phasing over permissive and prohibiting right-turns on red are tie with a score of three. Thus, status quo emerged as the most effective policy alternative with respect to intersection safety for the 19 intersections included in this study. The study concludes by suggesting that other policy options might be feasible for the three municipalities and each should determine which alternative would work best to reduce intersection casualties at high-risk intersections in their own jurisdictions.

To my mom

whose work goes unrecognized

everyday….

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Table of Contents

List of Figures and Tables

1 Policy Problem and Background

In attempting to provide policy advice to local municipalities, the Insurance Corporation of British Columbia (ICBC), and the Ministry of Transportation (MOT), this study examines intersection safety in BC by studying 19 intersections in Surrey, Richmond, and Vancouver. As there are obvious health, policing, insurance, and social costs associated with casualties, this study seeks to uncover physical factors or intersection characteristics that affect the number of casualties (injuries and fatalities) occurring at intersections in Surrey, Richmond and Vancouver.

Starting with the policy problem, intersection related casualties are on the rise, this study aims to identify which physical factors or intersection characteristics play a pivotal role in determining intersection safety. This stems from the notion that although behavioural traits of an individual driver play a crucial role in road safety, driver behaviour cannot be controlled; physical aspects of an intersection can be altered/improved through intersection design to improve intersection safety (Institute of Transportation Engineers, 2007). With that in mind, this study takes into account various factors such as traffic volume, posted speed, red light cameras, and the number of right, left and through lanes; and aims to identify other factors (restricted left-turns, vanpool/bus lanes and gas stations) to help traffic engineers and government agencies devise new policies to improve current practise and programs which will in-turn help reduce the frequency of casualties and; thus, improve intersection safety in the three municipalities.

This section provides the backdrop for the current situation in BC with respect to intersection safety. Section two explains the methodology used in this study and the possible effect each independent variable may have on the main dependent variable– casualty count. Moreover, it gives the reader an overview of the data used in the study. Section three provides a detailed description of all the sites used in the analysis along with a breakdown of the three municipalities (Surrey, Richmond and Vancouver). Section four focuses on the regression analysis findings and discusses the effect of each independent variable on intersection related casualties. Following the statistical analysis, a number of policy alternatives are explored along with set criteria to evaluate the policy alternatives: cost, casualty reduction and time delay. The study concludes with closing remarks with respect to study limitations and policy recommendations to improve intersection safety in Surrey, Richmond and Vancouver.

1.1 Road Accidents in BC

As Illustrated by Table 1, the number of automobile collisions in British Columbia (BC) is on the rise. In 2000, there were 42,652 collisions and this number rose to 49,478 by 2004: a 16 percent increase over a period of 4 years. The highest percent increase occurred in the year 2001, where the collisions jumped by nearly eight percent in comparison to the previous year. This increase is also present in the number of injuries and fatalities that occurred in the same time period (ICBC, 2000, 2001, 2002, 2003a and 2004). The number of injuries increased from 20,019 in 2000 to 20,300 by 2004, which is a minute increase of 1.5 percent. However, in the year 2003 the number of injuries increased by nearly five percent in comparison to the year 2000. The highest increase in the number of injuries occurred in the year 2003 in comparison to 2002 with a four percent jump. As for fatalities, the highest increase occurred in 2002 with an 11 percent increase from the year 2001. On average, there were 47,130 collisions, 20,319 injuries, and 391 fatalities between the years 2000 and 2004 in BC. Although, the number of collisions appears to be on the rise, the number of injuries and fatalities appears constant with a minute increase of one to three percent each year.

Table 1 Number of Collisions, Injuries and Fatalities in BC for Years 2000 Through 2004

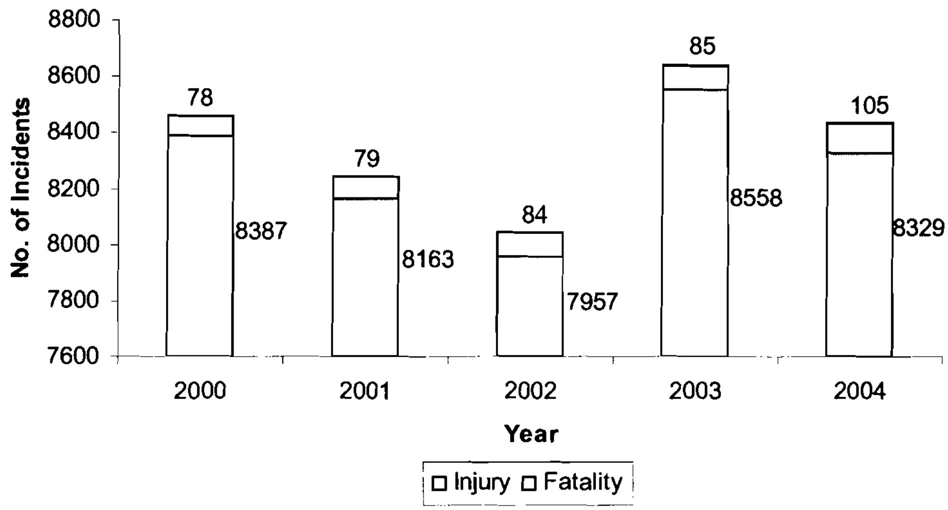
Year	Collisions	Injuries	Fatalities
2000	42,652	20,019	378
2001	45,905	20,220	369
2002	47,685	20,117	410
2003	49,930	20,938	402
2004	49,478	20,300	398
Average	47,130	20,319	391

ICBC, 2000, 2001, 2002, 2003a and 2004

1.2 Intersection Related Collisions, Injuries and Fatalities in BC

In British Columbia (BC), on average 44 percent of casualty collisions occurred at intersections from 2000 and 2004 (ICBC, 2000, 2001, 2002, 2003a and 2004). Traffic accidents occurring at intersections account for an average of 41 percent of accident related injuries and 22 percent of accident related fatalities (ICBC, 2000, 2001, 2002, 2003a and 2004). As evident by Figure 1, the number of intersection related fatalities increased by 35 percent by 2004 in comparison to the year 2000, with the average fatality count of 86 over five years, and the total being 431 fatalities. The highest increase occurred in 2004 when the number of fatalities jumped by 23 percent in comparison to the previous year. The number of injuries increased by nearly eight percent in the year 2003 in comparison to 2002. Though fluctuating slightly; there was not an overall increase in the number of injuries for the years 2000 to 2004, which had the average of 8,279 injuries per year, and 41,394 as the total for all the years.

Figure 1 Total Number of Injuries and Fatalities at BC Intersections from 2000 to 2004



ICBC, 2000, 2001, 2002, 2003a and 2004

1.3 Costs Associated with Injuries and Fatalities

According to a recent report by the Insurance Corporation of British Columbia (ICBC, 2006) – besides the obvious toll of human suffering – the average collision costs $25,000, which is based on claim-based data for severe injuries and fatalities at urban sites.[1] For severe injuries occurring at intersections between the years 2000 to 2004, it can be estimated that ICBC spent approximately $1.03 billion dollars on claims.[2] In addition, the average cost of a fatal collision to ICBC is estimated to be $220,000 per incident (Baker, 2007). From the years 2000 to 2004, it can be estimated that ICBC spent over $94.8 million dollars on fatalities occurring at intersections.[3]

[1] This amount does not reflect the cost of non-severe incidents (ICBC, 2006).
[2] Costs are based on the average cost of severe injuries and fatalities at urban sites multiplied by the 41,394 injuries that occurred at intersections between 2000 and 2004. These figures are estimates only and do not differentiate between severe and non-severe injuries. Segregated costs for severe and non-severe injuries could not be obtained.
[3] Costs are based on numbers provided by Laurie Baker of ICBC. The value is determined by multiplying the average cost to ICBC for fatality ($220,000) with the number of fatalities (431) that occurred at intersections from 2000 to 2004. These costs are endured by ICBC alone and do not include the costs of lost wages, productivity, and other social costs that may mount up. These figures are estimates only.

These dollar amounts are staggering and only include costs from intersection related collisions that result in severe injuries and fatalities for the years 2000 through 2004.[4]

The healthcare system, municipal emergency response and enforcement systems, and family and community supports to victims all bear the burden of automobile accidents. The costs to the health care system for attending to the victims at the collision scene vary and may increase depending on the severity of injuries sustained. The police and fire departments (and sometimes paramedics and/or ambulance services) are legally bound to attend reported accident scenes to ensure victims are attended to for emergency care and that an initial legal investigation is done. Victims' families, along with their extended communities such as employer, bear unexpected costs as well, which are unaccounted for in this report.

1.4 Who is Responsible for Intersection Safety in BC?

It is important to understand that road and traffic safety is a collaborative effort between many parties. Road safety is a shared responsibility between Ministry of Public Safety and Solicitor General, Ministry of Transportation, ICBC and local municipalities. Each agency plays a role in improving and maintaining road safety and the sole responsibility of road safety does not fall on one agency.

The Ministry of Public Safety and Solicitor General, which includes municipal and RCMP policing services, enforces the Motor Vehicle Act, 1984 (MVA).[5] The Solicitor General also oversees programs such as the red light camera program and used to administer the now terminated photo radar program in collaboration with other agencies, such as ICBC. Road maintenance is a shared responsibility between the Ministry of Transportation (MOT) and local municipalities. The MOT oversees the maintenance of all provincial highways and any infrastructure development within the province (MOT, 2001), while local municipalities are responsible for maintaining traffic signals and local streets within their jurisdiction.

ICBC is a Crown Corporation with a vested interest in road safety as it oversees the insurance industry in British Columbia (BC). It is a key stakeholder in road and traffic safety, as one of ICBC's priorities is to maintain low insurance rates and this is accomplished through encouraging many initiatives, programs and policies, across the province to improve road safety.

[4] The injury and fatality data used to estimate these costs are provided by ICBC. ICBC injury and fatality data counts multiple injuries and fatalities that occurred at one scene as one count, regardless of the number of injuries, fatalities, vehicles and parties involved. Therefore, these costs are not a true reflection of the actual dollar amount.

[5] MVA 1984 oversees vehicle operability and regulates the insurance industry in BC.

Examples include road improvement projects at high-crash intersections, increase in police enforcement and public awareness campaigns (ICBC, 2007).

1.5 Initiatives to Improve Intersection Safety in BC

Any intersection safety initiative in BC is approved and implemented through collaboration between municipal governments, ICBC, and the Ministry of Public Safety and The Solicitor General. The red light camera program provides an example of such an initiative. Red light cameras reduce red light-running incidents and helps curb the number of accidents at high-risk intersections (ICBC, 2003b). The program in BC is currently operational and initially cost taxpayers $120,000 per intersection to implement (City of Vancouver, 1999), which equates to $14.4 million dollars for all 120 sites across BC. This figure does not include annual operating costs. Local municipalities approved the placement of cameras within their jurisdictions, while ICBC and the Ministry of Public Safety and The Solicitor General currently oversee the operation and annual costs of the program.

The BC Ministry of Transportation (MOT) also initiates programs and projects to improve road safety. In 2005/06, the MOT spent $731 million dollars for transportation improvement projects (MOT, 2007b). It collaborated with ICBC, the Solicitor General, and local municipalities to implement safety improvement projects. The MOT conducted a preliminary study which compared sites prior to capital improvements and measured results after the safety improvements and found a reduction of 72 crashes between the years 2005 and 2006 at the target sites (MOT, 2007b).[6]

ICBC spent over $7.5 million dollars on the Road Improvement Program in 2006 (ICBC, 2007). In the same year, ICBC spent $745,900 dollars on improvements to 33 urban signalized intersections which included construction of left-turn lanes, phasing or signal upgrades, and implementation of left-turning arrows (ICBC, 2006). The evaluation report conducted a pre/post analysis of treatment sites that underwent safety improvements and found a 13 percent reduction in severe injuries and fatalities at these sites (ICBC, 2006). Comparison groups were used to account for factors of history and maturations. Sites with similar designs were also used to develop collision prediction models. The methodologies of this study differ from the ICBC study because the aim of the ICBC study is to evaluate levels of safety before and after a particular initiative. In contrast, this study aims to identify which physical factors of an intersection lead to an increase/decrease in intersection safety.

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[6] The number of test sites and the number of years undertaken in the analysis for the study are not stated.

This section outlines the policy problem (which is intersection related casualties are on the rise) and it helps to formulate a clear understanding of the current situation with respect to the collision rates in BC. The section then further elaborates on intersection related collisions in BC and discusses costs associated with these collisions. It then touches on initiatives undertaken by various agencies that share road safety responsibility in BC. This section provides the reader with an understanding of the policy problem and the background pertaining to intersection related collisions in BC. The following section discusses the methodology of this study in more depth.

2 Study Framework

This section discusses and defines the various variables and examines research surrounding the variables. It also explains how the data is collected and coded in the study. Furthermore, this section outlines the overall methodology, which touches on the Ordinary Least Squares (OLS) regression analysis and the interviews that were conducted to evaluate proposed policies to improve intersection safety.

2.1 Overall Approach of Methodology

This study attempts to determine which factors reduce intersection safety while accounting for physical characteristics (such as the number of right-turn lanes) and other intersection characteristics (such as phasing/signal changes) from 19 intersections in British Columbia (BC): Surrey (7), Richmond (5) and Vancouver (7). Data for the 19 intersection is collected from the period of 2000 to 2004. Each of the 19 intersections are treated as individual cases in each year, with a total sample size of 95.

Independent variables were selected after reviewing research on the matter. The 12 independent variables tested are red light cameras, traffic volume, posted speed, through lanes, left-turning lanes, left-turning arrows, permissive left-turns, restricted left-turns, right-turning lanes, gas stations, phasing/signal changes, and vanpool/bicycle lanes. Some variables, such as inclination of the intersection, could not be considered in the study as it required engineers to administer the measurements.

The variables are hypothesized to either display a positive or a negative relationship with the dependent variable and are tested in a regression analysis. This study uses Ordinary Least Squares (OLS) regressions to test the effects of the independent variables on the main dependent variable – casualty count – as a measure of intersection safety. Various test models were run, but only results from the final model are used to formulate policy.

A presentation of the findings and policy options were presented to officials (who specialize in transportation engineering and planning) from ICBC and The City of Surrey. The purpose of the presentation is to discuss the results and the acceptance of proposed policy alternatives by the engineering and transportation industry as well as the public. The discussion after the presentation was not tailored to specific questions; it was more relaxed and open ended. Follow-up emails were directed to Ann Coffin of City of Surrey and Laurie Baker and Peter Cooper of ICBC to obtain answers for specific questions that arose from the two presentations. The outcomes of the presentation discussions and emails are used for reference purposes and discussed more in detail in Section five, six and seven of this paper.

2.2 Site Selection Process

This study examines intersections in Surrey, Richmond, and Vancouver municipalities in the Greater Vancouver Regional District (GVRD). Surrey and Vancouver are selected because they are the two largest municipalities with the highest number of registered vehicles in the GVRD (GVRD, 2004c). Although Richmond ranks number 4 for the total number of registered vehicles, Surrey, Richmond, and Vancouver comprise 51 percent of the total vehicles registered in the GVRD, as illustrated by Table 2 (GVRD, 2004c).Vancouver comprises 25 percent of the total number of registered vehicles in the GVRD with Surrey following behind with 16 percent and Richmond with 10 percent.

Table 2 Total Number of Registered Vehicle in Surrey, Richmond, and Vancouver from 2000 to 2004

	2000	2001	2002	2003	2004
Surrey (S)	192,784	200,474	209,432	225,356	231,535
Richmond (R)	116,292	116,609	116,605	116,202	118,699
Vancouver (V)	287,141	290,698	295,250	306,321	304,981
SRV Total	596,217	607,781	621,287	647,879	655,215
GVRD Total	1,172,866	1,191,511	1,214,009	1,269,962	1,286,887

GVRD, 2006c

Surrey, Richmond, and Vancouver were also selected by the Attorney General's Office as the main test areas in the initial testing phase of the red light camera program, with the first trial location set up in Vancouver (City of Vancouver, 1999). The overall goal of the program is to reduced intersection collisions and red light-running offences and to allow police to determine liability for crashes, thereby reducing police and court costs (City of Vancouver, 1999). The sites selected in the red light camera program are classified as high-risk intersections.[7] Thus, these sites make ideal candidates for this study, as they did for the red light camera program.

The red light camera program selected 120 high-risk intersections across British Columbia (BC) which included 25 in Vancouver, 13 in Surrey and 5 in Richmond. However due to limited ICBC resources and mainframe system changes, ICBC agreed to provide data for only 20 intersections for the year 2000 onwards. Since data could only be provided from the year 2000 onwards, it was imperative to have target sites that had cameras in effect for 2000 year-end (November to December) in the dataset in order to account for the effect of red light cameras on intersection safety. Red light cameras operating in the last two months of the year would not have a significant effect on the number of collisions for that year. In this study, if the red light camera has been operational for less than and/or equal to two months of the given year, then the site is considered to not have a camera for that year. Camera live dates were provided by Lloyd Holtzmann of the Royal Canadian Mounted Police (RCMP) Traffic Division.[8]

With the exception of one site, all of the sites in Richmond were operational in November of 2000, but all five of those sites were selected for analysis from Richmond. Vancouver site selection was contingent on the availability of traffic volume data. Of the 25 sites in Vancouver, traffic volume data was available for seven sites which also had red light cameras operational by early 2001. The remaining eight sites were selected from Surrey based on camera live dates. However, one of the sites in Surrey was dropped as it belonged to the Ministry of Transportation (MOT), and obtaining data for phasing or signal change for that site would have exceeded time allocated for data collection.

2.3 Casualty Count: Main Dependent Variable[9]

In previous research, injury and crash rates are used as a measure of intersection safety. An increase or decrease in crash and injury rates is used as an indicator of whether road and intersection safety has improved or declined. Lau and May (1998) used injury data to determine the effect of through lanes on the number of injuries at intersections. ICBC used percent change in severe injuries as indicators of improved road and intersection safety for its evaluation of the Road Improvement Program (ICBC, 2006).

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[7] High-risk intersections are the most dangerous and deadliest intersections in Surrey, Richmond and Vancouver.

[8] See Table 12 in Appendix A for the list of test sites with live dates selected for analysis.

[9] ICBC provided data for two dependent variables. Due to its importance casualty counts was deemed more important to understand than property damage; although, the latter is used to solidify the findings of this study and can be found in Appendix B.

To be consistent with other studies and ICBC's measuring unit of improved road safety, this study uses casualty counts (CC) as the main indicator of intersection safety measured by the number of crash incidents resulting in injury and fatality occurring within the intersection.[10] It is important to note that CC does not differentiate based on the degree of injury sustained. Casualty count (CC) is one count regardless of the number of individuals and vehicles involved in the incident, as long as injury or fatality is sustained to a party involved in the collision. For example, a collision involving two cars and seven individuals with two of those people sustaining injuries would be counted as one casualty count. Data for this variable is obtained from ICBC for the 19 selected intersections for the period of January 1st, 2000 to December 31st, 2004. The CC are an approximate number and may vary from the final tally, and do not include parking lot incidents.[11]

2.4 Independent Variables

The study observes the effect of the following 12 independent variables on intersection safety: red light cameras (RLC), traffic volume (TV), posted speed (SPD), through lanes (TL), left-turning lanes (LFT), left-turning arrows (LFTA), permissive left-turns (PLT), restricted left-turns (RLFT), right-turning lanes (RT), phasing/signal changes (PSC), gas stations (GS) and vanpool/bicycle lanes (VL). Table 3 lists all the independent variables with their acronyms and hypothesized relationships.

[10] The Freedom of Information and Protection of Privacy Act of 1996 mandates ICBC to include fatality counts in the overall CC in order to protect individual privacy rights, as it would be fairly easy to determine the identity of individuals involved in collisions. Therefore, segregated fatality counts were not obtained from ICBC.

[11] The number of casualties may vary as all incidents (claims) that occurred in 2004 must be reported by end of 2006; this data was obtained in early December 2006.

Table 3 Hypothesized Relationships with Casualty Counts

Acronyms for Variables	Variable Name	Hypothesized Relationship[12]
RLC	Red Light Cameras	Negative
TV	Traffic Volume	Positive
SPD	Speed	Positive
TL	Through Lanes	Positive
LFT	Left-Turn Lanes	Negative
LFTA	Left-Turn Arrows	Negative
PLT	Permissive Left-Turns	Negative
RLFT	Restricted Left-Turns	Positive
RT	Right-Turn Lanes	Negative
PSC	Phasing/Signal Changes	Negative
GS	Gas Stations	Positive
VL	Vanpool/Bus/Bicycle Lanes	Negative

2.4.1 Red Light Cameras

Used worldwide, red light cameras (RLC) are mounted at intersections to take pictures of red light-running offences in hopes of reducing those incidents and curbing the number of accidents at high-risk intersections. Most of the numerous studies on the subject concur that they are an effective tool toward this end (ICBC 2003b, and Retting and Kyrychenko 2002). However, research also suggests that reductions in collisions at intersections cannot be attributed to RLC entirely (Andreassen, 1995 and Mann, et al., 1994).

Retting and Kyrychenko (2002) observed 11 RLC sites and compared them to 82 sites without the devices installed. The study collected data for 29 months pre- and post-implementation, and found a 7 percent decrease in total collisions, a 29 percent decrease in all injury rates, with a 69 percent decrease in right angle injuries, and a 32 percent decrease in right angle accidents.[13] There was a three percent increase in rear-end collisions, though this was not found to be statistically significant (Retting and Kyrychenko, 2002). They conclude RLC are effective in reducing the number of injuries and collisions occurring at intersections.

ICBC conducted pre/post analysis of 68 sites to test the effect of RLC on the number of crashes. The study used data from 1.5 years before and 1.5 years after the implementation of RLC

[12] A positive relationship indicates an increase in the number of casualties as the independent variable increases. A negative relationship indicates a decrease in casualties as the independent variable increases.
[13] Right angle injuries are injuries sustained to an individual after being in a two motor vehicle collision in which the vehicles were travelling at right angles to each other before the crash (Retting and Kyrychenko, 2002).

at the sites. The study conclusively found on average a 14 percent reduction of all crashes at these 68 sites (ICBC, 2003b).

Golob et al. (2003) tested 19 camera sites in San Diego and collected data from three to five years pre and one to three years post-implementation for the camera test sites. This study found red light cameras (RLC) to be effective in decreasing red light-running violations at all the test sites; however, the rate of decrease declined over time (Golob et al, 2003). There was a 40 percent decrease in right angle collisions, but interestingly enough the study also found a 40 percent increase in the number of rear end accidents.

Andreassen (1995) found no reduction in the number of collisions at the 41 test sites undertaken in his analysis. Moreover, he found a significant 13 percent increase. Mann et al. (1994) tested 13 target sites with cameras and compared them to 14 sites without cameras– concluding the reduction in the number of collisions at the camera sites was not statistically significant when compared to the reductions at the other sites.

This study hypothesizes that RLC are negatively associated with the number of casualties. The presence of a camera at an intersection is hypothesized to lower the casualty count, which results in safer intersections. RLC variable is coded into a dummy variable (0 = No RLC, 1 = RLC). If the camera was placed in last two months of the year (November to December), it is classified as a site with no camera as the placement of the camera would have no significant impact on the annual casualty count (CC) for the remaining year. If the camera was operational for the majority of the year (seven months) then it is classified as a site with a camera.[14]

2.4.2 Traffic Volume

Traffic volume (TV) tracks the total number of vehicles moving through intersection in a given year. The yard stick for measuring TV is known as Annual Average Daily Traffic (AADT). AADT counts are collected by electronic counters mounted on posts at target sites. The data is collected in 1 hour intervals for a 24 hour period, and is collected for both sides of the traffic flow (FHWA, 2001).

TV is an important variable in predicting intersection safety. The higher the volume at the intersection, the more likely collisions will occur (Kumara and Chin, 2002). Kumara and Chin (2002) studied 104 signalized intersections over a period of nine years in Singapore. They

[14] Refer to Table 12 in Appendix A for the list of RLC sites and live dates examined in this study.

conclude that traffic volume (TV) significantly affects the number of accidents at intersections. Khattak (2006) observed 41 intersections in Nebraska from 1988 to 2000. He found the frequency of accidents on major roads increases as TV increases above a 10,000 average daily traffic count.

In this study, TV is the movement and flow of all vehicles in all directions at a particular intersection. The effect of TV on casualty count (CC) is predicted to be positive. As indicated by research, an increase in TV will cause an increase in the number of casualties which results in a decrease in intersection safety. Availability of TV data varied between Vancouver, Richmond, and Surrey, as TV counts are expensive to conduct and are not conducted annually for all intersections and streets in some municipalities. Traffic flow counts could not be provided for all the years undertaken in the analysis, so they were obtained for any two years for all intersections. All TV counts were provided in AADT counts. A linear trend extrapolation was conducted to determine counts for the years which were not provided.[15]

2.4.3 Posted Speed

According to ICBC, speed is a contributing factor in more than 37 percent of all fatal collisions (ICBC, 2005a). From 2001 to 2005, 835 people were killed in unsafe-speed-related collisions (ICBC, 2005a). Speed limits have proven to be an important safety measure in reducing all traffic accidents.

Wilmont and Khanal (1999) highlight that high speed limits reduce road safety immensely, while reduced speed allows drivers more reaction time to avoid collisions and lowers the risk of high-impact collisions. Speed affects the severity of the accident; however, there is little evidence illustrating the relationship between speed and the number of accidents (Wilmont and Khanal, 1998). Khattak (2006) found speed limits to be an insignificant factor affecting intersection accident rates.

In this study, speed is not a reference to the actual speed at which vehicles proceed through the intersection, but instead refers to the posted speed (SPD) at each intersection. The SPD at these sites is either 50 or 60 kilometres per hour (km/h). The hypothesized effect of speed on the number of casualties is positive. The higher the speed posted, the higher the number of casualties. The data was collected manually by visiting each intersection. The speed variable is coded into a dummy variable (0 = 60 km/h, 1= 50 km/h).

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[15] See Table 14, 15 and 16 in Appendix A for extrapolated traffic volume counts for Surrey, Richmond, and Vancouver.

2.4.4 Through Lanes

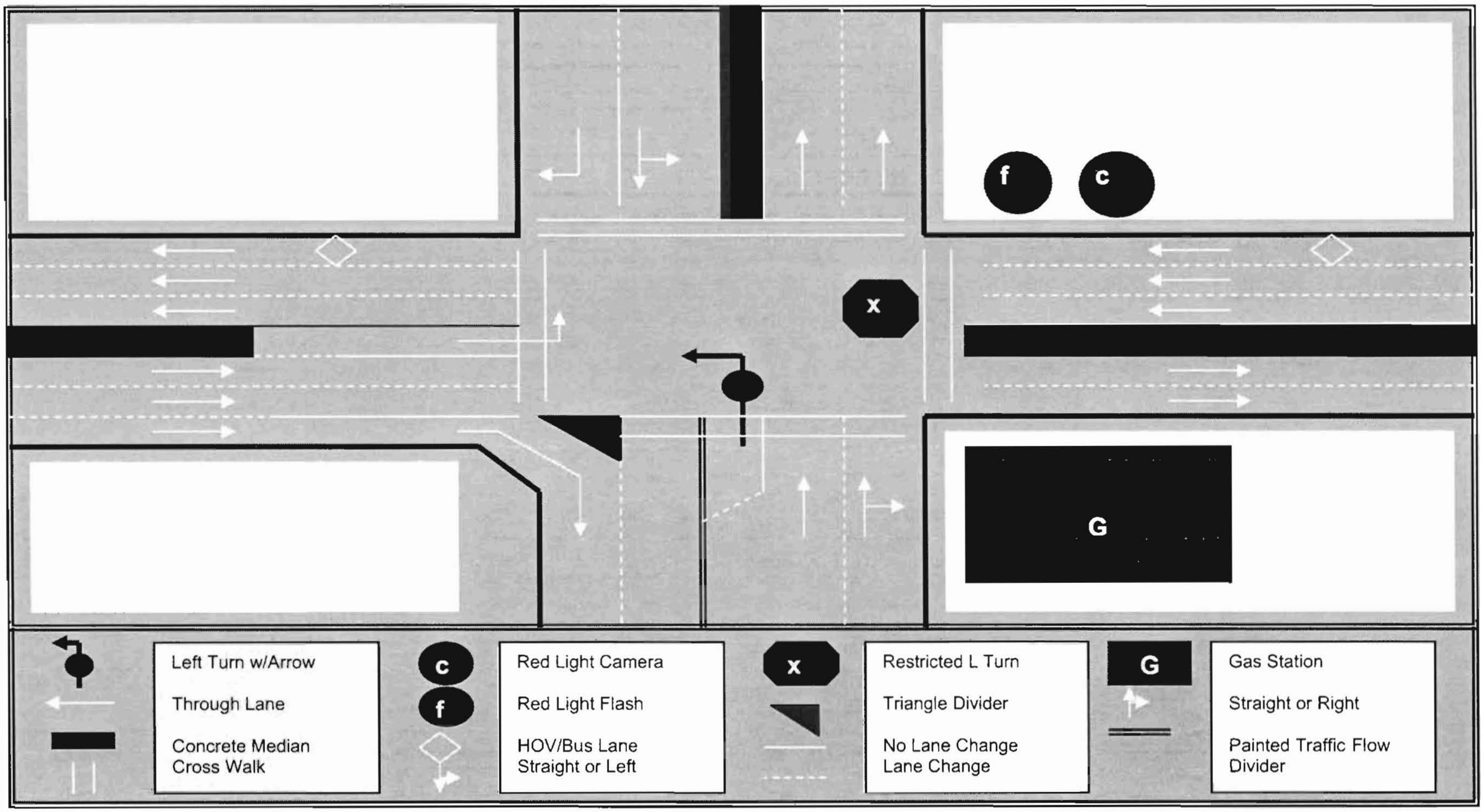
Research indicates the number of through lanes (TL) is a significant predictor in the number of accidents (Khattak, 2006). Bauer and Harwood (1996) studied 2,262 intersections in California and found that intersections with two or more lanes were statistically associated with higher accident rates in signalized urban intersections. Another study in California observed 17,000 signalized intersections for seven years and found TL to be statistically significant in predicting collisions which resulted in injury (Lau and May, 1988).

As illustrated by Figure 2, TL are lanes which cross the intersection. Through lanes are the number of lanes in each direction of traffic, excluding lanes exclusively for left and right-turns and vanpool/bicycle lanes.[16] If there are two lanes for each direction of traffic, there would be a total of eight through lanes at that intersection. For example in Figure 2, there are seven TL in the diagram. The number of TL ranged from four to ten in the dataset.

Data was obtained by manually counting lanes at each site. Data for construction of any new additional TL between 2000 and 2004 was obtained from the engineering departments of the particular municipality. There were no new lanes added in Vancouver and Richmond for the listed intersections in their jurisdiction. TL is hypothesized to have a positive relationship with intersection safety. The more TL at an intersection, the more casualties will occur at that intersection.

[16] Figure 2 illustrates physical characteristics of an intersection. This allows the reader to have a better understanding of how each independent variable is defined in this study.

Figure 2 Intersection Diagram



2.4.5 Left-Turn Lanes

Many studies find the addition of left-turn lanes (LFT) significantly decreases accidents at an intersection because exclusive LFT separates left-turning vehicles from through vehicles which proceed through the intersection at a higher speed (Kumara and Chin, 2002). Gluck et al. (1999) found in their analysis of 53 intersections in California that implementation of LFT reduced traffic accidents by 35 percent, and left-turn signalized intersections were found to reduce crashes by 18 percent. They compared intersections with LFT to intersections without LFT, and found intersections with LFT to have a lower accident rate of 1.06 (per million) (Gluck et al., 1999). Khattak (2006) also found intersections with LFT to have a lower rate of traffic collisions in comparison to intersections without LFT.

For this study, LFT are lanes exclusively designed to allow vehicles to make left turns. This variable excludes left-turning lanes that may have left-turn restrictions. The LFT ranged from zero to six in the data sample. These lanes are designed to differentiate between through and left-turning volume. LFT are predicted to correlate negatively with the number of casualty counts. The more LFT there are, the fewer the number of casualties. The data was collected by visiting each site and counting the number of LFT.

2.4.6 Left-Turn Arrows

The installation of left-turn arrows (LFTA) has been found to decrease accidents at intersections, specifically left-turn accidents, as left-turning vehicles have more time to clear the intersection. A study by Maze et al. (1994), observed 63 intersections over 5 years and found implementation of LFTA has a positive effect on intersection safety. The study found in particular cases that LFTA can reduce left-turn accidents by 35 percent at an intersection (Maze et al., 1994). Hauer (1988) found in his analysis that the installation of LFTA in combination with left-turn lanes significantly reduced accidents by 36 percent.

In this study, LFTA refer to green turning arrows on traffic signals that direct left-turning vehicles to make the turn on green and when all other vehicles have the red signal.[17] This variable counts a LFTA even if an exclusive left-turning lane is not present and it turns through lane into a left-turning lane to allow vehicles to make the turn. The number of LFTA ranged from a zero to a maximum of four in the study and the hypothesized relationship is that an intersection with a

[17] This variable does not distinguish between a protected left-turning signal and a permissive left-turning signal.

LFTA will decrease the number of collisions that occur as a result of the turn. The left-turning arrows are counted manually at each site for this variable. Information about any addition of LFTA to the intersections during the study period was obtained from the corresponding municipalities.

2.4.7 Permissive Left-Turns

A protected left-turning signal allows vehicles to make the turn only when the arrow is green. Once the signal for the left-turn is red, left-turning vehicles are not allowed to make the turn until the next phasing. However, a permissive left-turn signal (PLT) allows left-turning vehicles to turn on the green arrow and also allows vehicles to continue to make the left-turn with caution when there is a gap in opposing traffic. Agent and Nikiforos (1996) conducted a survey of six states in the United States, and found PLT reduced all accidents by 10 percent. In particular, left-turn collisions were reduced by 40 percent. Davis and Aul (2007) also found PLT to lower collision rates. Permissive left-turns (PLT) were also counted manually and ranged from a minimum of zero to maximum of four at each intersection. It is hypothesized that PLT will decrease the number of intersection casualties; therefore, negatively correlated with intersection safety.

2.4.8 Restricted Left-Turns

There is very little research on the effects of restricted left-turns (RLFT) on intersection safety, though Lau and May (1988) observed 2,488 signalized intersections in California over a seven year period and found RLFT to be statistically significant in predicting accidents. RLFT are mostly often found in Vancouver intersections. RLFT either prohibit left turns for left-turning volume or are restrictions placed on left-turning volume from specific periods during the day. For example, left turns are not allowed at some intersections during peak hours (7 am to 9:30am and 3pm to 6pm) in Vancouver.

This variable was collected manually. It was coded as a dummy variable (0 = No restriction on left-turns, 1= Yes restriction on left-turns). Research dictates that having left-turns decreases accidents and can have a positive effect on intersection safety (Maze et al., 1994; Hauer, 1988), and if you place restrictions on the left-turning volume, it is hypothesized that RLFT will have a positive relationship with intersection safety (if a restriction is placed on left-turning volume, the higher the intersection casualties).

2.4.9 Right-Turn Lanes

There is conflicting research on right-turn lanes (RT) and traffic collision rates. Harwood et al. (2000) conclude RT can reduce intersection crashes at a rate of anywhere between 2.5 and 5 percent. Kumara and Chin (2002) found in their analysis of 104 intersections that RT significantly reduced accident rates. Intersections without right-turning lanes have higher collision rates – especially rear-end crashes – because right-turning vehicles share their lanes with vehicles crossing the intersection at high speeds. Collisions occur when right-turning vehicles slow down to make the turn while vehicles passing at high speeds have to slow down to account for the turning vehicle (Kumara and Chin, 2002). On the contrary, Vogt and Bared (1998) observed 389 intersections in Minnesota and found RT can lead to a 27 percent increase in the number of intersection related accidents. Bauer and Harwood (1996) also argue, after studying 14,432 intersections, that RT contribute to an increase in the number of collisions and fatalities.

In this study, RT refers to exclusive lanes for traffic flow making right turns only. Lanes were counted by visiting each site. An example of RT can be found in Figure 2. No new right-turn lanes were reported by the municipalities for the years 2000 to 2004. The hypothesis is that the more RT, the lower the casualty rate, as the lanes separate right-turning vehicles proceeding into the intersection at much lower speeds than vehicles clearing the intersection. The number of RT ranges from a number of zero lanes to a maximum of four lanes at a given intersection.

2.4.10 Phasing or Signal Changes

Lau and May (1988) found signal phasing to be a significant predictor of intersection safety. Traffic phasing or timing can also play an important role in predicting collision rates. For instance, increasing the red phase or extending the yellow light phase can allow vehicles to clear intersections, which may reduce traffic collisions. The type of traffic signal can also significantly affect intersection safety. Light Emitting Diode (LED) traffic signals are used worldwide as they improve visibility and are energy efficient (Rensselaer Polytechnic Institute, 2006). Improved traffic signal visibility can decrease accident rates as drivers may be able to see the signal from a distance and react accordingly.

The phasing/signal change (PSC) variable refers to any changes made to traffic signals or the phasing of signals to improve intersection safety. For example, a new type of traffic signal may have been installed that improves signal visibility for drivers. Changes to the phasing plan could also include increasing time for the left-turn volume from four seconds to seven seconds, so more vehicles turning left can clear the intersection.

The variable is predicted to have a negative correlation with intersection safety as phasing/signal changes (PSC) are implemented to improve intersection safety. PSC is coded as a dummy variable (0 = No PSC were made, 1 = Yes PSC were made). PSC information is provided by the engineering departments of the corresponding municipalities.

2.4.11 Gas Stations

Gas station (GS) is included in the study because logic dictates that vehicles leaving the gas station are turning into through lanes at slower speeds and may collide with vehicles clearing intersections at high speeds. GS is hypothesized to increase collisions; hence, an increase in the number of casualties. The variable is collected by visiting each site and determining how long the GS has been at the particular intersection. The GS attendants or employees verified how long the GS has been in operation.[18] The variable is coded into a dummy variable (0 = No GS, 1 = Yes GS).

2.4.12 Vanpool, Bus and Bicycle Lanes

Vanpool, bus and bicycle lanes (VL) are designated lanes for individuals vanpooling or carpooling, for bus, and for individuals riding a bicycle. These lanes are mostly present in Vancouver. The relationship between VL and casualty count is hypothesized to be negative. Vanpool buses and bicycles travel at much lower speeds than other vehicles and therefore it separates them from speed-maintaining vehicles, resulting in a decrease in the number of collisions between slow and fast moving vehicles. This information was counted manually by visiting each site. This variable was coded as a dummy variable (0 = No VL, 1 = Yes VL).

The section allows the reader to understand the methodology of this study. It discusses the overall approach and then elaborates on the site selection process for this study. Further, it defines and discusses the dependent variable and the 12 independent variables. The following section will provide the descriptive statistics for the dependent and independent variables.

[18] Please note that this information is contingent on the employees' recollections.

3 Variable Descriptives

This section discusses the descriptives of the dependent variable (casualty count) and the 12 independent variables. Moreover, it provides the reader with an overview of the typical intersection in the dataset. It also sheds light on intersections in Surrey, Richmond and Vancouver.

3.1 Dependent Variable: Casualty Count

The total number of casualties for the 19 sites from the years 2000 to 2004 is 3,178 (Table 17 in Appendix A). Surrey leads the count with 1,771, which is 56 percent of the total number of casualties. Vancouver comprised 32 percent of the total number of casualties with a casualty count of 1,011. Richmond follows with only 396 casualties, which is only 12 percent of the total number of casualties. As shown in Table 4, the average casualty count for all the intersections is 33, with 110 being the highest casualty count, 5 being the lowest and the median being 29.

Table 4 Descriptive Statistics for Selected Variables

	CC	TV	TL	LFT	LFTA	PLT	RT
Mean	33	51089	8	3	2	2	1
Median	29	495820	8	4	2	2	1
Variance	495	275999486	1	3	2	3	2
Min	5	28127	6	0	0	0	0
Max	110	94127	10	6	4	4	4

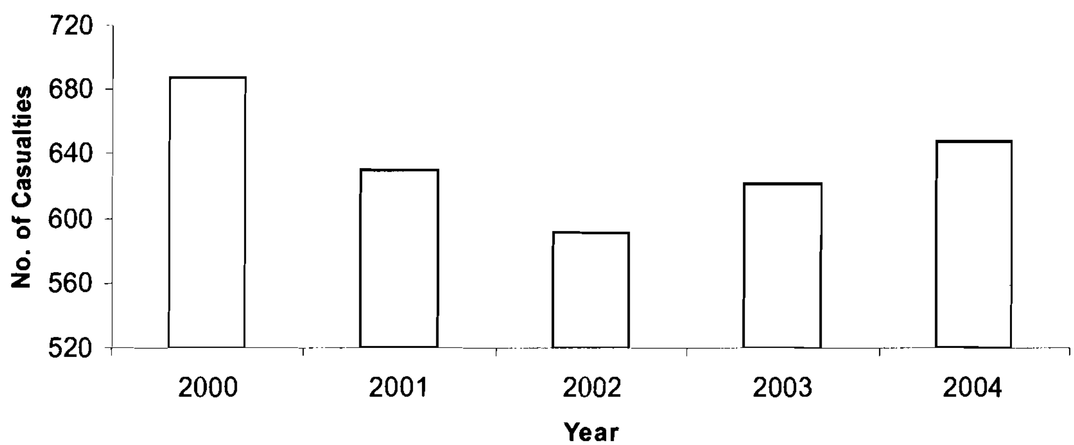
(CC= Casualty Count, TV= Traffic Volume, TL= Through Lanes, LFT= Left-Turn Lanes, LFTA= Left-Turn Arrows, PLT= Permissive Left-Turns, RT= Right-Turn Lanes)

As shown in Figure 3, there is a decrease in the number of casualties over the years in the dataset. The highest casualty count is in the year 2000, with 688 casualties and 2002 having the lowest with a count of 591, with the average being 635 for the 5 years. The number of casualties decreased by 8.4 percent by the year 2001 with 630 casualties in comparison to the year 2000, which had 688 casualties. The trend continued with a 14 percent decline in the number of casualties between the years 2000 and 2002.

The number of casualties at these 19 intersections declined between the years 2001and 2002, which were the years immediately after the implementation of red light cameras. However, the number of casualties increases after the year 2002 – the count jumped by 5 percent in the year 2003 with 621 casualties. The number of casualties continued to increase by nine percent in the year 2004 in comparison to 2002. Research on red light cameras (RLC) indicates that the success of the RLC program is short-lived, and this can explain perhaps the increase in casualties in the year 2003 and 2004, although our regression testing should help clarify this hypothesis.[19]

Baker (2007b) offers another explanation for the increase in 2003 and 2004. The increase can be attributed to an improved economy in 2003 which lead to an increase in travel and resulted in higher crashes rates (Baker, 2007b). Baker (2007b) also mentions that the police-reported injury collisions in 2001, 2002 and 2003 followed a similar pattern as the numbers showed a small dip in 2002 and increased in 2003 (eight percent increase in intersection injury collisions and a four percent increase in the total number of collisions that result in injury).

Figure 3 Casualty Count for Surrey, Richmond and Vancouver from 2000 to 2004



3.1.1 Casualty Counts at Surrey Intersections

The two intersections with the highest casualty counts of all the 95 cases are in Surrey. The intersection of 88th Avenue and King George Highway has the highest casualty count (491 over five years) within the dataset, totalling 28 percent of casualties in Surrey and 15 percent of casualties in the dataset (Table 5). The intersection on King George Highway and 96th Avenue is

[19] Andreassen (1995) found the number of collisions to increase by 13 percent after a slight decrease at the 41 red light camera sites over the course of 10 year period in his study.

the second highest in the number of casualties, with 313 casualties over 5 years. The average annual casualty count for Surrey is 354, with 51 being the average per intersection.

Table 5 Casualty Count for Intersections in Surrey from 2000 to 2004

Site	2000	2001	2002	2003	2004	Total	% of CC to 10,000 TV
King George & 96th Avenue	60	65	65	55	68	313	.081
64th Avenue & 152nd Street	23	28	15	25	39	130	.051
88th Avenue & 152nd Street	42	39	30	31	45	187	.058
88th Avenue & King George	110	97	84	100	100	491	.112
72nd Avenue & 128th Street	42	41	39	30	41	193	.075
96th Avenue & 128th Street	37	41	35	39	22	174	.070
72nd Avenue & Scott Road	48	60	68	53	54	283	.082
Total	362	371	336	333	369	1771	

(CC= Casualty Count, TV= Traffic Volume)

3.1.2 Casualty Counts at Richmond Intersections

The two intersections with the lowest casualty count (CC) in the overall sample are situated in Richmond (Steveston and No. 4 Road and No. 3 Road and Francis Road), with the highest casualty count of 107 at the intersection of Westminster Highway and No. 4 Road, which comprises 26 percent of the casualties in Richmond (Table 6). A total of 396 casualties occurred in Richmond over the 5 year, with 16 being the average CC per intersection.

Table 6 Casualty Count for Intersections in Richmond from 2000 to 2004

Site	2000	2001	2002	2003	2004	Total	% of CC to 10,000 TV
Westminster Highway & No 4 Road	19	19	24	22	23	107	.043
Steveston Highway & No. 4 Road	13	6	9	12	8	48	.028
Cambie Road & No. 4 Road	19	20	15	20	18	92	.061
Alderbridge Way & No. 4 Road	17	24	18	32	12	103	.039
No. 3 Road & Francis Road	11	11	11	5	8	46	.031
Total	**79**	**80**	**77**	**91**	**69**	**396**	

(CC= Casualty Count, TV= Traffic Volume)

3.1.3 Casualty Counts at Vancouver Intersections

Overall, 32 percent of the sample casualties occurred in Vancouver, with the highest casualty count (CC) of 78, the lowest being 11 and the average being 29. The intersection with the highest CC in Vancouver is Burrard Street and Pacific Street, with 264 casualties over the 5 years; comprising of 26 percent of Vancouver's casualties and 8 percent of the casualties in the dataset. In Vancouver, the year 2000 had the highest CC at 247, and the year 2002 had the lowest, with 178 (Table 7).

Table 7 Casualty Count for Intersections in Vancouver from 2000 to 2004

Site	2000	2001	2002	2003	2004	Total	% of CC to 10,000 TV
Burrard Street & W. Georgia Street	32	22	17	29	32	132	.041
S.W. Marine Drive & Cambie Street	52	32	28	30	33	175	.037
Oak Street & West 49th Avenue	32	26	26	21	23	128	.036
Granville Street & West 16th Avenue	25	31	36	35	38	165	.070
West 4th Avenue & Alma Street	15	11	17	11	14	68	.037
Howe Street & Smithe Street	13	14	17	12	23	79	.049
Burrard Street & Pacific Street	78	43	37	59	47	264	.102
Total	**247**	**179**	**178**	**197**	**210**	**1011**	

(CC= Casualty Count, TV= Traffic Volume)

3.2 Independent Variables: Overall Descriptives

The average number of through lanes (TL) is 8; 41 of 95 intersections have 8 lanes. Fifteen intersections have 9 lanes and another 15 have as many as 10 TL. Of the remaining intersections, 14 reported 6 lanes and 10 reported 7 TL (Table 19 in Appendix A).

The average number of left-turn lanes (LFT) is three and the median is four (Table 4). Fifty intersections report at least 4 LFT and 15 intersections have 0 LFT; 5 intersections report 6 LFT and 10 have 2 LFT respectively (Table 20 in Appendix A). Forty intersections have 4 left-turn arrows (LFTA) and 25 intersections have no signal at all, while 15 intersections have 1 LFTA and another 15 have 2 LFTA (Table 21 in Appendix A).

On average, there are 2 permissive left-turns (PLT) per intersection. Of the 95 cases, 30 intersections did not have PLT. Thirty-five intersections display as many as 4 PLT, 15 displays 2 PLT and another 15 had 1 PLT (Table 22 in Appendix A). The average number of right-turn (RT) lanes in the dataset is 1 and 45 intersections have no RT. Twenty intersections have 2 lanes and another 10 have up to 4 RT while another 20 intersections just have 1 RT (Table 23 Appendix A).

The following independent variables are coded as dummy variables and their descriptives are listed in Table 8. Eighteen of the 95 intersections included in the study have no cameras and 77 cases have red light cameras present at the intersections. Twenty-five cases have a posted speed limit of 60 Kilometres per hour (km/h) and the remaining 70 have a posted speed of 50 km/h. Of the cases in this study, 15 have restricted left-turn lanes and 80 did not have any restrictions whatsoever. Only 18 intersections underwent some phasing/signal upgrades from the years 2000 to 2004. The remaining 77 had no changes made to the phasing/signals. Fifty-nine intersections have no gas station and 36 do have at least 1 gas station present at the intersection corner. Of the 95 cases, 70 reported no designated lanes for vanpool, buses and bicycles and the remaining 25 do have vanpool lanes, which were mainly in Vancouver.

Table 8 Dummy Variable Descriptives

Coding	RLC	SPD	RLFT	PSC	GS	VL
0=No	18	70 (50km/h)	80	77	59	70
1=Yes	77	25 (60km/h)	15	18	36	25
Total	95	95	95	95	95	95

(RLC= Red Light Camera, SPD= Posted Speed, RLFT= Restricted Left-turn, PSC= Phasing/Signal Change, GS= Gas Station, VL= Vanpool Lane)

3.2.1 Independent Variable Descriptives of Surrey Intersections

The average traffic volume for Surrey is 53,721, and with an average of 8 through lanes. Surrey has an average of 4 left-turns lanes and 4 permissive left-turns (PLT) per intersection. Of the 35 cases in Surrey, 30 reported having 4 PLT and 5 reported having as little as 2 PLT. Twenty of the 35 cases have right-turn lanes and 21 cases reported gas stations at the intersection corners.

The average annual daily proportion of casualties per 10,000 traffic volume for each intersection in Surrey is estimated in the last column of Table 5.[20] The intersection of 88th Avenue and King George Highway has the highest average annual daily proportion of casualties with respect to 10,000 traffic volume (TV), which is estimated at .112 percent per 10,000 TV. This proportion is much higher in comparison to other intersections in Surrey, making 88th Avenue and King George Highway the most dangerous intersection in Surrey.

3.2.2 Independent Variable Descriptives of Richmond Intersections

Of the 25 cases in Richmond, 10 intersections had 2 permissive left-turns (PLT) and 5 had 1 PLT, with 10 reporting none. All of the 25 intersections reported no left-turn restrictions and vanpool lanes. The average annual daily proportion of casualties for each intersection, per 10,000 traffic volume (TV) is estimated in the last column in Table 6. The intersection of Steveston Highway and No. 4 Road reported the lowest average annual daily proportion of casualties, which is estimated at .028 percent per 10,000 traffic volume.

[20] The average annual daily proportion of casualties per 10,000 traffic volume is estimated by dividing average casualties per year with average annual daily TV for each intersection.

3.2.3 Independent Variable Descriptives of Vancouver Intersections

The intersection at Burrard Street and Pacific Street has the highest percentage of average annual daily proportion of casualties which is estimated at .102 percent per 10,000 traffic volume (TV). This proportion is much higher in comparison to other intersections in Vancouver, making this intersection the second most dangerous intersection in the sample.

Of the 35 cases in Vancouver, 10 reported no left-turn lanes (LFT), 15 reported as little as 1 LFT and the remaining 10 reported 4 or more LFT. While the 20 intersections reported having 20 left-turn signals, no cases of permissive left-turns are reported from the 20 intersection with left-turns. Fifteen intersections reported having restrictions on left-turning volume, and 20 reported having vanpool lanes, with an average of 9 through lanes per intersection.

This section provides the reader with an understanding of the data sample. It covers what an average intersection in the sample look like. The average intersection in the sample had 33 casualties, 8 through lanes, 3 left-turn lanes, 2 permissive left-turns, and 1 right-turn lane. It also described characteristics of Surrey, Richmond and Vancouver intersections such as the most dangerous intersection in the sample for each municipality. For Surrey the most dangerous intersection is at 88th and King George Highway, Westminster Highway and No. 4 road for Richmond and Burrard Street and Pacific Street in Vancouver. Below are some key findings from this section:

3.3 Key Findings

- The most dangerous intersection in the sample is 88th Avenue and King George Highway in Surrey, with second most dangerous located in Vancouver.
- Richmond has the lowest percent of average annual daily proportion of casualties per 10,000 traffic volume (TV) and Surrey has the highest in the sample with .112 percent per 10,000 TV.
- More of the Surrey intersections reported having permissive left-turn signals, in comparison to Richmond and Vancouver.
- Restricted left-turns and vanpool lanes are mainly found in Vancouver.
- Although Surrey only comprised of 16 percent of the total number of registered vehicles in the GVRD (Table 2 in Section 2), it comprises of the highest percentage of the total number of casualties in the data sample, with 56 percent.

It is evident from this section that Surrey intersections in sample are high-risk intersections with high number of casualties, with Vancouver trailing behind. The following section will help determine which intersection characteristics attribute to the high number of casualties. This in-turn can aid city officials, planners, and engineers in improving conditions at these high-risk intersections.

4 Regression Analysis

This section discusses the process of obtaining the results of estimations by Ordinary Least Squares (OLS) of the factors that affect the number of casualty counts (as a measure of intersection safety). The section explores which variables affect intersection safety and can potentially improve intersection safety in Surrey, Richmond and Vancouver. Findings are used to formulate policy options in the following section.

4.1 Ordinary Least Squares Analysis

A multivariate OLS model is utilized to determine how the independent variables account for the variations in intersection safety. The coefficients in the OLS model illustrate the change in the dependent variable, with one unit increase in the independent variable, holding all other independent variables constant (Studenmund, 2006). The regression analysis is based on the following equation[21]:

$$LCC = c - \beta_1 RLC + \beta_2 LTV + \beta_3 SPD + \beta_4 TL - \beta_6 LFT - \beta_7 PLT + \beta_8 RLFT - \beta_9 RT - \beta_{10} PSC + \beta_{11} GS - \beta_{12} VL + \epsilon.$$ [22]

The dependent variable is the log of the number of casualty counts (LCC) at each intersection. Logging casualty count (LCC) explains the change in the dependent variable in percentage terms if there is an increase of one unit of an independent variable, holding all other independent variables constant (Studenmund, 2006). For example, if there is an increase of one Left-turn lane at an intersection, this will result in a given *x* percent increase or decrease in the number of casualties, holding all other independent variables in the equation constant. As for

[21] The hypothesized relationship between intersection safety (casualty count) and the independent variables is listed in Table 3.

[22] Before performing the regression analysis, correlation coefficients are computed between explanatory variables to identify potential multicollinearity problems. Correlation is high for three variables: left-turning lanes (LTF), left-turning arrows (LFTA) and permissive left-turns (PLT). There is correlation between LFT and LFTA (.698), as shown in Table 13 in Appendix A. There is also a high correlation of .935 between LFTA and PLT. These correlations are of significant concern and can skew the results if not dealt with. PLT accounts for LFTA, as shown in Table 24 in Appendix A. Of the 70 intersections that had LFTA, only 5 intersections with LFTA did not have a PLT. The effect of the PLT on casualty count would be more significant to report; therefore, LFTA is dropped from the analysis. PLT and LFT remain in the equation, as there is no correlation of significant concern between the two variables.

traffic volume, log of traffic volume (LTV) was also taken. As LTV increases or decreases by one percent, this will result in a percentage increase or decrease in casualties.

There are a total of 11 independent variables in the equation (See footnote 22 explaining why variable left-turning arrow was dropped from the equation). Red light cameras (RLC), phasing/signal change (PSC) and vanpool lanes (VL) are coded as dummy variables and are hypothesized to have a negative effect on log of casualty count (LCC). Log of traffic (LTV) is expected to have a positive relationship with casualties. Posted speed (SPD), restricted left-turns (RLFT) and gas station (GS) variables are also coded as dummies and are expected to have a positive relationship with LCC. The number of through lanes (TL) is expected to have a positive relationship with LCC. The number of left-turn lanes (LFT), permissive left-turns (PLT), and right-turn lanes (RT) are expected to have a negative effect on LCC.

The results of the estimations are presented in Table 9. In Model 1, the 11 variables are used and all but 5 variables are statistically significant. LTV, PLT and RT are significant at one percent; whereas, RLFT and LFT are significant at the five percent level. The other variables tested RLC, SPD, VL, GS, PSC and TL are not shown to be significant. The Adjusted R^2 for this model is .771. Although the predictive strength of this model is very high as the independent variables significantly account for 77 percent of the variations in the dependent variable. Five of the 11 variables had the opposite hypothesized sign (SPD, TL, PLT, RT and PSC), which could be due to multicollinearity present in the model (Table 13 in Appendix A). The Tolerance score for LFT is below .20, which is an indication of a serious collinearity problem (Field, 2000). In order to resolve the multicollinearity issue, LFT was removed from the equation because PLT accounts for LFT (Table 25 in Appendix A).

Table 9 OLS Regression Models with Log of Casualty Count

Models→ Variables↓	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Final Model**
Constant	-3.793 (-3.636)	-1.990 (-2.953)	-2.032 (-3.524)	-2.150 (-4.020)	-2.260 (-4.287)
LTV	1.112 (4.423)**	.674 (4.200)**	.687 (5.528)**	.710 (6.125)**	.727 (6.345)**
PLT	.091 (9.047)**	.084 (8.583)**	.084 (8.735)**	.085 (9.263)**	.087 (9.518)**
RLFT	.127 (2.095)*	.201 (3.845)**	.203 (4.398)**	.192 (4.613)**	.192 (4.601)**
RT	.090 (6.627)**	.088 (6.349)**	.087 (7.089)**	.085 (7.271)**	.085 (7.287)**
RLC	-.037 (-1.039)	-.044 (-1.197)	-.044 (-1.206)	-.043 (-1.196)	
PSC	.022 (.572)	.029 (.753)	.030 (.793)	.031 (.822)	
SPD	-.059 (-1.282)	-.023 (-.515)	-.020 (-.523)		
GS	.064 (1.573)	.016 (.460)	.016 (.463)		
TL	-.008 (-.433)	.003 (.139)			
VP	-.055 (-1.246)	-.001 (-.035)			
LFT	-.052 (-2.228)*				
N	95	95	95	95	95
Adjusted R^2	**.771**	**.761**	**.766**	**.771**	**.771**

Significant at *5%, **1%. For the Final Model: the Lagrange-multiplier (LM) test value is less than 19.68 which demonstrates no evidence of heteroskedasticity in the model. Also, tolerance scores are above 0.2 and VIF scores above 1 and below 10, indicating no multicollinearity among the variables in the Final Model.

In Model 2, without the left-turn lane (LFT) variable, the multicollinearity issue appears to be resolved as all the Tolerance and VIF scores are normal.[23] Log of traffic volume (LTV), restricted left-turns (RLFT), permissive left-turns (PLT) and right turn lanes (RT) are all significant at the one percent level. The other remaining variables were insignificant in this

[23] All VIF scores are above 1 and below 10. Tolerance scores are all above .20, which indicates no signs of mulitcollinearity in the model (Field, 2000).

model. Posted speed (SPD), permissive left-turns (PLT), right-turn lanes (RT) and phasing/signal change (PSC) still have the opposite expected sign. The through lane (TL) variable had the opposite expected sign in Model 1; however, in this model the sign is found to be consistent with theory. The predictive strength of this model is slightly lower than Model 1. The Adjusted R^2 for this model is .761; the independent variables significantly account for 76 percent of the variations in the dependent variable. The following model is estimated to try to improve the prediction strength.

In Model 3, vanpool lanes (VL) and the through lanes (TL) variable are eliminated as the significance of these coefficients are very low. The *p* values of these two variables are high, indicating their non-significance in Model 2. The variable coefficients indicate to what degree each variable affects the outcome, if the effects of all other variables are held constant (Field, 2000). If a VL is present, this would increase casualties by .001 percent and if the number of TL increases by one, this would increase casualties by .003 percent. In the case of VL and TL, these two variables do not affect the number of casualties significantly if all other variables are held constant. When VL and TL are not included in Model 3, the level of significance of the other variables remains the same as in Model 2. However, the predictive strength of this model increases to .766. All the independent variables account for 76.6 percent of the variation in the dependent variable. Model 3 also improves the coefficient values of log of traffic volume (LTV), restricted left-turns (RLFT), and phasing/signal changes (PSC) in comparison to Model 2.

A total of six independent variables are input for Model 4. The gas station (GS) and posted speed (SPD) variable are eliminated from Model 4, as the *p* values of these variables indicate their non-significance in Model 3. The coefficients of these variables are also significantly low. GS and SPD do not affect the number of casualties significantly if all other variables are held constant. Log of traffic volume (LTV), restricted left-turns (RLFT), permissive left-turns (PLT) and right-turn lanes (RT) are still significant at one percent. Red light cameras (RLC) and phasing/signal change (PSC) are also not significant in Model 4. The predictive strength of Model 4 increases to .771 in comparison to .766 in Model 3. In this model, the independent variables account for 77.1 percent of the variations in the dependent variable. The coefficient values of LTV and PLT increase in Model 4; hence, so do the effects of each variable on the number of casualties holding all other variables constant.

4.2 Final Model

A total of four independent variables are included in the Final Model: log of traffic volume (LTV), permissive left-turns (PLT), restricted left-turns (RLFT) and right turn lanes (RT). Red light cameras and phasing/signal change variables are eliminated from the Final Model, as they were not shown to have a statistically significant impact on the dependent variable. This is also evident as the variables are insignificant. LTV, RLFT, PLT and RT are significant at one percent. The predictive strength of this model remains constant at .771. However, the coefficient value of traffic volume increases to .727, which translates to a .73 percent increase in casualties if LTV increases by one percent in comparison to .71 percent in Model 4. The coefficient value for permissive left-turns also increases to .087 from .085 in Model 4. This Final model demonstrates no evidence of heteroskedasticity and multicollinearity among the variables (Field, 2000).[24]

4.3 Analysis

Table 9 shows the influence of four independent variables (i.e., LTV, RLFT, PLT and RT) on the number of casualties that occur at intersections. The significance of traffic volume is consistent with theory (Khattak, 2006; Kumara and Chin, 2002). A one percent increase in traffic volume increases intersection casualties by .73 percent, holding all other variables constant. For example, a one percent decrease in traffic volume at King George Highway and 88th Avenue would have resulted in one less casualty in 2004.[25]

Presence of a restricted left-turn (RLFT) at an intersection increases casualties by nearly .2 percent, holding all other variables constant. Using the same example as above, one less right-turn lane present at the King George and 88th Avenue would decrease .2 casualties at the intersection – or one less casualty every five years. The variable also has the positive predicted sign. As for RLFT, Coffin (2007a) suggests that the relationship between casualty count and RLFT is not as evident and is difficult to explain. Casualty rates may be related to RLFT when drivers choose to violate restrictions placed on left-turning volume. Vehicles attempting to make left-turns at intersections with left-turn restrictions cause other vehicles to slow down and brake

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[24] The four significant variables in the Final Model are used with log of property damage (LPD) (as the dependent variable) in order to test the solidity of the results obtained in the Final Model. All explanatory variables are also statistically significant at the one percent level and have the hypothesized signs. There is no indication of multicollinearity and the predictive strength of the LPD model is .721, which suggests that the independent variables account for 72.1 percent of the variation in the dependent variable. The results for LPD can be found in Appendix B.

[25] Casualty count of 100 from 2004 for King George Highway and 88th Avenue are used to determine the decrease in the number of casualties.

in order to miss the vehicle making the left-turn. The final result of this illegal action is a rear-end collision when the vehicle approaching the intersection cannot stop in time, which may result in a collision (Coffin, 2007a).

However, right-turning lanes (RT) and permissive left-turn lanes (PLT) had the opposite hypothesized relationship on the dependent variable. While these variables were predicted to have a negative relationship with the dependent variable, it appears that more RT and more PLT result in an *increase* in the number of casualties at an intersection, which is contrary to research (Davis and Aul, 2007; Harwood, 1996). From the Final Model, addition of one PLT results in a .087 percent increase in the number of casualties. With the same Surrey example, one less PLT will result in about one less casualty every ten years year at King George Highway and 88th Avenue. PLT puts left-turning vehicles at a greater risk of collision in comparison to protected phasing as drivers have to assess the gap between oncoming traffic to make the turn (Cooper, 2007 and Coffin 2007).

Right-turning lanes (RT) have the lowest elasticity with intersection casualties, where one additional right-turning lane at an intersection increases the number of casualties by .085 percent, which translates to approximately one less casualty every ten years at King George Highway and 88th Avenue if there is one less RT. The findings of this study are found to be consistent with some previous research on RT which also found an increase in the number of collisions at intersections with RT (Vogt and Bared, 1998; and Bauer and Harwood, 1996). RT are used by city engineers and planners as a means to get the right-turning traffic flow moving; however, engineers failed to take into account vehicles that may potentially make right-turns during red phasing into lanes with vehicles approaching at high speeds (Baker, 2007). This can cause collisions between vehicles turning right on red into a lane which has vehicles approaching at higher speeds.

Seven independent variables were found to be insignificant even when projected to be significant in previous research: red light cameras, posted speeds, through lanes, left-turn lanes, phase/signal changes, gas stations and vanpool/bicycle lanes. This could be due to mulitcollinearity in the data sample. Policy recommendations will be based on variables found to be statistically significant in this study.

Policy, which can be found in the following section, will be driven to address the negative effect of traffic volume, restricted left-turns, permissive left-turn arrows and right turn lanes on intersection safety. The following section outlines the five policy alternative proposed and defines the three criteria that will be used to evaluate each alternative as the final step of this study.

5 Policy Alternatives and Criteria

Section four discusses the statistical analysis undertaken to determine which variables are significant in predicting intersection safety. The policy alternatives proposed in this section are based on the regression findings. The aim is to propose alternatives that counter the adverse effects of the four significant independent variables on intersection safety. The five policy alternatives and the three criteria used to evaluate the policy are defined in this section, with analysis offered in Section six.

5.1 Policy Alternatives

Based on regression analysis, five possible policy alternatives are presented in this section including: maintaining status quo, reducing traffic volume through traffic calming, eliminating the use of restricted left-turns, using protected left-turns over permissive left turns, and prohibiting right-turns on red. Each policy alternative is described below.

5.1.1 Alternative 1: Status Quo

Status quo refers to the efforts currently employed at these 19 intersections to reduce casualties. Currently, aside from minor street repairs, the red light cameras are the only other visible efforts employed at these sites to combat the large number of casualties. Note that the average intersection in the sample has 33 casualties, 8 through lanes, 3 left-turn lanes with 2 being permissive left-turns and 1 right-turn lane.

5.1.2 Alternative 2: Reduce Traffic Volume

Traffic volume is a significant predictor of intersection safety. Speed and traffic volume are found to be correlated (Ewing, no date). Speed limits can be lowered to reduce the amount of traffic volume at intersections through various traffic calming measures such as speed bumps, reducing posted speed limits (Ewing, no date). Although traffic calming is designed to lower speeds and not traffic volume, it may result in reduced traffic (Cooper, 2007). Other traffic calming alternatives include prohibiting particular vehicles (heavy and commercial trucks);

installing barriers for street closures on certain routes, but this may unnecessarily and dangerously add volume and congestion to the alternative routes.

5.1.3 Alternative 3: Eliminate the Use of Restricted Left-Turns

Restricted left-turns are prohibitions placed on left-turning volume from turning left. From the analysis, it is evident that restricted left-turns lead to an increase in intersection related casualties. Eliminating the use of restricted left-turns at busy signalized intersections could reduce the number of casualties significantly at intersection with restricted left-turns. Note that restricted left-turns are mainly a Vancouver characteristic.

5.1.4 Alternative 4: Use Protected Left-Turns Over Permissive Left-Turns

Permissive left-turns allow vehicles to make the turn during left-turn phasing and without phasing by relying on the driver making the turn to use caution when assessing gaps between oncoming traffic. Although permissive left-turns have proven to be the best method to accommodate left-turning volume (Martin, 1998), it still puts left-turning vehicles at a greater risk of collision compared to protected left-turns (Cooper, 2007). According to Coffin (2007b), protected left-turns are safer as individual drivers do not have to assess the gap between oncoming vehicles and the traffic to make the turn.

When vehicles are allowed to complete turns only during the left-turning phase, friction between oncoming and left-turning traffic is decreased. Drivers are not making left-turns during the green-light phase when oncoming vehicles are clearing the intersection, which significantly reduces the chance of collisions. According to Hauer (2004), changing protected left-turns to permissive left-turns increases accidents by a factor of 1.4, and Upchurch (1991) found that using strictly protected phasing decreases left-turn collisions by 14 percent. Accordingly, this policy option requires using protected left-turns at busy intersections which allows drivers to make the turn only during the left-turning phase, decreasing the chance of collisions. This option proposes the use of protected left-turns over permissive left-turns at high-risk intersections.

5.1.5 Alternative 5: Prohibit Right-Turns on Red

Right-turn lanes are used to allow right-turning vehicles to clear the intersection during green and red phasing. The driver must assess the gap between his/her vehicle and the oncoming traffic to make the turn on red. This can present some danger if vehicles are approaching at high speeds and the driver miscalculates the distance. According to the Institute of Transportation

Engineers (2007), prohibiting drivers from turning right on red is a cost-effective measure that can result in a 20 to 25 percent reduction in the total number of crashes. From the regression analysis, it is also evident that right-turn lanes increase intersection related casualties. This option is proposing to prohibit right-turns during red phasing.

5.2 Criteria for Evaluating Alternatives

The above policy alternatives are assessed using three criteria: cost, casualty reduction and time delay. Each criterion is defined and measured to assess each policy option. The measures are assigned a numerical value on a scale from one to three. These scores are then tabulated to recommend the alternatives in the order of being most effective in improving intersection safety.

5.2.1 Cost

Cost is the direct monetary value spent on implementing the policy option. This criterion determines direct costs associated with each alternative and excludes any indirect costs that may arise. Direct cost is any cost for construction and alterations made to intersections as the policy alternative is implemented. This criterion is not a cost-benefit analysis; it simply estimates the project costs of implementation for each policy alternative. To measure each policy alternative, scores are given from low to high with an attached numeric value. A low cost alternative is given a high score with a numerical value of three. Low cost projects require little to no changes and costs below between $0 to $5,000 dollars per intersection. An alternative that requires phasing or signage changes is ranked medium with a score of two. Projects such as signage improvement and left-turn phasing at urbanized signalized intersections range from $6,000 to $23,000 per intersection (ICBC, 2006).[26] A low score is given to a policy alternative if it costs above $23,000 per intersection and requires infrastructure changes such removal/addition of a lane. A project which costs high is given a high rank, as per the cost scale.

5.2.2 Casualty Reduction

Casualty reduction is purely based on the percentage reduction in the number of casualties at intersections. The results from the regression findings in the previous section will be used to evaluate each policy option. A policy is ranked low if it reduces casualties between .7 to one percent or more, and is given a score of three. A medium rank score with a value of two is

[26] These costs may vary per project as all intersections are different.

given to the policy that reduces casualties between 0.4 to .6 percent. A policy alternative is given a high rank with a value of one if it only reduces casualties between 0 and .3 percent. Note that the reduction in the number of casualties is contingent on increasing the independent variable by one unit/percent.

5.2.3 Time Delays

This criterion aims to assess whether the policy alternative in question reduces capacity of the intersection. According to Coffin (2007b) engineers and planners are continually faced with the dilemma of balancing intersection safety with intersection capacity. Intersection capacity refers to the functionality of an intersection with respect to traffic impact studies, future roadway design and signal congestion management (Husch and Albeck, 2003). Intersection Capacity Utilization (ICU) method is used to assess intersection capacity; however, due to the complexity of measuring and calculating ICU, this study will instead look at time delays for traffic flow as a way of measuring intersection capacity. Expert opinion (elite interviews) will determine whether implementation of the policy alternative increases time delays for traffic flow.

A low rank is given a score of three if the policy alternative minimizes travel time or creates the least amount of increase in travel time for all directions of traffic flow. This means that the alternative does not create travel delays for any direction of traffic flow. A medium score with a value of two is assigned to an alternative that increases travel time for one direction of traffic flow but also decreases travel time for another. For example, allowing more vehicles to make left-turns on left-turning arrows helps clear left-turning volume, but may increase time delays for ongoing traffic in through lanes because vehicles that did not clear the intersection during the left-turning phase may block through going vehicles. If an alternative increases time delays for two or more directions of traffic, it is given a high rank with a value of one. For this criterion, interviews with City of Surrey traffic planners and engineers and Insurance Corporation of British Columbia (ICBC) experts will be used to determine whether the policy increases/decreases travel time.

This section clearly outlines each policy alternative and the three criteria. The following table is a summation of the three criteria and the grading scale. The following section evaluates each policy alternative and sums the results from the policy analysis.

Table 10 Summation of Listed Criteria

Criteria	Description	Evaluation Approach	Source	Measurement
Cost	Monetary costs of implementing the policy	Estimated $ costs	ICBC Road Improvement Study	L (3)= $5,000 or below M (2)= Between $6,000 to $23,000 H (1)= Above $23,000
Casualty Reduction	Reduction in casualties as a result of implementing the policy	% reduction in casualties	Regression analysis results & research studies	L (3)= if casualties are ↓ between .7 and 1 or more M (2)= ↓ casualties only between .4 to .6 H (1)= ↓ casualties between 0 to .3
Time Delay	Estimates time delays as a result of implementing the policy	↑ or ↓ in time delay	Elite Interviews	L (3)= does not ↑ time delay for any directions of flow M (2)= ↑ time delay for one direction of traffic flow and ↓ time delay for another H (1)= ↑ time delay for 2 or more directions of traffic flow

6 Policy Evaluation

This section analyzes the policy alternatives based on the scores and concludes with an evaluation summary and final recommendations that are proposed based on the scoring results. Section seven covers study limitations and some key issues. Below is the policy analysis for each alternative.

6.1 Evaluation: Status Quo

The cost for this alternative is projected to be significantly low as costs are in reference to any new additions being made to the intersections. Under status quo, there are no new additions that would require any alterations to the intersections. Status quo ranks very low on the cost scale with a score of three.[27] With respect to casualty reduction, the percent reduction between the year 2003 and the year 2004 in the data sample is used to score this policy alternative. It is determined that there has been an overall casualty increase of four percent between the years 2003 and 2004. Status quo is contributing nothing to reducing the casualty count; therefore, a high rank is given with a score of one. Since no new changes are being introduced that could result in a time delay to any flow of traffic or reduce intersection capacity, status quo ranks low with a score of three as per the time delay criterion.

6.2 Evaluation: Reduce Traffic Volume Through Traffic Calming

It is projected that it may cost anywhere between $5,000 per intersection to install speed bumps and barriers for traffic calming techniques.[28] Street closures may require barriers to be installed, which would entail some infrastructure and signage changes, which drives up the costs for implementing this policy. For signage and signal changes it can cost up to $23,000 per intersection (ICBC, 2006). Another way to look at the costs is if this policy alternative were to be implemented at the 120 high-risk intersections across British Columbia (BC) it would amount to

[27] Cost for street repairs, which may or may not be needed, are not included in the estimates.
[28] Costs are estimates only and were taken from the 2006 Road Improvement Program evaluation report (ICBC. 2006). Costs to improve shoulder, V-alignment, barrier and drainage were estimated to be as low as $5,000.

2.76 million dollars, which is significantly high. After calculating the costs, it is estimated that this alternative ranks high on the cost scale, with a score of one.

Traffic volume is the most significant predictor of casualty count as evident by the findings of the regression analysis. A one percent reduction in traffic volume can decrease casualties by .73 percent. Therefore, a score of three is given with a low rank among all the policy alternatives. To give an example, if there is a one percent decrease in traffic volume it can decrease .24 casualties at the average intersection from the dataset, which has an average casualty count of 33. The findings are also consistent with the study conducted by Khattak (2006), who found that the frequency of accidents increased as traffic volume increased above a 10,000 average daily traffic count.

Traffic calming techniques are designed to lower speeds, not volume – but can result in volume reduction (Cooper, 2007). However, traffic calming techniques such as lowering speed limits on main artery roads can create longer rush hours and lead to driver frustration (Canada Safety Council, 2006). More importantly, this can also have an impact on public services such as emergency services, snow clearing, and public transit (Canada Safety Council, 2006). All flows of traffic would be delayed as a result of traffic calming to reduce traffic volume which in turn reduces intersection capacity. This option ranks very poor with a high rank with a score of one on the time delay criterion. Furthermore, drivers may migrate to nearby alternative routes to avoid changes in speed limits – resulting in increased numbers of collisions at these nearby intersections (ICBC, 2005b).

6.3 Evaluation: Eliminating the Use of Restricted Left-Turns

In terms of cost, this option scores high with a score of one. Although there are low costs for signage removal for left-turn restrictions; there maybe costs involved with new signage and traffic signals to inform drivers of the changes, which can increase the overall costs. Such costs can run up to $23,000 per intersection (ICBC. 2006).

This alternative ranks high on the casualty reduction criterion with a score of one as it would only reduce casualties by .20 percent if there is a restriction placed on left-turns. Using the average casualty count of 33 as an example, removing the left-turn restriction can decrease .07 casualty at an intersection. Restricting left-turns is the second highest predictor of intersection safety, behind traffic volume.

Restricting left-turns enables Vancouver engineers and planners to clear the traffic in downtown as quickly as possible during rush hours (Coffin, 2007a). Restrictions on left-turns are found to increase casualties in this study, which suggests that drivers violate the restriction and make the turn anyway. Coffin (2007b) agrees that when drivers become frustrated it encourages them to break the law. By allowing driver to make the left-turn, this option accommodates left-turning volume and through going vehicles. However, left-turning vehicles waiting to turn may spill onto through lanes and block through-going vehicles in which case this policy alternative would get a medium rank with a score of two for the time delay criterion.

6.4 Evaluation: Using Protected Left-Turns Over Permissive Left-Turns

This alternative ranks high on the cost scale with a score of one as it may cost above $23,000 per intersection to implement the protected left-turn phasing change (ICBC, 2006). This option does not require any infrastructure changes to the intersection; however, it may require new signage and signal changes to warn drivers of the new changes, which drive up the costs.

Cooper (2007) states that protected left-turns should be superior to permissive in terms of crash risk since it separates the flows. Protected left-turns therefore should be implemented over permissive. On the casualty reduction criterion scale, this alternative ranks high with a score of one. Based on the findings of this study, permissive left-turn lowers casualties by .087 percent as there is a decrease of one permissive left-turn lane. For example, one less permissive left-turn can result in .03 less casualty at the average intersection (average casualty count of 33) in the data sample.

There maybe time delays to left-turning and through going volume. Coffin (2007) explains that when there are many gaps available to make the left-turn and the sight distance is good during peak periods, it is frustrating to drivers and reduces the capacity of the intersection. Restricting left-turning volume to make the turn when there are adequate gaps increases time delays for left-turning volume that did not make the turn under the protected left-turn phase. It can also slow down through-going vehicles if the left-turning volume spills into the through lanes. Thus, this alternative receives a score of one with a high rank (as it reduces intersection capacity and creates time delays). Protected left-turns use up time in the signal cycle and creates overall intersection delays to all other movements at the intersection (Coffin, 2007b).

6.5 Evaluation: Prohibiting Right-Turns on Red

This alternative allows engineers and planners to prohibit right-turns on red. Restricting right-turns on red ranks high on the cost scale and is assigned with the corresponding score of one.[29] This alternative requires no infrastructure changes – just signage and signals prohibiting the right-turn on red, which can costs approximately $23,000 per intersection (ICBC, 2006). Again, the costs are significantly high when implemented at intersections across BC.

This option ranks high with a score of one on the casualty reduction scale as it reduces casualties by only .085 percent. This alternative ranks the lowest with respect to reduction in casualties in comparison to other alternatives. Using the average casualty count of 33, one less right turn lane will reduce .03 less casualty. At 389 intersections in Minnesota, right-turns were found to increase accidents by 27 percent (Vogt and Bared, 1998). Bauer and Harwood (1996) also found an increase in the number of collisions and fatalities after studying 14,432 intersections.

Prohibiting right-turns on red will impede on right-turning volume and through going volume. It can cause delays to right-turning volume that can make the turn during red. Through-going vehicles must also wait and incur delays while right-turning vehicles wait for their opportunity to make the turn during the green light (Coffin, 2007b). Also, in urban and suburban areas where there is a high level of pedestrian traffic, if a driver has the green light while making the right turn, they must yield to pedestrians to make the turn; hence, only a few vehicles may be able to complete the turn before pedestrians from the perpendicular direction begin to cross the intersection (Coffin (2007b). This significantly reduces intersection capacity and causes time delays for right-turning volume and through going vehicles. Therefore, this alternative is given a score of one with a high rank.

6.6 Evaluation Summary: Recommendations

Table 11 summarizes how each policy performed using the three criteria: cost, casualty reduction and time delay. Each alternative can receive a score as high as 12. As evident by Table 11, status quo ranks the highest with an overall score of seven. Reducing traffic volume ranked second with a score of five with eliminating the use of restricted left-turns trailing behind with a score of four. Using protected left-turn phasing over permissive and prohibiting right-turns on red are tie and rank the lowest among all the policy alternatives with a score of three.

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[29] Cost excludes any costs associated with the legislative process.

Table 11 Summation Matrices of Policy Evaluation

Criteria→ Policy Options↓	Cost	Casualty Reduction	Time Delay	Total Score (Out of 12)
Status Quo	L (3)= No new additions/changes (costs below $5,000)	H (1)= 4% ↑ in casualties between 2003 & 2004	L (3)= No time delays to any flow of traffic	**7**
Reduce Traffic Volume Through Traffic Calming	H (1)= Costs can amount up to $23,000	L (3)= .73 % reduction in casualties if traffic volume decreases by 1 %	H (1)= Creates time delay for all flows of traffic	**5**
Eliminate Use of Restricted Left-turn	H (1)= New signage & signal upgrades (costs around $23,000)	H (1)= .20% reduction in casualties	M(2)= Increases time delay for through going vehicles and decreases travel time for left-turning volume	**4**
Use Protected Left-turn Over Permissive	H (1)= New signage & signal upgrades (costs around $23,000)	H (1)= .087% reduction in casualties	H (1)= Creates time delays for all flows of traffic	**3**
Prohibit Right Turn on Red	H (1)= New signage & signal upgrades (costs around $23,000)	H (1)= .085% reduction in casualties	H (1)= Increase time delay for through and right-turning volume	**3**

Status quo ranks low on cost, high on casualty reduction and low on the time delay scale. The current initiatives employed to improve intersection safety and reduce casualties is overall the most effective alternative in reducing casualties at intersections. In comparison to status quo, which has little to no costs, traffic volume is a much more expensive alternative to implement. However, it performed better on the casualty reduction scale, as it reduces casualties by .73 percent in comparison to status quo, where there has been an increase of four percent in the number of intersection related casualties from 2003 to 2004.

Eliminating the use of restricted left-turns scores higher in comparison to protected left-turns and prohibiting right-turn on reds. The three policy alternatives score the same on all the criteria with the exception of time delay. Eliminating use of restricted left-turns scores higher on the time delay scale as it increase time delays for through going vehicles, but decreases time delay for left-turning volume. Use of protected left-turn over permissive performed equivalent to prohibiting right-turn on red across the board.

Status quo is least costly and does not slow down any flow of traffic in comparison to the other alternatives. Overall, status quo appears to be the most effective and viable policy alternative given that there has been an increase in the number of casualties at intersections in British Columbia (BC). The following section covers study limitations and some key implementation issues with each of the policy alternatives and concludes with some overall closing remarks

7 Limitations and Conclusion

The previous section recommended status quo as the most effective policy with respect to intersection safety. This section discusses some study limitations and key issues with some of the policies proposed. Subsequent to that, this section will conclude with closing remarks.

7.1 Limitations

Due to limited data provided by the Insurance Corporation of British Columbia (ICBC), this study is limited to the three municipalities; moreover, specific intersections and time period. ICBC could only provide data for the years 2000 and onwards and for only 20 of the high-risk intersections. If data could have been provided for years prior to 2000, the trend (increase or decrease) for the number intersection related casualties would have been better illustrated.

Also, other independent variables such as visibility of the traffic signals at night, lighting conditions and inclination were omitted from the analysis and would have added to the study.[30] For policy analysis, it would have been interesting to include motorist opinion as a criterion. Motorist opinion poll to determine the acceptance of the policy alternatives would have provided for a more comprehensive policy evaluation, but due to time constraints a poll could not be conducted.

7.2 Key Issues

Although status quo proved to me the most effective policy alternative, it does not completely rule out the other alternatives. There are key implementation issues with policies discussed in the previous section. It is important to discuss these issues as some of them may appear practical to city planners and engineers in their specific jurisdictions. The following is a discussion of implementation issues surrounding traffic volume reduction through traffic calming, eliminating the use of restricted left-turns, protected left-turn over permissive and prohibiting right-turn on red.

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[30] These variables were omitted due to budget constraints and weather conditions as site visits were conducted in the months of December and January.

Besides the fact that traffic volume would create time delays for all flows of traffic, using traffic calming techniques to reduce traffic volume can result in traffic volume to spill over onto surrounding intersections (ICBC, 2005b), resulting in higher casualty rates at those sites. The spill over effect occurs when traffic volume shifts to surrounding intersections when drivers change routes to avoid situations (ICBC, 2005b). Peter Cooper (2007) would not recommend using traffic calming techniques to reduce traffic volume as the volume would just be displaced to surrounding intersections. He goes on to say that changing traffic volume patterns requires a network approach and should be part of a long-term regional traffic plan.

As for restricted left-turns, allowing left-turns at intersections that originally prohibited the turn can prove to be problematic as left-turning vehicles that are waiting to turn may block through-going vehicles. This issue can be easily resolved by implementing left-turn arrows in conjunction with removing the restriction which would allow both left-turning volume and through-going vehicles to clear the intersection. With that said, this may not be applicable to intersections with high left-turning volume. Local agencies need to asses the practicality of this option to applicable intersections.

Although protect left-turns are safer than permissive, choosing protected over permissive left-turn is much more complicated. Permissive left-turns are widely used in Surrey and other municipalities to best accommodate left-turning traffic volume at high volume intersections (Coffin, 2007a; Martin, 1998). Problems with permissive left-turns are not due to the phase itself, but are more related to poor sight distance as a result of relatively high speeds or complexity of the intersection itself in which case protected left-turns should be implemented (Coffin, 2007). Moreover, this requires analysis of each intersection on an individual basis to accurately asses the practicality and desirability of protected and permissive phasing at high-volume intersections.

Last but no least, prohibiting right-turns on red requires drivers to alter their driving behaviour, which is difficult to achieve (Institute of Transportation Engineers, 2007; Coffin, 2007b; Cooper, 2007). Cooper (2007) and Coffin (2007b) believe that prohibiting right-turns on red may be very frustrating and unpopular with the motorists. When drivers become frustrated it encourages them to break the law (Coffin, 2007), which insinuates that drivers would most likely violate the prohibition and make the right-turn anyway.

Huang (2000) conducted an analysis of driver opinions of right-turn prohibitions on red. He found in his analysis of six intersections, in which three had the prohibition on right-turns and the remaining three intersections allowed the right-turn, that only between 2.3 to 4.8 percent of motorists made right-turns where right-turns were illegal in comparison to 30 percent at sites where it was allowed. This indicates that if the prohibition were to exist, motorists would largely abide by the prohibition. This is an area of further study. Analysis of driver opinion on right-turn prohibitions would better determine the desirability and feasibility of this option in British Columbia (BC).

7.3 Conclusion

This study aims to identify which physical characteristics and factors influence the number of intersection related casualties. Nineteen intersections in BC are undertaken in the analysis from Surrey, Richmond, and Vancouver from the period of 2000 to 2004. Findings reveal that traffic volume, restricted left-turns, permissive left-turns and right-turns have a negative affect on intersection safety in comparison to all the other 12 independent variables.

Five policy alternatives are proposed 1) status quo, 2) reduce traffic volume through traffic calming, 3) eliminate the use of restricted left-turns, 4) use protected left-turns over permissive and 5) prohibit right-turns on red. Three criteria are used to evaluate the above noted policies: 1) cost, 2) casualty reduction, and 3) time delays. From the policy evaluation, it is evident that status quo is effectively improving intersection safety. Nevertheless, the other policy alternatives cannot be ruled out all together.

Each municipality should conduct individual intersection analysis to understand the complexity and to determine which policy alternative would serve best to reduce casualties and improve intersection safety. Test sites are strongly recommended and should be undertaken to specifically determine what is effective in reducing the number of casualties at these high-risk intersections. After the implementation of test site projects, pre/post analysis could easily better shed some light on whether the policy is effective, with an eye of considering widespread implementation at intersections in Surrey, Richmond and Vancouver.

Appendices

Appendix A: Tables

Table 12 Target Intersections in Surrey, Richmond, and Vancouver

City	Site	Live Date (Y-M-D)
Vancouver	Burrard Street at West Georgia Street	01-05-11
Vancouver	Southwest Marine Drive at Cambie Street	01-05-11
Vancouver	Oak Street at West 49th Avenue	01-05-11
Vancouver	Granville Street at West 16th Avenue	01-05-11
Vancouver	West 4th Avenue at Alma Street	01-05-11
Vancouver	Howe Street at Smithe Street	01-05-11
Vancouver	Burrard Street at Pacific Street	01-05-11
Surrey	64th Avenue at 152nd Street	00-11-24
Surrey	152nd Street at 88th Avenue	00-11-24
Surrey	88th Avenue at King George Highway	01-02-13
Surrey	72nd Avenue at 128th Street	00-11-24
Surrey	96th Avenue at 128th Street	01-01-23
Surrey	72nd Avenue at Scott Road	01-01-23
Surrey	King George Highway at 96th Avenue	01-01-23
Richmond	Westminster Highway at No. 4 Road	99-07-15
Richmond	Steveston Highway at No. 4 Road	00-07-14
Richmond	Cambie Road at No. 4 Road	00-11-03
Richmond	Alderbridge Way at No. 4 Road	00-11-24
Richmond	No. 3 Road at Francis Road	00-11-03

Source: List was obtained from the Camera Unit Division within the RCMP.

Table 13 Correlations Coefficients Matrix

	CC	PD	RLC	TV	SPD	TL	LFT	LFTA	PLT	RLFT	RT	PSC	GS	VL
CC	1													
PD	.810**	1												
RLC	-.081	-.021	1											
TV	.528**	.673**	-.032	1										
SPD	.092	.182	-.052	.047	1									
TL	.179	.399**	.007	.531**	.307**	1								
LFT	.352**	.327**	.018	.579**	-.354**	-.057	1							
LFTA	.567**	.390**	-.003	.368**	-.180	.040	.698**	1	.					
PLT	.479**	.241*	.001	.157	-.244*	-.054	.540**	.935**	1					
RLFT	.077	.286**	-.012	.088	.224*	.449**	-.521**	-.381**	-.326**	1				
RT	.696**	.627**	-.022	.333**	.224*	-.016	.192	.215*	.074	.095	1			
PSC	.228*	.221*	.097	.182	-.080	.147	.179	.224*	.220*	-.062	.064	1		
GS	.204*	.276**	-.010	.330**	.137	.078	.536**	.465**	.305**	-.338**	.104	.121	1	
VL	.086	.151	-.016	.209*	.309**	.357**	-.335**	-.126	-.192	.397**	.163	-.045	.026	1

N= 95, **Significant at** *<.05, **<.01 (CC= Casualty count, PD=Property Damage, RLC= Red Light Cameras, TV= Traffic Volume, SPD= Posted Speed, TL= Through Lanes, LFT= Left-Turn Lanes, LFTA= Left-Turn Arrows, PLT= Permissive Left-Turns, RLFT= Restricted Left-Turns, RT= Right-Turn Lanes, PSC= Phasing/Signal Changes, GS= Gas Stations, VL= Vanpool/Bicycle Lanes).

Table 14 Extrapolated Traffic Volume Counts for Surrey

Site	2000	2001	2002*	2003	2004	2005	2006
King George and 96th Ave.	63150	63650	64150	64650	65150	65650	66150
64^{th} Ave. and 152nd St.	39825	40962.5	42100	43237.5	44375	45512.5	46650
152nd St. and 88th Ave.	51650	52400	53150	53900	54650	55400	56150
88^{th} Ave. and King George	71725	72237.5	72750	73262.5	73775	74287.5	74800
72nd Ave. and 128th St.	41775	42187.5	42600	43012.5	43425	43837.5	44250
96^{th} Ave. and 128th St.	52650	48150	43650	39150	34650	30150	25650
72nd Ave. and Scott Rd.	57648	57649	57650	57651	57652	57653	58150

The City of Surrey Engineering Department provided traffic volume (TV) counts for the years 2002 and 2006 for the seven intersections in its jurisdiction. Traffic counts for Surrey list two counts for East and West bound traffic and two counts for North and South bound traffic. The average of the two counts was tabulated so that a single count was obtained for East and West and North and South bound traffic. The numbers were then added to get a count for all directions of traffic flow. This method is used to get traffic flow data for each intersection for both 2002 and 2006. Extrapolations were conducted to forecast TV counts for the years 2000, 2001, 2003 and 2004 by using the counts from the two years.

Table 15 Extrapolated Traffic Volume Counts for Richmond

Site	2000	2001	2002	2003	2004
Westminster Hwy. at No 4 Rd.	49048	49582	50116	50650	51184
Steveston Hwy at No. 4 Rd.	33897	33978	34059	34140	34221
Cambie Rd. at No. 4 Rd.	31979	31016	30053	29090	28127
Alderbridge Way at No. 4 Rd.	55558	54021	52484	50947	49410
No. 3 Rd. at Francis Rd.	29445	29572	29699	29826	29953

Engineering Services at the City of Richmond provided traffic volume counts for 2002 and 2003 for the intersections in their jurisdiction. A linear trend extrapolation estimated the counts for the year 2000, 2001 and 2004.

Table 16 Extrapolated Traffic Volume Counts for Vancouver

Site	2000	2001	2002	2003	2004	2005	2006
Burrard St. at W. Georgia St.	71549	68072	64595	61118	57640	54163	50686
SW Marine Dr. at Cambie St.	94127	94059	93991	93923	93855	93787	
Oak St. at W. 49th Ave.	73313	72492	71671	70850	70029	69208	
Granville St. at W.16th Ave.	47776	47397	47018	46638	46259		
W. 4th Ave. at Alma St.	35735	36376	37017	37657	38298		
Howe St. at Smithe St.	33367	32788	32209	31630	31051		
Burrard St. at Pacific St.	53913	52828	51743	50658	49573		

Traffic volume (TV) counts for the City of Vancouver were the most difficult to determine as counts for all the intersections were not all available. For example, the city could only provide counts for Granville Street (North and South bound) at West 14th Avenue, and West 16th Avenue (East and Westbound) at Heather Street for the Granville Street and West 16th Avenue site undertaken in this study (counts provided were from different years). In this example, the counts for Granville at West 14th Avenue were provided for 1998 and 2003 and counts for West 16th Avenue at Heather Street were provided for 2000 and 2004. Continuing with the example, Granville (South and North bound) at West 14th Avenue traffic flow data for the years 1998 and 2003 were used to predict for the years 2000, 2001, 2002 and 2004. Same applies for the counts for West 16th Avenue (East and Westbound) at Heather Street. These counts were summed with the corresponding years to get a total traffic flow count for all four directions of traffic for any of the two given years. The extrapolated counts for 2000 and 2004 for Granville at West 14th Avenue and West 16th Avenue at Heather were tabulated to obtain a count for the two years. Finally, these counts were then used to predict TV counts for Granville and West 16th for the remaining years. These counts are therefore estimates of traffic flow for each test site.

Table 17 Annual Casualty Counts for Surrey, Richmond, and Vancouver

Site	2000	2001	2002	2003	2004	Total
Burrard St at West Georgia St.	32	22	17	29	32	132
SW Marine Dr. at Cambie St.	52	32	28	30	33	175
Oak St. at W. 49th Ave.	32	26	26	21	23	128
Granville St. at W.16th Ave.	25	31	36	35	38	165
W. 4th Ave. at Alma St.	15	11	17	11	14	68
Howe St. at Smithe St.	13	14	17	12	23	79
Burrard St. at Pacific St.	78	43	37	59	47	264
King George Hwy. at 96th Ave.	60	65	65	55	68	313
64th Ave. at 152nd St.	23	28	15	25	39	130
152nd St. at 88th Ave.	42	39	30	31	45	187
88th Ave. at King George Hwy.	110	97	84	100	100	491
72nd Ave. at 128th St.	42	41	39	30	41	193
96th Ave. at 128th St.	37	41	35	39	22	174
72nd Ave. at Scott Rd.	48	60	68	53	54	283
Westminster Hwy. at No 4 Rd.	19	19	24	22	23	107
Steveston Hwy at No. 4 Rd.	13	6	9	12	8	48
Cambie Rd. at No. 4 Rd.	19	20	15	20	18	92
Alderbridge Way at No. 4 Rd.	17	24	18	32	12	103
No. 3 Rd. at Francis Rd.	11	11	11	5	8	46
Total	**688**	**630**	**591**	**621**	**648**	**3178**

Table 18 Annual Property Damage Counts for Surrey, Richmond and Vancouver

Site	2000	2001	2002	2003	2004	Total
Burrard St at W. Georgia St	56	41	38	45	51	231
SW Marine Dr. at Cambie St.	120	85	87	79	68	439
Oak St. at W. 49th Ave.	33	38	47	42	40	200
Granville St. at W.16th Ave.	87	68	75	58	84	372
W. 4th Ave at Alma St.	13	34	20	29	19	115
Howe St. at Smithe St.	27	30	30	32	29	148
Burrard St. at Pacific St.	88	91	70	92	92	433
King George Hwy. at 96th Ave.	89	92	74	85	70	410
64^{th} Ave. at 152nd St.	25	23	34	26	39	147
152nd St. at 88th Ave.	41	36	40	44	58	219
88^{th} Ave. at King George Hwy	76	110	100	110	120	516
72nd Ave. at 128th St.	39	41	50	59	49	238
96^{th} Ave. at 128th St.	36	41	52	30	43	202
72nd Ave. at Scott Rd	87	93	95	110	96	481
Westminster Hwy at No 4 Rd	23	29	31	31	18	132
Steveston Hwy at No. 4 Rd	9	6	11	13	9	48
Cambie Rd. at No. 4 Rd.	31	17	13	21	20	102
Alderbridge Way at No. 4 Rd.	38	44	28	41	36	187
No. 3 Rd. at Francis Rd.	16	14	10	12	14	66
Total	**934**	**933**	**905**	**959**	**955**	**4686**

Table 19 Number of Through Lanes for All Intersections

No. of Through Lanes	Frequency	Percent
6	14	14.7
7	10	10.5
8	41	43.2
9	15	15.8
10	15	15.8
Total	95	100.0

Table 20 Number of Left-Turns for All Intersections

No. of Left-Turns	Frequency	Percent
0	15	15.8
1	15	15.8
2	10	10.5
4	50	52.6
6	5	5.3
Total	95	100.0

Table 21 Number of Left-Turn Arrows for All Intersections

No. of Left-Turn Arrows	Frequency	Percent
0	25	26.3
1	15	15.8
2	15	15.8
4	40	42.1
Total	95	100.0

Table 22 Number of Permissive Left-Turns for All Intersections

No. of Permissive Left-Turns	Frequency	Percent
0	30	31.6
1	15	15.8
2	15	15.8
4	35	36.8
Total	95	100.0

Table 23 Number of Right-Turns for All Intersections

No. of Right-Turns	Frequency	Percent
0	45	47.4
1	20	21.1
2	20	21.1
4	10	10.5
Total	95	100.0

Table 24 Cross tabulation of Left-Turning Arrows and Permissive Left-Turns

		Permissive Left-Turns				
		0	1	2	4	Total
Left-Turn Arrows	0	25	0	0	0	25
	1	0	15	0	0	15
	2	5	0	10	0	15
	4	0	0	5	35	40
Total		30	15	15	35	95

Table 25 Cross tabulation of Left-Turning Lanes and Permissive Left-Turns

		Permissive Left-Turns				
		0	**1**	**2**	**4**	**Total**
Left-Turn Lanes	**0**	10	0	5	0	15
	1	5	10	0	0	15
	2	10	0	0	0	10
	4	0	5	10	35	50
	6	5	0	0	0	5
Total		30	15	15	35	95

Appendix B: Property Damage

Property Damage: Another Dependent Variable

Property damage (PD) counts are based on the number of crash incidents that resulted in damage to vehicles. The PD counts do not differentiate based on the amount of damage to the vehicle. ICBC counts PD as one count regardless of the number of individuals and vehicles involved, as long as there are no injuries and fatalities sustained. For example, an incident involving three vehicles and three individuals who sustained no injuries would count as one PD count. Property damage data is obtained from ICBC for the selected 19 intersections in this study from the period of January 1st, 2000 to December 31st, 2004.

Property damage (PD) counts are another dependent variable that is found to be strongly correlated with casualty counts (.810) (Table 13 in Appendix A). Studenmund (2006) explains that when there is correlation between two variables, they essentially are explaining the same thing. Since casualty count is more significant to report, it was used as the main dependent variable. The independent variables found to be significant in the regression analysis of log of casualty count (Table 9) are inputted into a model with PD as the dependent variable to solidify the findings of this study.

The average property damage (PD) count for the sample is 49, with 6 being the lowest property damage count and 120 being the highest. There are a total of 4,686 PD counts for the 19 intersections between the years 2000 and 2004 (Table18 in Appendix A). Surrey leads the count with 2,213, which equates to 47 percent of total PD counts. Vancouver followed behind, comprising 41 percent and Richmond thereafter with merely 11 percent.

Property damage (PD) counts remained consistent between the year 2000 (with a PD count of 934) and 2001 (with a PD count of 933).The lowest PD count is in the year 2002, with 905 counts, which increases to 6 percent in the following year with 959 counts (Table 18 in Appendix A). The PD counts remained constant between 2003 and 2004.

The average property damage (PD) counts for Surrey is 63, with 23 being the lowest and 120 being the highest PD count in Surrey. The intersection at 88th Avenue and King George Highway has the highest total PD count in the sample with 516 from 2000 to 2004. Richmond has an average PD count of 21, with 6 being the lowest and 44 being the highest. The intersection at Alderbridge way and No. 4 road has the highest PD count in Richmond for the period of 2000 and 2004 with a total count of 187. The average PD count in Vancouver is 55, with 120 being the highest and 13 being the lowest. The intersection at SW Marine Drive and Cambie has the highest total PD count in Vancouver with 439 from 2000 to 2004.

The final four variables: traffic volume (TV), restricted left-turns (RLFT), permissive left-turns (PLT), and right-turn lanes (RT) are inputted into the following equation to determine the effect on PD counts:

$$LPD= c - \beta_1 LTV + \beta_2 RLFT + \beta_3 PLT + \beta_4 RT + \epsilon.$$

The dependent variable is the log of the property damage counts (LPD). Logging property damage (LPD) explains the change in the dependent variable in percentage terms if there is an increase of one unit of an independent variable, holding all other independent variables constant (Studenmund, 2006). Log of traffic volume (LTV), restricted left-turns (RLFT), permissive left-turns (PLT), and right-turn lanes (RT) are projected to have a positive relationship with LPD. Positive relationship indicates an increase in the dependent as the independent variable increases.

As evident by Table 26, the four variables have the projected relationship and are also found significant at the one percent level. The predictive strength of this model is .721, which means that the independent variables significantly account for 72 percent of the variations in the dependent variable, in this case log of property damage (LPD). The results are consistent with the log of casualty model (Table 9) and affirm the findings of this study.

Table 26 OLS Regression Models with Log of Property Damage

Variables↓	**Model**
Constant	-3.856 (-6.248)
LTV	1.119 (8.341)**
PLT	.050 (4.716)**
RLFT	.253 (5.181)**
RT	.072 (5.259)**
N	95
Adjusted R^2	**.721**

Significant at **1%. Tolerance scores are above 0.2 and VIF scores above 1 and below 10, indicating no multicollinearity among these variables.

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