MONASH University
Accident Research Centre

EVALUATION OF THE CRASH EFFECTS OF VICTORIA'S FIXED DIGITAL SPEED AND RED-LIGHT CAMERAS

by

Laurie Budd
Jim Scully
Stuart Newstead

May, 2011

Report No. 307

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE
REPORT DOCUMENTATION PAGE

Report No.	Date	ISBN	ISSN	Pages
307	May 2011	0 7326 2377 4	1835-4815 (online)	21 + Appendices

Title and sub-title: Evaluation of the Crash Effects of Victoria's Fixed Digital Speed and Red-Light Cameras

Author(s): Budd, L., Scully, J. & Newstead, S.

Sponsoring Organisation(s):
This project was funded through the Centre's Baseline Research Program for which grants have been received from:

Department of Justice
Roads Corporation (VicRoads)
Transport Accident Commission

Abstract:

The aim of this study was to evaluate the crash effects of 87 signed fixed digital speed and red light (FDSRL) cameras and accompanying warning signs placed at 77 signalised intersections across Victoria. Fixed Speed cameras have been shown to be generally effective at decreasing crash rates whilst the effectiveness of Red Light Cameras (RLCs) to reduce crashes has been studied on many occasions with mixed results. The use of combination speed and red light fixed camera enforcement is relatively uncommon and has not been previously evaluated. Data were analysed using a before-after quasi-experimental design incorporating controls and Poisson regression to calculate the adjusted percentage reduction in the number of casualty crashes at treated sites in the post-treatment period when compared with the pre-treatment period.

Analysis results estimated large decreases in casualty crashes associated with the FDSRL cameras and their associated signage. When only the crashes involving vehicles travelling form the approach intersection leg where the camera was placed are considered, the estimated casualty crash reduction was 47% (95% CI:(36, 56), $p<0.0001$). When crashes involving vehicles from all approaches are compared, the estimated casualty crash reduction was 26% (95% CI:(16, 35), $p<0.0001$). A 44% reduction (95% CI:(31, 64), $p<0.0001$) in right angle and right turn against crashes, those particularly targeted by red light enforcement, was also estimated. Whilst use of the FDSRL cameras was associated with a reduction in overall casualty crash risk, there was no evidence for a reduction in relative crash severity meaning the cameras were associated with equal reductions in minor injury crashes as serious injury and fatal crashes.

Across the 77 intersection where the cameras evaluated were installed, it was estimated that 17 serious or fatal crashes per year and 39 minor injury crashes would be prevented representing crash cost savings to the community of over $8M. Based on the outcomes of the evaluation, continued and expanded use of combined fixed red-light and speed cameras in Victoria is expected to improve driver safety, save lives and reduce crash related costs.

Key Words:
Red Light Camera, Speed Camera, Poisson Regression, Quasi experiment, Data Analysis, Statistics, Melbourne Victoria

Monash University Accident Research Centre,
Building 70, Clayton Campus, Victoria, 3800, Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

www.monash.edu.au/muarc

Preface

Project Manager / Team Leader:

- Dr Stuart Newstead

Research Team:

- Jim Scully
- Laurie Budd

Contributorship Statement

Laurie Budd – Data preparation and analysis, preparation of report manuscript
James Scully – Oversight of data analysis and manuscript review
Stuart Newstead – Project management, study concept and design and manuscript review

Ethics Statement

Ethics approval was not required for this project.

Contents

Figures

Tables

EXECUTIVE SUMMARY

A number of studies internationally have shown fixed speed cameras to be generally effective in reducing the incidence of speeding and crashes within the area local to the fixed camera site. The effectiveness of Red Light Cameras (RLC) to reduce crashes has also been studied on many occasions with mixed results. Combined speed and red light cameras, as have been used in Victoria for a number of years, are a relatively new technology. As yet they have yet not been the subject of rigorous evaluation.

The aim of this study was to evaluate the crash effects of Victoria fixed digital speed and red light (FDSRL) cameras that have been in operation at a number of intersection for nearly 7 years. Generally FDSRL cameras in Victoria only detect infringements on a single leg of the intersection although at a small number of intersections cameras are placed on 2 legs. In Victoria warning signs are used on each leg of an intersection where a camera is placed warning of the presence of a camera being used in the area. The evaluation aimed to specifically examine effects associated with camera presence on crashes involving vehicles travelling on the intersection leg where the camera was placed. It also aimed to examine crash effects across the intersection as a whole as a measure of intersection-wide general deterrence associated with the presence of both the camera and associated signage.

A before-after quasi-experimental design with controls often used to evaluate road safety programs with highly localised effects and non-random deployment was used in this study to measure the effectiveness of red-light speed cameras at reducing casualty crashes. Data were analysed using Poisson regression to calculate the adjusted percentage reduction in the number of casualty crashes at treated sites in the post-treatment period when compared with the pre-treatment period.

In its approach to the evaluation of Fixed Digital Speed and Red Light (FDSRL) cameras, this study aimed to eliminate some of the problems of questionable results from poor statistical power, and at reducing the problem of poor ability to generalise results by using casualty crash observations from 10,245 crashes on 1189 intersections, from rural and metropolitan areas within the state of Victoria over the years 2000 to 2009. The treated sites consisted of 87 camera units placed at 76 discrete intersections.

Results from this study show large decreases in casualty crashes associated with FDSRL cameras. When only the crashes resulting from vehicles travelling in the approach direction to the camera were compared, a casualty crash reduction of 47% (95% CI: (36, 56), $p<0.0001$) was estimated. When crashes involving vehicles from all approaches were examined, a 26% reduction (95% CI:(16,35), $p<0.0001$) in all casualty crashes, a 44% reduction (95% CI :(31,64), $p<0.0001$) in targeted crashes (namely right angle and right turn against crashes) and a 37% reduction (95% CI :(22, 49), $p<0.0001$) in severe injury/fatal crashes of all types was estimated. These results show that camera placement is associated with crash reductions across the intersection as a whole, with particularly large effects on the leg where the camera was placed, on crashes resulting from behaviour targeted by camera enforcement and on fatal and severe injury crashes.

Estimates of crash effects at individual intersections were not robust due to the limited quantities of crash data at each site however the estimate of average crash effect across all 77 intersections studied was robust. The analysis approach used was able to test whether the average crash effect estimated across all intersections was homogeneous across individual intersections. The crash effect was estimated as homogenous across sites when ‘all approach’ crashes were examined ($p=0.17$) but on ‘targeted approach’ analysis, heterogeneity was significant (p=0.0001). Efforts to conclude which of these heterogeneous sites performed better failed because the evidence to determine significant reductions in casualty crashes from targeted approach vehicles at each of the individual sites was weak.

Whilst use of the FDSRL cameras was associated with a reduction in overall casualty crash risk, there was no evidence for a reduction in relative crash severity meaning the cameras were associated with equal reductions in minor injury crashes as serious injury and fatal crashes.

Across the 77 intersection where the cameras evaluated were installed, it was estimated that 17 serious or fatal crashes per year and 39 minor injury crashes would be prevented representing crash cost savings to the community of over $8M. Based on the outcomes of the evaluation, continued and expanded use of combined fixed red-light and speed cameras in Victoria is expected to improve driver safety, save lives and reduce crash related costs.

EVALUATION OF THE CRASH EFFECTS OF FIXED DIGITAL SPEED AND RED-LIGHT CAMERAS

1. INTRODUCTION

Driving behaviours including red-light running and speeding have long been associated with severe injury and fatal crashes (Retting, 1999). The probability of a crash has been proven to be associated with both the average individual vehicle speed and the average traffic speed (TRB, 1998 & Elvik, 2005). Fatal crashes also have a proven association with speed (NHTSA, 2006). In Victoria, Australia, Police (Victoria Police, 2009) identified speeding as the main cause of 20% of fatal and serious injury collisions. Generally intersections have a high crash risk, however running the red light increases that risk. Victoria Police (2009) estimate that 20% of casualty crashes occurring at major intersections in metropolitan Melbourne are caused by red light running. Retting, Williams, Farmer, and Feldman, A (1999) reported that “Motorists are more likely to be injured in crashes involving red light running than in other types of urban crashes.” Other studies have confirmed the association between red-light running and crashes with injuries (Council, Persaud, Eccles, Lyon & Griffith, 2005; & Aeron-Thomas and Hess, 2005). Together, both running a red-light and exceeding the speed limit on approach to a signalised intersection can put the driver at considerable risk of a casualty crash.

Exceeding speed limits generally is a fairly common behaviour. In a USA based study Fitzpatrick (2003) found that 68-78% of urban drivers exceed speed limits. Given the dangers associated with speeding and running red-lights, many countries have implemented automated enforcement systems (AES) to reduce these behaviours. In Victoria, speed cameras have been used since 1991 and red light cameras (RLCs) since 1983 (Victoria Police, 2009). Currently, Victoria uses over 150 speed cameras and 83 RLCs to modify driver behaviour and an average of 2.8 million vehicles are speed checked per month (Victoria Police, 2009).

The primary measures of effectiveness of AES at deterring high risk behaviours such as red-light running and speeding is the measurement of changes in frequency and severity of crashes. Fixed speed cameras with warning signs or alerts have been shown to be effective by reducing casualty crashes by around 20% (ARRB Group, 2005; Elvik, 1997).

The use of RLCs, as a method to improve driver red-light compliance behaviour, has been evaluated with mixed results. Lum and Wong (2003) evaluated the impacts of installing and operating RLCs on the stopping propensity of drivers in response to an amber signal. Red light cameras were found to increase”stopping propensity” on targeted approaches only. They found that the propensity (by odds ratio) for stopping at matured in-service red-light camera approaches was 17 times more than at non-camera approaches.

In contrast, Erke (2009) found that RLCs do not seem to be a successful safety measure. This study found that the installation of RLCs had non-significant effects on the number of crashes by conducting a meta-analysis of 21 studies from mostly the USA and Australia over the period of 1996 to 2007. Results of the analysis found that overall crashes increased by 15%, rear-end collisions increased by about 40% and right angle collisions reduced by about 10%. It concluded that poor handling of regression to the mean and spill-over effects was a key bias present in each previous study where crash reductions associated with the RLCs were identified.[1] However, Lunde, Kyrychencko, and Retting (2009) found that Erke's meta analysis study lacked critical review and the weighting of two questionable studies could have produced misleading results.

RLCs are aimed primarily at reducing crashes from vehicles turning across the on-coming traffic on the red light and from vehicles proceeding straight though on a red light into the path of vehicles with a green light. However the benefit may be off-set by increases in rear-end crashes. Obeng and Burkley (2008) considered only rear-end crashes in a study which aimed at modelling the effects of offsetting driver behaviour and found that "changes in driver behaviour when drivers see red light cameras indeed offsets the advantages of red light cameras by increasing rear end crashes".

Some of the problems encountered in the previous RLC studies included low statistical power and control of spillage and regression to the mean. Many of these studies examined driver behaviour or casualty crashes over a small number of intersections (<20) and over short periods of time (days, weeks, months). Correction of the identified problems with study design and size is critical for obtaining robust estimates of AES effectiveness in reducing crashes. Furthermore, the evaluation of a large number of installations would allow comment on the general applicability of AES technology in combating both speeding and red light running beyond what has been possible in previous meta-analyses.

Although combination automated camera based technology that enforces both of speed and red-light offences at intersections has been in use in Victoria for over 6 years its use outside of Australia appears to be limited and there are no published evaluations of its effectiveness. Furthermore, fixed speed cameras are generally not placed at intersections so their effectiveness in this application is also unknown. Speeding increases the severity and risk of a crash so a measure that aims to reduce speed and red-light running is expected to be more effective at reducing crash casualties at intersections than RLCs alone.

Fixed digital speed and red light cameras have been installed or are planned to be installed across a number of Australian states. In New South Wales 200 are being installed over four years from 2009 and there are plans to install a number in Queensland. The NSW Road Traffic Authority is expecting a reduction in casualty crashes at camera sites of 30% (NRMA, 2010, VicRoads, 2010). In Victoria 88 fixed speed and red light cameras are in operation at 77 fixed sites. These became operational over a period from 31/12/2004 to 6/1/2009. Four of the sites have cameras targeting two approaches and seven site approaches use two cameras in order to cover straight and right turning vehicles. All fixed speed cameras in Victoria are signed on the approach to the intersection where they are installed not only on the installed intersection leg but also generally on other unenforced legs.

[1] Spillage or spill-over effects are the decreases in treatment effect observed from increased in safe behaviour in control intersections proximal to the treatment sites. 'Regression to the mean' is the statistical tendency, resulting from random variation, where a measured drop in crash frequencies over time without treatment.. It is a particular problem when high crash frequencies sites are chosen for observation.

1.1 AIMS AND SCOPE

The aim of this report is to evaluate the casualty crash effects of Victoria fixed digital speed and red-light cameras, both as a general deterrent on all approach legs of the intersection and as a specific deterrent on the targeted approach alone. A casualty crash is a crash in which at least one person involved in the crash sustained an injury.

The null hypotheses tested are:

H_{01}: That across all legs of the intersections where installed, the FDSRL cameras and associated signage had no effect on casualty crash frequency or severity.

H_{02}: That the FDSRL cameras and associated signage had no effect on the frequency or severity of casualty crashes where at least one vehicle was travelling on the camera's targeted approach intersection leg.

H_{03}: That there was no difference between sites of the effect of FDSRL cameras and associated signage on casualty crash frequency.

The tests were made against two sided alternative hypotheses, since it is valid that red-light speed cameras could also cause an increase in casualty crash data, for example from increased rear-end crashes caused by increased 'short' stopping.

Evaluations of the first hypothesis were carried out on all casualty crashes, casualty crashes resulting in death or serious injury, rear-end crashes and crash types specifically targeted by the enforcement (namely right angle crashes and right turn against crashes). Evaluation of hypothesis 3 was carried out on all casualty crash data from all intersection legs and from camera enforced legs of treated intersections.

2. DATA

2.1 TREATMENT DATA

FDSRL cameras were placed on 77 unique intersection sites. One of the 77 sites was excluded from analysis because of poor quality crash data. All but 5 (placed in Geelong (3), Echuca and Bendigo) were placed in the Greater Melbourne area. The identification of each site using intersection street names, suburb, municipality, target approach and dates of construction completion and activation was supplied by Department of Justice.

Of the remaining 76 sites, four had two cameras at different approaches to the intersection, and seven sites had two sets of cameras on the same approach to detect vehicles travelling straight as well as vehicles turning right. A treatment site was defined as a traffic light controlled intersection with one or more FDSRL cameras.

FDSRL cameras included in the study were installed over the period 3/11/2004 to 11/2/2008 and commissioned from 31/12/2004 to 6/1/2009.

Signs warning that safety cameras are used in the local vicinity were placed on the approach to all legs of the intersection on which the FDSRL cameras were installed.

2.2 CRASH DATA

VicRoads supplied records of all police reported casualty crash data in Victoria from 1/1/2000 to 31/12/2009 (inclusive) for use in the analysis. The crash data was then reduced to include only those crashes that could be used as treatments or controls.

Inclusion criteria included that the crash be at an intersection controlled by traffic lights and that the intersection be a treatment site or within a postcode containing a treatment site. If there was not enough information in the data to identify the crash postcode and the presence of traffic lights, the crash was not included. If there was insufficient information to uniquely identify the intersection as a treatment and not a control site, it was excluded. The treatment site in postcode 3045 (A02 at Terminal Drive and Centre Road, Melbourne airport) had to be excluded for this reason.

Exclusion criteria for control sites included those that may have had a red light camera during the period. Current lists of intersections with wet film and digital red light cameras were provided by Department of Justice. Sites with deactivated wet film cameras were also identified and excluded. In total 59 control sites were excluded for having cameras: 22 with digital speed RLCs, 26 with wet film cameras and 11 with inactive wet film cameras.

Of the 76 treatment sites, two were formerly sites of wet film cameras:

East Burwood, Burwood Highway and Blackburn Road
Caulfield, Glen Eira Road and Kooyong Road

Crashes that occurred between the before and after treatment periods defined in Section 2.3 below were also excluded. This in between period may be considered as the realization and acclimatization phases.

Crashes resulting from targeted approaches at treatment site intersections were defined as those where at least one of the crashing vehicles could be identified as approaching the intersection from the direction that is photographed by the FDSRL camera. Accidents not meeting this definition including those with insufficient information were excluded from targeted approach analysis.

Specific crash types targeted by the enforcement were defined as all casualty crashes coded as 110 or 121 by VicRoads' Definition for Classification of Accidents (DCA). These accidents result from either two vehicles proceeding straight through an intersection from adjacent directions (right angle crashes) or from two vehicles approaching from opposite directions with one vehicle turning right in front of the other (right turn against crashes). These are the two main types of crashes that red-light cameras aim to reduce.

Rear-end crashes were defined as all casualty crashes coded as 130, 131 or 132 using the same classification scheme. Severe injury crashes were crashes that resulted in hospitalisation or death. Targeted crashes, rear-end crashes and severe injury crashes were not mutually exclusive, because an accident could involve several vehicles as well as cyclists and pedestrians.

A frequency table for the crash control data used is presented in table 2.3.1 below. Total analysis data covered 10,245 crashes: 1664 crashes at treatment sites (1304 in the 'before' period) and 8581 crashes at control sites (6197 in the 'before' period). The treatment data for targeted approach analysis was reduced to 956 crashes (799 in the 'before' period) as shown in Table 2.3.2.

Summaries of Data by specific treatment site and period are presented in Table 7.6.1 of Appendix F.

2.3 DATA MANAGEMENT

The statistical package SPSS (PASW Statistics 18 Release 18.0.0 July 30, 2009) and the spreadsheet software Microsoft Excel 2007 were used to manage data and export a data set for analysis by SAS version 9.1 for Windows (SAS Institute Inc., Cary, NC, USA.).

In order to use the data, inconsistencies in suburb, postcode, city and street names by which crash locations were identified had to be addressed since some intersections were labelled by multiple names in the data. A data set was created with a consistent set of intersection names and which met the inclusion and exclusion criteria. Each crash was labelled as treatment or control sites and as within the before or after treatment periods.

If the crash site was not a signalised intersection at one of the 76 treatment sites but within a postcode of a treatment site, then it was labelled as a control.

In order to match with controls, the before and after cut-offs were defined by postcode rather than individual treatment sites. The before treatment crashes were defined as crashes that occurred at least 1 month before the earliest completion date of construction of the treatment sites within a postcode. The after treatment crashes were defined as crashes that occurred at least 1 day after the latest activation date of the treatment sites within a postcode.

The crashes at treatment sites were further classified as "crashes where at least one of the vehicles was approaching from the target approach of the camera" and "crashes where neither of the vehicles was approaching from the target approach of the camera".

The treatment site labelled with postcode 3019 had no controls site crashes. This site (Ashley Street and Churchill Avenue, Maribynong) bordered postcode 3012, so it was included with 3012 data. Postcode 3107 treatment sites were low on control sites, so controls from postcode 3108, which is a nearby and characteristically similar suburb, were added. These were not used elsewhere.

Crash data approach directions were compared with the DOJ supplied camera targeted direction, Google images of the actual cameras and the directional layout of intersections in the Melways Melbourne Street Directory. This enabled targeted approaches at treatment sites to be confirmed and inconsistencies in data to be corrected.

To investigate the 'regression to the mean' effect a reduced data set was created whereby the controls were chosen to better match the crash frequency distribution of the treatment intersections in the before treatment period. This was done by removing all control intersections which had fewer crashes per intersection in the before period than observed for the treatment intersections in the same postcode. If there was more than one treatment intersection in a postcode, then the minimum crash per treatment intersection was used for that postcode. The observations were reduced to 414 unique traffic controlled intersections (76 treatment intersections) over a period of 10 years. This reduces the control crashes to 3419 control crashes (2426 in the 'before' period).

Table 2.3.1: Frequency of Casualty crashes at treatment and control sites in before and after treatment periods.

Postcode of Crash Location	Site	treatment		control	
		before	after	before	after
3000				900	336
	A12	27	9		
	A25	17	4		
	C01/C03	62	12		
	C25	29	12		
3002				209	56
	C02/C04	40	4		
	C05/C08	43	8		
	C13	30	8		
3003				137	44
	B01	30	1		
	C10	27	14		
	C21	21	2		
3004				209	71
	A11	22	5		
3011				190	52
	A13	16	2		
3012				65	45
	A37	18	6		
	C35	17	3		
3020				144	81
	A07	16	5		
3047				87	42
	C07	19	2		
3051				143	48
	B02	18	4		
3053				177	56
	C34	27	6		
3058				151	39
	A18	8	2		
3061				42	10
	A91K	21	3		
3065				53	12
	A00	16	4		
	A03	9	1		
3066				56	27
	A50	9	6		
3070				72	26
	C20	31	8		
3072				178	67
	C24	30	8		
3101				78	33
	A21	24	8		
3102				23	11
	A28	7	3		
	A75	2	3		
3104				34	13
	A85	6	2		
3107				77	22
	A51	3	2		
	A89	5	2		
3122				57	24
	A22	11	3		
3124				77	41
	A76	5	0		
3127				30	16
	B23/A56	6	1		
3128				76	33
	A42	5	1		
	B10	16	4		
3129				32	9
	A41	7	2		
	C09	25	5		
3130				69	26
	C15	31	6		

Postcode of Crash Location	Site	treatment		control	
		before	after	before	after
3134				171	86
	C32	22	10		
3136				111	49
	B26	12	4		
3141				141	40
	C06	32	7		
	C11	27	4		
3143				64	24
	A17K	15	8		
3145				129	37
	C26K	24	10		
3146				81	20
	A49	4	1		
3150				189	68
	B17	23	4		
3151				44	17
	C17	29	14		
3152				86	53
	A06	15	5		
	A57	12	3		
	C23	16	5		
3153				36	16
	B12	14	3		
3156				89	37
	B25	6	3		
3161				84	37
	A45	15	1		
	A60	12	3		
	B24	4	4		
3162				64	28
	B20	7	2		
3168				83	43
	A39	2	3		
	A83	5	1		
3174				74	49
	A47	8	4		
	A84	5	2		
3175				231	166
	A09	12	6		
	A46	7	3		
3179				40	9
	A86K	29	8		
3182				283	68
	B22	15	4		
3183				57	15
	B14	18	4		
3192				86	30
	A23	8	5		
	C16K	18	11		
3194				55	18
	C19	28	9		
3205				163	57
	C14	27	8		
3214				67	13
	A55	15	3		
3220				168	44
	A66	3	0		
	A92	11	3		
3550				125	61
	A81	6	1		
3564				9	4
	A59	6	2		
3805				101	55
	A16	36	11		
	total	1304	360	6197	2384

Table 2.3.2: Frequency of Casualty crashes from targeted approaches at treatment sites in before and after treatment periods.

Postcode of Crash Location	Site	before	after
3000			
	A12	11	1
	A25	9	0
	C01/C03	58	12
	C25	15	4
3002			
	C02/C04	34	3
	C05/C08	39	7
	C13	23	6
3003			
	B01	15	0
	C10	20	11
	C21	12	0
3004			
	A11	13	3
3011			
	A13	8	1
3012			
	A37	9	1
	C35	10	1
3020			
	A07	7	2
3047			
	C07	15	0
3051			
	B02	9	2
3053			
	C34	14	2
3058			
	A18	5	2
3061			
	A91	14	3
3065			
	A00	8	1
	A03	7	1
3066			
	A50	4	2
3070			
	C20	21	5
3072			
	C24	12	1
3101			
	A21	10	2
3102			
	A28	4	1
	A75	1	1
3104			
	A85	3	1
3107			
	A51	2	2
	A89	5	2
3122			
	A22	5	0
3124			
		0	0
3127			
	A56&B23	5	1
3128			
	A42	5	1
	B10	9	0
3129			
	A41	4	0
	C09	21	4
3130			
	C15	25	6
3134			
	C32	10	3
3136			
	B26	5	0
3141			
	C06	25	6
	C11	23	4
3143			
	A17	11	4
3145			
	C26	14	2
3146			
	A49	3	0
3150			
	B17	9	0
3151			
	C17	21	3
3152			
	A06	10	4
	A57	11	2
	C23	12	4
3153			
	B12	4	2
3156			
	B25	1	2
3161			
	A45	6	0
	A60	3	2
	B24	2	1
3162			
	B20	1	1
3168			
	A39	2	2
	A83	5	0
3174			
	A47	3	2
	A84	4	1
3175			
	A09	9	2
	A46	3	0
3179			
	A86	13	2
3182			
	B22	9	2
3183			
	B14	8	2
3192			
	A23	6	1
	C16	15	3
3194			
	C19	8	1
3205			
	C14	19	2
3214			
	A55	5	1
3220			
	A66	1	0
	A92	8	0
3550			
	A81	3	0
3564			
	A59	5	1
3805			
	A16	11	3
	total	799	157

3. METHOD

3.1 STUDY DESIGN

A before-after quasi-experimental design incorporating controls was used to measure the effectiveness of FDSRL cameras at reducing casualty crashes. This “Simultaneous Before-After Comparisons with Control Group” approach uses Poisson regression to calculate the percentage reduction in the number of casualty crashes at treated sites in the post-treatment period when compared with the pre-treatment period adjusted for parallel changes in the control group.

The design primarily requires that the treatment group was not selected as a result of its (high) accident count in the before period to avoid the “regression to the mean” effect. Figure 7.3.1 in Appendix C show that the treatment sites do not have abnormally high crash counts. Most intersections within the before period, in both the treatment and control groups have less than 40 crashes (based on 90^{th} percentile).

The ‘percentage reduction’ in casualty crash frequency is adjusted with the counts of casualty crashes at the control sites in the before and after treatment periods. The adjustment controls for factors other than the treatment which may affect casualty crash counts at the treatment site; factors such as changes in traffic flow, economic trends and the effects of other road changes.

Control sites were chosen in order to reflect the effects of other broad local influences on casualty crash frequency at the treatment sites other than the FDSRL cameras. Lum, K and Wong, Y (2002) have emphasized the importance of choosing intersections for controls which were geographically close, so they could share similar traffic patterns and volumes. Controls were chosen as all other signalised intersection within the same postcode area (that meets inclusion and exclusion criteria). Matching controls in this way ensured local influences on crash frequency on intersection crashes on roads of the same general geometry, size and traffic volume were reflected. Use of a large group of treatment sites and a large ratio of control sites to treatment sites ensured the study achieved power for statistical testing and produced estimates that were generally representative of the likely effectiveness of FDSRL camera enforcement in other applications.

The quasi experimental design requires that the control group is measured for entirely the same time as the treatment group in both the ‘before’ and the ‘after’ periods, although the before and after periods need not be the same length. For this study the before and after periods were identical for controls and treatments within each postcode location. The distribution of length of time for each postcode is summarized in Appendix B. The before period is significantly bigger than the after period in order to reduce “regression to the mean” effects.

For the second analysis, which used only treatment crashes where at least one vehicle was from a targeted approach, treatment site crashes were excluded if they were from crashes involving only unknown or non-targeted approach vehicles. The same control matching protocol was used for this analysis. The non-targeted approach crashes were not used as controls since they may be affected by spill over effects because of their proximity to the treatment site. (Crash frequency at control site decreases and thus reduces the treatment effect.)

3.2 STATISTICAL ANALYSIS

Statistical Analysis was carried out using SAS on counts of casualty crash data tabled by postcode, crash period (before/after) and treatment (control/individual treatment sites).

3.2.1 Crash Frequency Analysis

Medical literature shows that the most appropriate means of analysing count data from trials to estimate net treatment effects relative to a control is via log-linear analysis with a Poisson error structure (Breslow & Day, 1987). Table 3.2.1 shows the structure of the contingency format used in the analysis.

Table 3.2.1: Format for 1 of ℓ 2x2 Contingency tables.

A	B	Before	After
	Control Group	n_{11}	n_{12}
	Treatment Group	n_{21}	n_{22}

n are the counts of crashes, j=1,2 for treatment and control , k=1,2 for before and after. ℓ is the number of treatment sites.

Using the symbols from Table 3.2.1, the model for ℓ 2x2 contingency tables has the form:

$\ln(n_{ijk})=$ + + + j, k=1,2 ; i=1,2....., ℓ .....(Eqn 1)

where β are the model parameters, i are the crash site numbers and together form the mean of the i^{th} site. The measure factors for each site are equal to The model can be used to test the Null Hypothesis: H_0: H_1:

The percentage casualty crash reduction at site i attributable to the treatment adjusted for the corresponding change in casualty crash frequency at the control site is:

Δ_i=100x(1-exp( ))% ......(Eqn 2)

The model, fitted using SAS generalized linear models with the Poisson distribution of errors and a log link, produces the parameters , its confidence interval and statistical significance. Δ_i and its upper and lower confidence limits are calculated with equation 2 and its statistical significance is the same as for .

Bruhning and Ernst (1985) show how with subtle modifications to this model, an estimation of the average treatment effect across all treatment sites can be made. This method was used to estimate the treatment effect over all sites for this study. A simultaneous interaction effect is added: and the second order interaction term is removed.

$\ln(n_{ijk})=$ + + + j,k=1,2 ; i=1,2..... ℓ .....(Eqn 3)

The simultaneous measure factor is equal to The model can be used to test the Null Hypothesis: H_0: H_1:

The percentage casualty crash reduction simultaneously at all sites attributable to the treatment adjusted for the corresponding changes in casualty crash frequency at the control sites is:

Δ_i=100x(1-exp( ))%

The model, fitted using SAS generalized linear models with the Poisson distribution of errors and a log link, produces the parameter , its confidence interval and statistical significance. Δ_i and its upper and lower confidence limits are calculated with equation 2 and its statistical significance is the same as for .

Homogeneity across the measure factors for each site was also tested using likelihood ratio tests. (Null Hypothesis: H_0: β =)

The distribution assumptions for this model were shown to be consistent with this casualty crash data. There was not an over-representation of 0 counts and the over-dispersion of the Poisson distribution did not have significant effects on the standard error estimates of the treatment effect.

Using all casualty crash data, there were only 2 cells with counts of 0 in the contingency tables exported for analysis with SAS. These were for treatment sites and represented only 1.3% of the treatment casualty crash intersections within the before and after periods.

The Poisson distributions of the casualty crash counts were over-dispersed. The increased variance is because of heterogeneity of street-specific crash rates. This means that standard errors are underestimated unless over-dispersion is corrected for. Two methods to adjust for over-dispersion were employed. Both methods produced results very similar to the uncorrected model, thus showing robustness of the uncorrected model to any inconsistencies to distribution assumptions. Details of this analysis are given in Appendix A.

Correlation of results within clusters is expected. Repeated measures are made within postcodes and repeated counts are made on the same street intersections across the before and after periods. These are treated as independent observations. Thus variance will potentially be underestimated. Generalized Estimating Equations (GEEs) work well to account for correlation when there are large numbers of small clusters like this case (GEEs can be used with the SAS GENMOD command which is commonly used for Poisson analyses.). GEEs have no terms for between cluster variation but that is sufficient as this analysis was only interested in the population means with correlation being a nuisance factor. Also, GEE can’t handle several levels of hierarchy. Here that would mean both postcode and intersection clusters. In this analysis control intersection crashes have been aggregated, and attempts to control before-after correlation (regression to the mean effect) has been carried out by design. This leaves only one level of clustering: clustering by postcode. There are 53 different postcodes with a maximum of 4 treatment sites and 1 aggregate of control sites per period analysed within each treatment group.

The model comparisons for correlation by postcode adjustments are presented in table 7.1.2, Appendix A. The model deviance, effect estimate and significance factor are all unchanged from the Poisson model and the confidence interval has increased only slightly. In the interest of parsimony and because of its robustness (clustering correlation and overdispersion effects are small) the unadjusted Poisson was used to report overall and ‘by site’ analysis.

The measurement periods for each period by postcode are the same so the calculation of an offset ‘time of measurement’ ‘variable is unnecessary in this analysis.

Postcodes and intersections are not randomly drawn so statistical generalizations to other population of intersections should be made with caution. Strictly, results of this study are applicable to the treatment sites being studied only. However, given the size of this study, it is likely to be possible to apply these results with caution to similar sites within Melbourne, Victoria.

3.2.2 Crash Severity Analysis

Examination of the change in relative severity of crashes at treatment sites compared to control sites associated with FDSRL cameras was made using logistic regression. The general linear logistic model is widely used for analysing binary response data with explanatory variables. Here the binary response: 1= a crash with at least one severe or fatal injury versus and 0= a crash with injuries not requiring hospitalisation. The main explanatory variables are the treatment, period and postcode. However, the odds was also adjusted for road type, road geometry and speed zone. Road type was classified as major (highway, tollway or freeway) or minor (all others). Intersection geometry could be T, Y, cross or multiple. All the explanatory variables were treated as categorical in the model.

The general logistic model has the form:

Logit π_i= —— ......(Eqn 4)

where $\boldsymbol{\beta}$ is the model parameter vector, i are the individual accident numbers and x_i are, in this case, the dummy variables corresponding to the factor levels for the explanatory variables and postcode-treatment interaction, postcode-period interaction and treatment-period interaction variables.

The model can be used to test the Null Hypothesis that the treatment-period interaction effect is zero which is a test of the null hypothesis that the FDRLS cameras have no effect on crash severity. The odds of a severe injury outcome at treatment sites after camera installation relative to before installation adjusted for the same relative odds at the control sites and all other explanatory variables used in the model is:

exp( ) ......(Eqn 5)

The model, fitted using SAS logistic models with the binomial distribution of errors and a logit link, produces the treatment-period interaction parameter, its 95% Wald confidence interval and statistical significance. The statistical significance for the odds ratio is the same as for its parameter.

3.3 ACCIDENT MIGRATION AND REGRESSION TO THE MEAN

One possible outcome of treating sites on the road network is accident migration, which involves the casualty crash risk being moved, either entirely or partly, from the treated site to another site nearby.

The most likely cause of accident migration in this study would be reduced treatment site crashes due to reduced treatment traffic flow through avoidance of the treatment site. The bias from this is likely to be small given that data from many treatment sites were averaged and that treatments are on major or arterial roads which cannot easily be avoided. Also any overestimation of the benefit is likely to be counteracted by some spillage effects. And given that there are many more control than treatment sites, spillage effect is also likely to be very small.

Another cause of accident migration might be through an unrelated treatment causing a more altered traffic volume at a treated site than at the controls. The effect could equally be to decrease or to increase crash rates at treatment sites and its effects are likely to cancel each other out over the "all site" average given the number of sites being examined.

Both types of accident migration are unable to be accounted for since traffic volume data and information on unrelated treatments has not been provided. However, volume corrections may not have much of an effect since in a smaller before-after red-light camera study of only 24 intersections over 5 years in 1 city and 10 in another, Shin and Washington (2007) found that the analysis was fairly robust to volume corrections. Elvik (2002) argued that controlling for volume is not needed and constitutes double counting, if a large comparison group is used. A large comparison group was used in this study to minimise potential traffic migration effects.

When safety measures, such as FDSRL cameras, are placed at sites known for their high frequency of crashes, the measured treatment benefit is over estimated because random variation alone can lead to a measured treatment benefit. This effect is called "regression to the mean". Regression to the mean is not as likely if crash rates are similar in the before period for the control and treatment sites and if the before period is sufficiently long. In this study, a long before treatment time period has been chosen and treatment crash rates in the before period are not in the high range end of the count distribution for intersections overall. As an extra precaution a sensitivity analysis for the regression to the mean effect was carried out. The reduced dataset (described in Data Management section) had controls which better matched the before treatment crash frequency distribution of treatments in the before period. (Figure 7.3.2). A correction, using Pearson's Chi Square statistic, had to be made for over-dispersion in this analysis (Tables 7.3.1 and 7.3.2, Appendix C). The correction produced a much better fitting model. The method is detailed in Appendix A.

4. RESULTS

4.1 DATA SUMMARY

Table 4.1.1 summarises the treatment and control site crash frequencies in aggregate across all sites in the before and after treatment time periods. It also gives key crash distribution percentiles across sites and lists the number of treatment and control sites.

Table 4.1.1: Summary statistics for intersection casualty crash counts by period and treatment type

				Crashes per intersection		
		N of sites	Total crashes	median	25th percentile	75th percentile
before	**control**	1113	6197	4	2	9
	treatment	76	1304	16	7	26
after	**control**	1113	2384	2	1	4
	treatment	76	360	4	2	7

4.2 CHANGES IN CASUALTY CRASH FREQUENCY ACROSS THE ENTIRE INTESECTION WHERE A FDSRL IS LOCATED

Analysis estimated a statistically significant ($p<0.0001$) net average 26% reduction in the frequency of casualty crashes associated with the use of FDSRL cameras and accompanying signage across the entire intersection where a camera is located. The 95% confidence limits for this estimated reduction ranged from a 16% to 35%.

Adding site interactions to the model had no significance ($p=0.17$), indicating that the site reduction effects are homogenous across sites. However, 6 treatment sites showed some weak evidence of very large percentage decreases in crash frequencies between the before and after periods (Table 4.2.1). FDSRL cameras and associated signage were associated with between 48% and 90% reductions in casualty crashes at these sites. The probability of getting each of these results purely by chance in a single test is less than 10%. However, due to the Bonferroni effect produced when carrying out simultaneous multiple testing, these tabled p-values represent weak evidence only. 4 of these 6 sites showed stronger evidence in having 95% confidence intervals for the estimates that did not include 0. The complete list of results by site is given in Table 7.4.1 of Appendix D.

Table 4.2.1: All Approach Treatment effects with p<0.10 for red-light speed cameras on casualty crashes.

Treatment Intersection	Postcode	Site ID	% change in crash frequency (-ve value is reduction, +ve value is increase) estimate	Wald 95% confidence limits	Estimate std err.	p-value
FLINDERS STREET & WILLIAM STREET, MELBOURNE	3000	C03 &C01	-48	(-72 , -3)	0.32	0.04
HODDLE HIGHWAY & VICTORIA STREET, MELBOURNE	3002	C04 &C02	-63	(-87 , 9)	0.55	0.07
HAWKE STREET & KING STREET, MELBOURNE	3003	B01	-90	(-99 , -22)	1.03	0.03
ASHLEY STREET & CHURCHILL AVENUE, MARIBYRNONG	3019	C35	-75	(-93 , -8)	0.66	0.04
BARRY ROAD & KING STREET, HUME	3047	C07	-78	(-95 , -2)	0.77	0.05
GLEN EIRA ROAD & KOOYONG ROAD, GLEN EIRA	3161	A45	-85	(-98 , 19)	1.05	0.07

4.3 CHANGES IN CASUALTY CRASH FREQUENCY INVOLVING VEHICLES FROM THE INTERSECTION LEG WHERE THE FDSRL CAMERA IS PLACED

Analysing crashes involving vehicles travelling on the specific intersection leg where the camera is placed estimated a statistically significant (p <0.0001) 47% reduction in the frequency of casualty crashes associated with the use of FDSRL cameras and accompanying signage. The 95% confidence limits on this estimate ranged from a 36% to 56% reduction.

Adding site interactions to the model significantly improved the fit (p=0.0001) showing that the estimated crash effects are not homogenous across sites. 3 of the 6 treatment sites identified in the previous analysis, and 1 other site, showed weak evidence of very large percentage decreases in crash frequencies between the before and after periods. FDSRL cameras and associated signage were responsible for between 45% and 86% reductions in casualty crashes at these 4 sites (Table 4.3.1). The probability of getting each of these results purely by chance in a single test is measured at below 10%. The complete set of results by treatment site is given in Table 7.5.1 of Appendix E.

Table 4.3.1: Targeted Approach Treatment effects with p<0.10 for red-light speed cameras on casualty crashes.

Treatment Intersection	Postcode	Site ID	% change in crash frequency (-ve value is reduction, +ve value is increase) estimate	Wald 95% confidence limits	Estimate std err.	p-value
FLINDERS STREET & WILLIAM STREET, MELBOURNE	3000	C03 &C01	-45	(-71 , 4)	0.32	0.07
HODDLE HIGHWAY & VICTORIA STREET, MELBOURNE	3002	C04 &C02	-67	(-90 , 11)	0.62	0.07
GEELONG ROAD & SOMMERVILLE ROAD, MARIBYRNONG	3012	A37	-84	(-98 , 31)	1.07	0.09
ASHLEY STREET & CHURCHILL AVENUE, MARIBYRNONG	3019	C35	-86	(-98 , 17)	1.07	0.07

4.4 INVESTIGATING REGRESSION TO THE MEAN EFFECT

An additional analysis for all intersection approaches with a reduced set of controls matched for pre treatment crash frequency was undertaken to investigate sensitivity to the regression to the mean effect. This analysis estimated a statistically significant (p<0.0001) 46% reduction in the frequency of all casualty crashes associated with the use of FDSRL cameras and accompanying signage. The 95% confidence limit ranged from a 27% to a 60% reduction.

The same analysis for crashes involving vehicles entering the intersection from the camera located approaches estimated a 69% reduction in the frequency of all casualty crashes (p <0.0001) associated with the use of FDSRL cameras and accompanying signage. The 95% confidence limits ranged from a 54% to an 80% reduction.

The effect estimates with control intersections matched by crash frequency compared with the full use of all potential control intersections were not as good a fit (Table 7.3.1, Appendix C) but improved greatly with over-dispersion adjustment. The above results are calculated with over-dispersion correction using Pearson's Chi-Square (1.62 for all crashes and 1.55 for targeted approach crashes). The effect of the correction widened the confidence interval without changing the estimate.

Results of this comparative analysis show that the estimates of FDSRL camera crash effects have not been inflated by regression to the mean. Narrowing the controls to intersections of similar prior crash frequency, and hence similar regression to the mean potential, in fact resulted in increased treatment effect estimates rather than reduced estimates.

4.5 ANALYSIS BY CRASH TYPE

Analysis of specific crash types targeted by the FDSRL cameras (DCA types 110 and 121) estimated a 44% reduction across the entire intersection in the frequency of all casualty crashes of these types associated with the use of FDSRL cameras and accompanying signage (p <0.0001,). The 95% confidence limits on the estimates ranged from a 31% to a 54% reduction. A 37% reduction in the frequency of severe-injury or fatal target crashes associated with camera installation was also estimated (p<0.0001) with 95% confidence limits ranging from a 22% to 49% reduction.

There is no statistically significant estimated change in rear end casualty crashes (p=0.13) with the 95% confidence limits ranging from a 6 % reduction to a 67% increase.

4.6 CRASH SEVERITY EFFECT

Analysis estimated no statistically significant change in the odds of a severe crash at the treatment sites after camera installation relative to the control sites (p=0.87). The adjusted relative odds of a severe crash at a treatment intersection post treatment relative to pre treatment was estimated at 0.98 with a 95% confidence interval spanning from 0.74 to 1.29. Further adjusting for road type and geometry and speed zone barely changed this result (0.97, 95% CI is 0.74 to 1.28, p=0.83). This result confirms that the effect of FDSRL cameras on fatal and serious injury crashes is the same as that on minor injury crashes.

Analysis of change in the severity of camera targeted and rear-end crashes associated with camera installation produced questionable convergence of analysis algorithms due to limited data quantities. Furthermore, estimates obtained did not reach statistical significance so no conclusions from this analysis could be generally drawn.

4.7 COST SAVINGS

Table 4.7.1 shows the break-down by crash severity of before treatment period crashes at treatment sites and applies the estimated crash reduction of 26% to derive the expected total crash savings over the before treatment period. These have been converted into community cost savings using the Austroads (2007) estimated crash costs for 2007 in Victoria in urban areas given in Table 4.7.1. Urban costs were used as the sites were within metropolitan Melbourne, Geelong, Bendigo or Echuca. Using the average before treatment period of 6.07 years, the expected annual crash and crash cost savings have been derived.

Table 4.7.1: Predicted Cost savings on casualty crashes at treated sites.

	fatal	serious injury	minor injury	all casualty
number of crashes	8	396	900	1304
expected crash savings over 6.07 year period	2	103	234	339
expected annual crash savings	0.33	17	39	56
average 2007 cost per crash	$1,929,000	$467,000	$20,600	$150,000
expected crash cost savings over 6.07 year period	$4,012,320	$48,082,320	$4,820,400	$50,856,000
expected annual crash cost savings	$661,008	$7,921,305	$794,135	$8,378,254

Table 4.7.1 shows that the 87 FDRLS cameras are estimated to save the Victorian community 56 casualty crashes per annum, 17 of which would be serious or fatal injury crashes, representing over $8 million dollars in community costs saved each year.

5. DISCUSSION AND CONCLUSION

5.1 DISCUSSION

This study provides strong evidence that installation of FDSRL cameras in Victoria has been associated with reductions in casualty crashes and associated costs to the community from road trauma. When considering crashes involving vehicles travelling from all legs of the intersection where a FDSRL camera was installed, a 26% reduction in all casualty crashes was estimated. When only the crashes involving vehicles travelling from the intersection leg where the camera the camera was installed, a higher 47% reduction was estimated. This suggests that the FDSRL cameras have their highest deterrence effect on the intersection leg where the camera is located but also achieve effects on the non-enforced intersection legs also. This is likely to be a result of the accompanying signage warning of the presence of the cameras which is generally placed at each leg of the enforced intersection in Victorian installations. It is also possible that the visual presence of the camera, which can often be seen from intersection legs other than the one on which they are place, has a deterrent effect beyond the camera installed leg.

Importantly from the perspective of being able to generalise the results of this study to other potential applications of FDSRL cameras, effects on casualty crashes across the whole intersection were homogenous across sites. This suggests that the cameras have potential to be equally effective in reducing crashes across a range of application sites. There was some evidence of heterogeneous crash effects between sites when considering only crashes involving vehicles travelling from the enforced leg however evidence for individual site effects here was relatively weak. This also suggests that the balance between camera specific and intersection generalised effects might be different from site to site although the resulting total effects across the intersection are similar across sites. This balance may be related to how conspicuous the camera installation is at each site of and requires further consideration.

Estimates of crash reductions associated with camera use were higher at 44% when considering crashes particularly targeted by red light enforcement, namely right angle crashes and right turn against crashes. The stronger relationship with crash reductions specifically targeted by the technology provides some evidence for the causal link between camera operations and crash reductions. Unlike studies of the effectiveness of single purpose red light enforcement cameras, the FDSRL combination cameras showed no significant increase in rear end crashes associated with their use. This suggests that the addition of speed enforcement to red light enforcement has overcome this noted dis-benefit of single purpose red light camera enforcement through adding enforcement of speed compliance. It highlights a need to augment all single purpose red light camera enforcement with speed enforcement, even if speeding is not a noted primary problem in the intersection.

Whilst use of the FDSRL cameras was associated with a reduction in overall casualty crash risk, there was no evidence for a reduction in relative crash severity. This result implies that the cameras were associated with equal reductions in minor injury crashes as serious and fatal injury crashes. This result contrasts the evaluation of other speed enforcement initiatives which generally produce larger reductions in higher severity crashes than minor injury or property damage only crashes. This could suggest that combined FDSRL cameras are primarily an effective tool in deterring red light infringements with the speed enforcement component deterring accelerating to beat light changes and hence causing rear end crashes. Unfortunately speed observations and red light infringement data before camera installation were not available for this study. Such data would have allowed the mechanisms leading to the estimated crash reductions to be more closely examined as part of the evaluation. Collection of speed profile and red light infringement data both before and after camera installation at treatment and control sites is recommended for any future evaluation of FDSRLC effectiveness to better understand mechanisms of effectiveness.

The design of this study attempted to maximise statistical power and minimise the effects of confounders such as regression to the mean by using a large control set and a long "before" period. As a further check, analysis utilising an alternative control group chosen to match the treatment sites on pre treatment crash frequency and hence potential for regression to the mean effects, was undertaken. It showed no indication that the results obtained using the broader control group are compromised by 'regression to the mean' effects. In fact the alternative analysis estimated slightly higher crash effects associated with camera installation suggesting the results presented might be slightly conservative although the differences between the estimates obtained using the two different controls were not outside the bounds of chance variation. Comparison of the two results sets did show the estimates obtained were relatively robust for the choice of control sites.

The likelihood of observing regression to the mean effects in this study is also considered low after reviewing the manner in which sites were selected for location of the 87 FDSRL cameras analysed in this evaluation. Regression to the mean bias is most likely in analyses of sites chosen primarily on high crash frequency. It is understood that location of the cameras analysed in this study was not chosen primarily on crash history but on recommendation by police or the local community based on observed red light running or speeding behaviour. It is worthy of note that the crash effects associated with the FDSRL cameras identified in this study were identified despite the treated sites not necessarily having a particular crash problem. It is possible that choosing sites for future cameras based on high crash history could yield higher crash reductions although any evaluation would need to be accommodate this selection process. Further installation of FDSRL cameras have been undertaken in Victoria subsequent to those sites that have been analysed in this evaluation and these have been chosen on the basis of crash history. Further evaluation of the effectiveness of FDSRL cameras including these new sites when appropriate is recommended to give further insight into the effectiveness of this style of automated enforcement technology.

The method of crash frequency analysis used in this study is supported by the literature and was robust to both over-dispersion and cluster correlation effects in the estimation of the all-site averages. If another study was undertaken with sufficient power to study the individual site effects, it would be recommended that cluster correlation corrections be used. Their effect was to widen confidence intervals, so were irrelevant in this study where the site estimates intervals were already relatively wide due to the limited data available on a site by site basis.

One limitation of the study was that it was not sufficiently powerful to identify significant individual treatment sites effects hence it is not possible to comment on the effectiveness of treatments at specific locations. This problem is relatively common amongst accident black spot studies which have many parallels with this study. Given the identified homogeneity of treatment effect found in this study this is not considered a major limitation.

5.2 CONCLUSION

Evaluation of the installation of FDSRL cameras in Victoria provides strong evidence that this automated enforcement technology has been associated with reductions in casualty crashes and associated costs to the community from road trauma. Effects were demonstrated over a large population of signalised intersections in Metropolitan Melbourne and regional Victorian cities.

When considering crashes involving vehicles travelling from all legs of the intersection where a FDSRL camera was installed, a 26% reduction in all casualty crashes was estimated. When only the crashes involving vehicles travelling from the intersection leg where the camera the camera was installed, a higher 47% reduction was estimated. Effects on casualty crashes across the whole intersection were homogenous across sites. Whilst use of the FDSRL cameras was associated with a reduction in overall casualty crash risk, there was no evidence for a reduction in relative crash severity meaning the cameras were associated with equal reductions in minor injury crashes as serious injury and fatal crashes.

Estimates of crash reductions associated with camera use were higher at 44% when considering crashes particularly targeted by red light enforcement, namely right angle crashes and right turn against crashes. Unlike studies of the effectiveness of single purpose red light enforcement cameras, the FDSRL combination cameras showed no significant increase in rear end crashes associated with their use.

Across the 77 intersection where the cameras evaluated were installed, it was estimated that 17 serious or fatal crashes per year and 39 minor injury crashes would be prevented representing crash cost savings to the community of over $8M. Based on the outcomes of the evaluation, continued and expanded use of combined fixed red-light and speed cameras in Victoria is expected to improve driver safety, save lives and reduce crash related costs.

6. REFERENCES

Aeron-Thomas, A. & Hess, S.(2005). Red light cameras for the prevention of road traffic crashes. *Cochrane Database of Systematic Reviews 2005*, (Issue 2).

ARRB Group Project Team (2005). *Evaluation of the Fixed Digital Speed Camera Program in NSW* (RC2416). New South Wales, Australia: Roads and Traffic Authority.

Breslow, N.E. & Day, N. E. (1987) *Stastical Methods in Cancer Research*, World Health Organisation, International Agency for Research on Cancer, Scientific Publication 82,.

Bruhning, E. & Ernst, G. (1985)'Log-linear models in effectiveness studies- an application to simultaneous before-after comparisons with control group', *Proceedings Evaluation '85, International Meeting on the Evaluation of Local Traffic Safety Measures*, 1985, Paris, France.

Council, F., Persaud, B. Eccles, K, Lyon C & Griffith, M. (2005). Safety Evaluation of r*ed light cameras* (FHWA-HRT-05-048). Washington, DC: U.S. Department of Transportation, Federal Highway Administration.

Elvik, R. (2005). Speed and road safety: synthesis of evidence from evaluation studies (paper 05-0223). Paper presented at the annual meeting of the Transportation Research Board, Washington, DC.

Elvik, R (2002). The importance of confounding in observational before-and-after studies of road safety measures. *Accident Analysis and Prevention*, 34,pp631-635.

Elvik, R (1997), Effects on accidents of automated speed enforcement in Norway. *Transportation Research Record*, 1595, 14-19.

Erke, A (2009) 'Red-Light Cameras? A Meta-analysis of the Effects of Red-light Cameras on Crashes', *Accident Analysis and Prevention*, 41 (5),pp897-905. 10.1016/j.aap.2008.08.011.

Fitzpatrick, K., Carlson,P., Brewer,M., Wooldridge, M & Miaou, S-P (2003). *Design, Speed, Operating Speed and Posted Speed Practices* (NCHRP Report 504). Washington, DC: Transportation Research Board.

Lum, K & Wong, Y (2003) 'A before-and-after study of driver stopping propensity at red light camera intersections', *Accident Analysis and Prevention* 35, pp111-120.

Lum, K & Wong, Y (2002) 'A study of stopping propensity at matured red light camera T-intersections', *Journal of Safety Research*, 33, pp355-369.

Lund,K., Kyrychenko, S & Retting, R (2009) 'Caution: A comment on Alena Erke's red light for red-light cameras? A meta-analysis of the effects of red-light cameras on crashes', *Accident Analysis and Prevention*, 41 (4),pp895-896.

New South Wales Road Traffic Authority (RTA), 'Safety Cameras', Accessed November 3, 2010.
http://www.rta.nsw.gov.au/roadsafety/speedandspeedcameras/safetycameras/index.html .

Obeng, K & Burkley,M (2008)' Explaining crashes at intersections with red-light cameras: A note', *Transportation Research Part A 42*, pp811-817.

Perovic, J., Evans,C., Lloyd, B. And Tsolakis, D. (2007). Guide to Project Evaluation, Part 4: Project Evaluation Data (AGPE04/08) Sydney, NSW: Austroads Incorporated.

Retting, R.A. (1999). Automated enforcement of traffic laws. *TR News*, 201 (29),pp15-18

Retting, R., Williams, A., Farmer, C & Feldman, A. (1999) 'Evaluation of red light camera enforcement in Oxnard, California' *Accident Analysis and Prevention* 31, pp169-174.

Shin, K & Washington, S (2007) 'The impact of red light cameras on safety in Arizona', *Accident Analysis and Prevention* 39, pp1212-1221.

Transportation Research Board. (1998). *Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits* (Special Report 254). TRB Committee for Guidance on Setting and Enforcing Speed Limits. Washington, DC: Transportation Research Board, National Research Council.

U.S. Department of Transportation. (2006). *Red light camera systems operational guidelines* (FHWA-HRT-06-045, HRTC- 01/01-06 (1M)E). Washington, DC: U.S.. Department of Transportation, Federal Highway Administration.

U.S. Department of Transportation. (2006). *Traffic Safety Facts, 2006 Data: Speeding* (DOT HS 810 809). Retrieved on December 6, 2010 from www-nrd.nhsta.dot.gov/Pubs/810809.pdf Washington, DC: National Highway Safety Administration, National Center for Statistics and Analysis.

Victoria Police (2009), 'Safety Camera Program', Last modified January 8 2009. http://www.police.vic.gov.au/content.asp?Document_ID=280.

Victorian VicRoads (2010), 'Arrive Alive', Last modified October 30, 2010. http://www.arrivealive.vic.gov.au/initiatives/safer_roads_and_roadsides/speed_and_sp/red_light_speed_cameras.html#1 .

7. APPENDICES

7.1 APPENDIX A: OVERDISPERSION IN CASUALTY CRASH COUNTS

Table 7.1.1 shows that the intersection crash counts by categories of period and treatment status are over-dispersed. Variance (square of standard deviation) is clearly greater than the mean for each group.

Table 7.1.1: Summary statistics for casualty crash counts per intersection by period and treatment type.

		N of sites	mean	std dev	min	max
before	control	984	6.3	6.2	1	59
	treatment	76	17.2	11.3	2	62
after	control	796	3.0	2.4	1	20
	treatment	74	4.9	3.3	1	14

Two methods to adjust for over-dispersion were examined.

Method one: Model of constant overdispersion.

The square root of the ratio of Pearson's Chi squared to the degrees of freedom is used to inflate the Poisson Standard errors. Means are unaffected.

Method 2: Negative binomial distribution

Negative binomial distribution is used instead of the Poisson distribution and overdispersion is treated as a random effect. It increases with the mean and is not assumed constant. The overdispersion is $1+ \alpha*\mu_i$. If alpha is 0 there is no overdispersion. The mean should be a similar value to method one.

Table 7.1.2 compares the 3 models. We see similar goodness of fit, treatment effect estimate and standard error of estimate. Also the scale for model B was calculated near to unity. The negative binomial regression was questionable in SAS with the negative of Hessian was not positive definite.

When targeted approach only treatment site crashes were modelled similarly for analysis, we also see similar goodness of fit, treatment effect estimate and standard error of estimate.

In conclusion the use of the Poisson model in this instance to estimate total casualty crash reduction shows robustness to inconsistencies in model assumptions.

Table 7.1.2: Complete Data Set Model information, Goodness of Fit and Treatment effects.

Model Information	A	B	C	D
distribution	Poisson	Poisson	Negative binomial	Poisson with GEE correlation correction.
correlation				-0.09999
scale	fixed	√(Pearson's χ2/df)		√Pearson's χ2/df)
	1	0.917		0.917
dispersion			0.0375	

Goodness of fit

		A	B	C	D
deviance	df=75	66.3		65.0	66.3
Scaled deviance			78.8		78.8
Pearson χ2		63.1		65.2	63.1
Scaled Pearson χ2			75.0		75.0
Log Likelihood		35746	42510	35659	42510

treatment parameter

	A	B	C	D
estimate	-0.305	-0.305	-0.307	-0.305
SE	**0.067**	**0.061**	**0.088**	**0.052**
95% CI Wald	(-0.44,-0.17)	(-0.43, -0.19)	(-0.48,-0.13)	(-0.41,-0.20)
pr>Wald χ2	<.0001	<.0001	0.0008	<.0001

7.2 APPENDIX B: MEASUREMENT TIMES BY POSTCODE AND PERIOD

The period of count measurement varied for each postcode. From Table 7.2.1 and Figure 7.3.1 we can see that the after period was shorter and that the variation was high for both periods.

Table 7.2.1: Summary statistics for measurement times in days.

	before	after
MEAN	2214	1135
STD DEV	260	196
MIN	1738	358
MAX	2725	1539
RANGE	987	1181

7.3 APPENDIX C: CRASH COUNTS IN BEFORE PERIOD

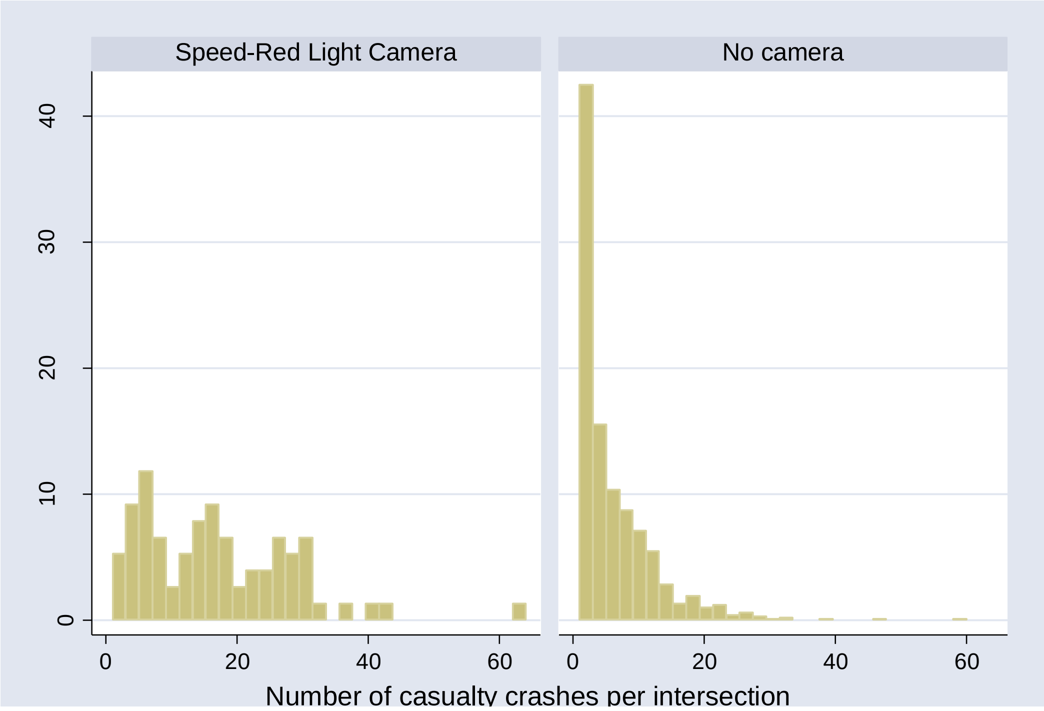

Figure 7.3.1
Casualty Crash Counts in before period by treatment site group

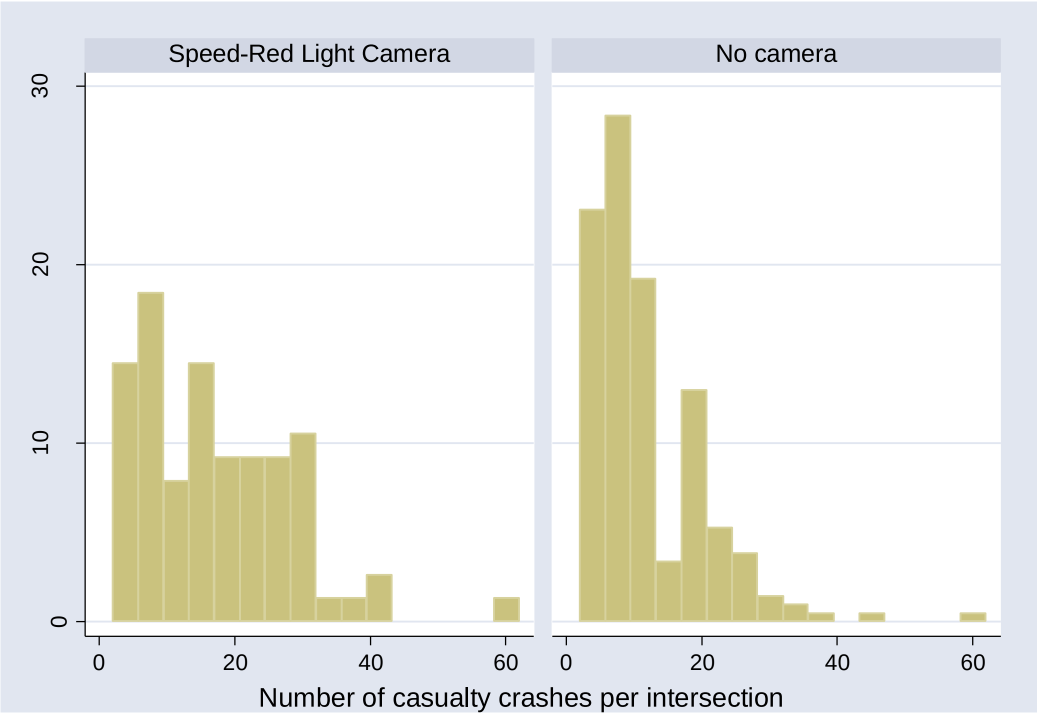

Figure 7.3.2
Casualty Crash Counts in before period by treatment site group, after removal of low crash frequency control intersections.

Table 7.3.1: Reduced Data Set Model information for RTM sensitivity, Goodness of Fit and Treatment effects using Poisson distribution modelling.

Information		Full set	RTM set	RTM set for targeted approaches
√Pearson's χ2/df) scale		0.917	1.623	1.552
Goodness of fit				
deviance	df=75	66.3	219	193
Scaled deviance		78.8	83.0	79.9
Pearson χ2		63.1	197	178
Scaled Pearson χ2		75.0	75.0	74.0
Log Likelihood		35746	14148	12574
Log Likelihood with scaling		42510	5374	5218

Table 7.3.2: Summary statistics for casualty crash counts per intersection by period and treatment type for the reduced data set.

		N of sites	mean	std dev	min	max
before	control	208	11.7	8.3	2	59
	treatment	76	17.2	11.3	2	62
after	control	311	3.2	2.8	1	16
	treatment	74	4.9	3.3	1	14

7.4 APPENDIX D: ESTIMATED PERCENTAGE CHANGE IN CRASHES FOR EACH TREATMENT SITE

Table 7.4.1: Summary of percentage change in casualty crash frequency for each treatment site.

			% change in crash frequency (-ve value is reduction, +ve value is increase)			
Treatment Intersection	**Postcode**	**Site ID**	**estimate**	**Wald 95% confidence limits**	**Estimate std err.**	**p-value**
ELIZABETH STREET & LATROBE STREET, MELBOURNE	3000	A12	-11	(-58 , 92)	0.39	0.77
ELIZABETH STREET & VICTORIA STREET, MELBOURNE	3000	A25	-37	(-79 , 89)	0.56	0.41
FLINDERS STREET & WILLIAM STREET, MELBOURNE	3000	C03&C01	-48	(-72 , -3)	0.32	0.04
SWANSTON STREET & VICTORIA STREET, MELBOURNE	3000	C25	11	(-44 , 120)	0.35	0.77
HODDLE HIGHWAY & VICTORIA STREET, MELBOURNE	3002	C04&C02	-63	(-87 , 9)	0.55	0.07
NICHOLSON STREET & VICTORIA STREET, MELBOURNE	3002	C08&C05	-31	(-69 , 56)	0.41	0.38
ALBERT STREET & NICHOLSON STREET, MELBOURNE	3002	C13	0	(-57 , 129)	0.43	0.99
HAWKE STREET & KING STREET, MELBOURNE	3003	B01	-90	(-99 , -22)	1.03	0.03
PEEL STREET & VICTORIA STREET, MELBOURNE	3003	C10	61	(-22 , 235)	0.37	0.20
LATROBE STREET & SPENCER STREET, MELBOURNE	3003	C21	-70	(-93 , 32)	0.76	0.11
ST KILDA ROAD & UNION STREET, PORT PHILLIP	3004	A11	-33	(-76 , 83)	0.51	0.43
BARKLY STREET & GORDON STREET, MARIBYRNONG	3011	A13	-54	(-90 , 105)	0.77	0.31
GEELONG ROAD & SOMERVILLE ROAD, MARIBYRNONG	3012	A37	-52	(-82 , 31)	0.51	0.15
ASHLEY STREET & CHURCHILL AVENUE, MARIBYRNONG	3012	C35	-75	(-93 , -8)	0.66	0.04
BALLARAT ROAD & DUKE STREET, BRIMBANK	3020	A07	-44	(-80 , 57)	0.53	0.27
BARRY ROAD & KING STREET, HUME	3047	C07	-78	(-95 , -2)	0.77	0.05
FLEMINGTON ROAD & GATEHOUSE STREET, MELBOURNE	3051	B02	-34	(-79 , 105)	0.58	0.48
PRINCES STREET & RATHDOWNE STREET, MELBOURNE	3053	C34	-30	(-72 , 79)	0.48	0.46
OHEA STREET & SUSSEX STREET, MORELAND	3058	A18	-3	(-80 , 374)	0.81	0.97
BARRY ROAD & HUME HIGHWAY, HUME	3061	A91	-40	(-85 , 142)	0.71	0.47
ALEXANDRA PARADE & SMITH STREET, YARRA	3065	A00	10	(-69 , 290)	0.64	0.88
ALEXANDRA PARADE & GEORGE STREET, YARRA	3065	A03	-51	(-94 , 325)	1.10	0.52
JOHNSTON STREET & WELLINGTON STREET, YARRA	3066	A50	38	(-55 , 328)	0.58	0.57
ARTHURTON ROAD & ST GEORGES ROAD, DAREBIN	3070	C20	-29	(-71 , 75)	0.46	0.46
BELL STREET & PLENTY ROAD, DAREBIN	3072	C24	-29	(-69 , 62)	0.42	0.42
BURKE ROAD & WHITEHORSE ROAD, BOROONDARA	3101	A21	-21	(-68 , 93)	0.46	0.60
BURKE ROAD & HARP ROAD, BOROONDARA	3102	A28	-10	(-81 , 314)	0.78	0.89
BURKE ROAD & THE BOULEVARD, BOROONDARA	3102	A75	214	(-54 , 2057)	0.98	0.25
DONCASTER ROAD & GARDENIA ROAD, BOROONDARA	3104	A85	-13	(-84 , 388)	0.88	0.88
MACEDON ROAD & MANNINGHAM ROAD, MANNINGHAM	3107	A51	133	(-63 , 1385)	0.94	0.37
HIGH STREET & LYNNWOOD PARADE, MANNINGHAM	3107	A89	40	(-75 , 672)	0.87	0.70
BURWOOD ROAD & GLENFERRIE ROAD, BOROONDARA	3122	A22	-35	(-83 , 153)	0.70	0.53
GLEN IRIS ROAD & TOORAK ROAD, BOROONDARA	3124	A76	-100	(-100 , *)	6950.53	1.00
MONT ALBERT ROAD & UNION ROAD, BOROONDARA	3127	A56 &B23	-69	(-97 , 183)	1.12	0.30
ARNOLD STREET & ELGAR ROAD, WHITEHORSE	3128	A42	-54	(-95 , 310)	1.12	0.49
ELGAR ROAD & WHITEHORSE ROAD, WHITEHORSE	3128	B10	-42	(-82 , 85)	0.60	0.35
DONCASTER-MORDIALLOC ROAD & EASTERN FREEWAY, WHITEHORSE	3129	A41	2	(-82 , 477)	0.89	0.99
STATION STREET & THAMES STREET, WHITEHORSE	3129	C09	-29	(-79 , 139)	0.62	0.58
SURREY ROAD & WHITEHORSE ROAD, WHITEHORSE	3130	C15	-49	(-81 , 37)	0.50	0.18
RINGWOOD STREET & WHITEHORSE ROAD, MAROONDAH	3134	C32	-10	(-59 , 99)	0.40	0.80
DORSET ROAD & MOUNT DANDENONG ROAD, MAROONDAH	3136	B26	-24	(-77 , 146)	0.60	0.64
ALEXANDRA AVENUE & CHURCH STREET, STONNINGTON	3141	C06	-23	(-68 , 88)	0.45	0.57
DOMAIN ROAD & HODDLE HIGHWAY, MELBOURNE	3141	C11	-48	(-83 , 58)	0.56	0.25
ORRONG ROAD & PRINCES HIGHWAY, GLEN EIRA	3143	A17	42	(-47 , 278)	0.50	0.48
BELGRAVE ROAD & PRINCES HIGHWAY, GLEN EIRA	3145	C26	45	(-36 , 231)	0.42	0.37
HIGH STREET & SUMMERHILL ROAD, BOROONDARA	3146	A49	1	(-89 , 856)	1.15	0.99
HIGH STREET ROAD & SPRINGVALE ROAD, MONASH	3150	B17	-52	(-84 , 45)	0.56	0.19
BLACKBURN ROAD & BURWOOD HIGHWAY, WHITEHORSE	3151	C17	25	(-47 , 192)	0.43	0.61
BORONIA ROAD & WANTIRNA ROAD, KNOX	3152	A06	-46	(-81 , 57)	0.55	0.26
MOUNTAIN HIGHWAY & WANTIRNA ROAD, KNOX	3152	A57	-59	(-89 , 50)	0.67	0.18
HIGH STREET ROAD & STUD HIGHWAY, KNOX	3152	C23	-49	(-82 , 46)	0.54	0.21
BAYSWATER ROAD & CANTERBURY ROAD, MAROONDAH	3153	B12	-52	(-88 , 91)	0.70	0.30
BURWOOD HIGHWAY & SELMAN AVENUE, KNOX	3156	B25	20	(-71 , 407)	0.73	0.80
GLEN EIRA ROAD & KOOYONG ROAD, GLEN EIRA	3161	A45	-85	(-98 , 19)	1.05	0.07

Table 7.4.1: Summary of percentage change in casualty crash frequency for each treatment site. Continued.

CORRIGAN ROAD & LIGHTWOOD ROAD, DANDENONG	3174	A84	-40	(-89 , 224)	0.86	0.56
LONSDALE STREET & WEBSTER STREET, DANDENONG	3175	A09	-30	(-74 , 89)	0.51	0.48
GLADSTONE ROAD & HEATHERTON ROAD, DANDENONG	3175	A46	-40	(-85 , 134)	0.70	0.46
FERNTREE GULLY ROAD & STUD HIGHWAY, KNOX	3179	A86	23	(-58 , 256)	0.54	0.71
ALMA ROAD & CHAPEL STREET, PORT PHILLIP	3182	B22	11	(-64 , 245)	0.58	0.86
CARLISLE STREET & HOTHAM STREET, PORT PHILLIP	3183	B14	-16	(-75 , 187)	0.62	0.79
CHARMAN ROAD & PARK ROAD, KINGSTON	3192	A23	79	(-46 , 490)	0.61	0.34
BAY ROAD & KAREN STREET, KINGSTON	3192	C16	75	(-26 , 313)	0.44	0.20
NEPEAN HIGHWAY & WARRIGAL HIGHWAY, KINGSTON	3194	C19	-2	(-61 , 147)	0.47	0.97
KINGS WAY & PARK STREET, PORT PHILLIP	3205	C14	-15	(-64 , 97)	0.43	0.70
PRINCES HIGHWAY & THE BOULEVARD, GEELONG	3214	A55	3	(-74 , 308)	0.70	0.97
BELMONT-CORIO ROAD & NOBLE STREET, GEELONG	3220	A66	-100	(-100 , *)	6950.53	1.00
NEWTOWN-WHITTINGTON ROAD & PRINCES HIGHWAY, GEELONG	3220	A92	4	(-72 , 289)	0.67	0.95
CALDER HIGHWAY & LODDON VALLEY HIGHWAY, BENDIGO	3550	A81	-66	(-96 , 190)	1.09	0.32
MURRAY VALLEY HIGHWAY & NORTHERN HIGHWAY, CAMPASPE	3564	A59	-25	(-90 , 447)	1.01	0.78
PRINCES HIGHWAY & WEBB STREET, CASEY	3805	A16	-44	(-74 , 19)	0.38	0.13

* standard error too high for estimate of upper confidence interval due to 0 treatment crashes in the after period.
Site A02, Terminal Drive and Centre Road, Melbourne Airport, PC 3045 was excluded from analysis.

7.5 APPENDIX E: ESTIMATED PERCENTAGE CHANGE IN TARGETTED APPROACH CRASHES FOR EACH TREATMENT SITE

Table 7.5.1: Summary of percentage change in casualty crash frequency for each treatment site for targeted approach crashes.

			% change in crash frequency (-ve value is reduction, +ve value is increase)			
Treatment Intersection	**Postcode**	**Site ID**	**estimate**	**Wald 95% confidence limits**	**Estimate std err.**	**p-value**
ELIZABETH STREET & LATROBE STREET, MELBOURNE	3000	A12	-76	(-97 , 89)	1.05	0.18
ELIZABETH STREET & VICTORIA STREET, MELBOURNE	3000	A25	-100	(-100 , *)	11459.49	1.00
FLINDERS STREET & WILLIAM STREET, MELBOURNE	3000	C03&C01	-45	(-71 , 4)	0.32	0.07
SWANSTON STREET & VICTORIA STREET, MELBOURNE	3000	C25	-29	(-76 , 117)	0.57	0.55
HODDLE HIGHWAY & VICTORIA STREET, MELBOURNE	3002	C04&C02	-67	(-90 , 11)	0.62	0.07
NICHOLSON STREET & VICTORIA STREET, MELBOURNE	3002	C08&C05	-33	(-72 , 58)	0.44	0.36
ALBERT STREET & NICHOLSON STREET, MELBOURNE	3002	C13	-3	(-62 , 151)	0.48	0.96
HAWKE STREET & KING STREET, MELBOURNE	3003	B01	-100	(-100 , *)	11459.49	1.00
PEEL STREET & VICTORIA STREET, MELBOURNE	3003	C10	71	(-24 , 285)	0.41	0.19
LATROBE STREET & SPENCER STREET, MELBOURNE	3003	C21	-100	(-100 , *)	11459.49	1.00
ST KILDA ROAD & UNION STREET, PORT PHILLIP	3004	A11	-32	(-81 , 145)	0.66	0.56
BARKLY STREET & GORDON STREET, MARIBYRNONG	3011	A13	-54	(-94 , 273)	1.07	0.46
GEELONG ROAD & SOMERVILLE ROAD, MARIBYRNONG	3012	A37	-84	(-98 , 31)	1.07	0.09
ASHLEY STREET & CHURCHILL AVENUE, MARIBYRNONG	3019	C35	-86	(-98 , 17)	1.07	0.07
BALLARAT ROAD & DUKE STREET, BRIMBANK	3020	A07	-49	(-90 , 150)	0.81	0.41
BARRY ROAD & KING STREET, HUME	3047	C07	-100	(-100 , *)	11459.49	1.00
FLEMINGTON ROAD & GATEHOUSE STREET, MELBOURNE	3051	B02	-34	(-86 , 217)	0.80	0.61
PRINCES STREET & RATHDOWNE STREET, MELBOURNE	3053	C34	-55	(-90 , 105)	0.77	0.30
OHEA STREET & SUSSEX STREET, MORELAND	3058	A18	55	(-71 , 729)	0.86	0.61
BARRY ROAD & HUME HIGHWAY, HUME	3061	A91	-10	(-78 , 274)	0.73	0.88

Table 7.5.1: Summary of percentage change in casualty crash frequency for each treatment site for targeted approach crashes. Continued

Treatment Intersection	Postcode	Site ID	% change in crash frequency (-ve value is reduction, +ve value is increase) estimate	Wald 95% confidence limits	Estimate std err.	p-value
ALEXANDRA PARADE & SMITH STREET, YARRA	3065	A00	-45	(-94 , 384)	1.11	0.59
ALEXANDRA PARADE & GEORGE STREET, YARRA	3065	A03	-37	(-93 , 462)	1.12	0.68
JOHNSTON STREET & WELLINGTON STREET, YARRA	3066	A50	4	(-82 , 502)	0.90	0.97
ARTHURTON ROAD & ST GEORGES ROAD, DAREBIN	3070	C20	-34	(-77 , 93)	0.55	0.45
BELL STREET & PLENTY ROAD, DAREBIN	3072	C24	-78	(-97 , 74)	1.05	0.15
BURKE ROAD & WHITEHORSE ROAD, BOROONDARA	3101	A21	-53	(-90 , 128)	0.80	0.35
BURKE ROAD & HARP ROAD, BOROONDARA	3102	A28	-48	(-95 , 425)	1.18	0.58
BURKE ROAD & THE BOULEVARD, BOROONDARA	3102	A75	109	(-88 , 3563)	1.46	0.61
DONCASTER ROAD & GARDENIA ROAD, BOROONDARA	3104	A85	-13	(-92 , 816)	1.20	0.91
MACEDON ROAD & MANNINGHAM ROAD, MANNINGHAM	3107	A51	250	(-53 , 2529)	1.03	0.22
HIGH STREET & LYNNWOOD PARADE, MANNINGHAM	3107	A89	40	(-75 , 672)	0.87	0.70
BURWOOD ROAD & GLENFERRIE ROAD, BOROONDARA	3122	A22	-100	(-100 , *)	11459.49	1.00
MONT ALBERT ROAD & UNION ROAD, BOROONDARA	3127	A56 &B23	-62	(-96 , 249)	1.14	0.39
ARNOLD STREET & ELGAR ROAD, WHITEHORSE	3128	A42	-54	(-95 , 310)	1.12	0.49
ELGAR ROAD & WHITEHORSE ROAD, WHITEHORSE	3128	B10	-100	(-100 , *)	11459.49	1.00
DONCASTER-MORDIALLOC ROAD & EASTERN FREEWAY, WHITEHORSE	3129	A41	-100	(-100 , *)	11459.49	1.00
STATION STREET & THAMES STREET, WHITEHORSE	3129	C09	-32	(-82 , 149)	0.66	0.56
SURREY ROAD & WHITEHORSE ROAD, WHITEHORSE	3130	C15	-36	(-77 , 73)	0.51	0.38
RINGWOOD STREET & WHITEHORSE ROAD, MAROONDAH	3134	C32	-40	(-84 , 122)	0.67	0.44
DORSET ROAD & MOUNT DANDENONG ROAD, MAROONDAH	3136	B26	-100	(-100 , *)	11459.49	1.00
ALEXANDRA AVENUE & CHURCH STREET, STONNINGTON	3141	C06	-15	(-68 , 120)	0.49	0.73
DOMAIN ROAD & HODDLE HIGHWAY, MELBOURNE	3141	C11	-39	(-80 , 88)	0.57	0.39
ORRONG ROAD & PRINCES HIGHWAY, GLEN EIRA	3143	A17	-3	(-72 , 234)	0.63	0.96
BELGRAVE ROAD & PRINCES HIGHWAY, GLEN EIRA	3145	C26	-50	(-89 , 129)	0.78	0.37
HIGH STREET & SUMMERHILL ROAD, BOROONDARA	3146	A49	-100	(-100 , *)	11459.49	1.00
HIGH STREET ROAD & SPRINGVALE ROAD, MONASH	3150	B17	-100	(-100 , *)	11459.49	1.00
BLACKBURN ROAD & BURWOOD HIGHWAY, WHITEHORSE	3151	C17	-63	(-90 , 40)	0.68	0.14
BORONIA ROAD & WANTIRNA ROAD, KNOX	3152	A06	-35	(-81 , 117)	0.62	0.48
MOUNTAIN HIGHWAY & WANTIRNA ROAD, KNOX	3152	A57	-70	(-94 , 38)	0.79	0.12
HIGH STREET ROAD & STUD HIGHWAY, KNOX	3152	C23	-46	(-83 , 76)	0.60	0.31
BAYSWATER ROAD & CANTERBURY ROAD, MAROONDAH	3153	B12	13	(-81 , 578)	0.92	0.90
BURWOOD HIGHWAY & SELMAN AVENUE, KNOX	3156	B25	381	(-58 , 5369)	1.24	0.21
GLEN EIRA ROAD & KOOYONG ROAD, GLEN EIRA	3161	A45	-100	(-100 , *)	11459.49	1.00
KOOYONG ROAD & PRINCES HIGHWAY, GLEN EIRA	3161	A60	51	(-76 , 844)	0.93	0.66
HAWTHORN ROAD & INKERMAN ROAD, GLEN EIRA	3161	B24	14	(-90 , 1191)	1.24	0.92
NORTH ROAD & THOMAS STREET, BAYSIDE	3162	B20	129	(-86 , 3686)	1.43	0.56
CENTRE ROAD & SPRINGS ROAD, KINGSTON	3168	A39	93	(-74 , 1318)	1.02	0.52
BUCKLAND STREET & CENTRE ROAD, KINGSTON	3168	A83	-100	(-100 , *)	11459.49	1.00
CORRIGAN ROAD & HEATHERTON ROAD, DANDENONG	3174	A47	1	(-84 , 525)	0.93	0.99
CORRIGAN ROAD & LIGHTWOOD ROAD, DANDENONG	3174	A84	-62	(-96 , *)	1.13	0.39
LONSDALE STREET & WEBSTER STREET, DANDENONG	3175	A09	-69	(-93 , 45)	0.79	0.14
GLADSTONE ROAD & HEATHERTON ROAD, DANDENONG	3175	A46	-100	(-100 , *)	11459.49	1.00
FERNTREE GULLY ROAD & STUD HIGHWAY, KNOX	3179	A86	-32	(-87 , 258)	0.84	0.65
ALMA ROAD & CHAPEL STREET, PORT PHILLIP	3182	B22	-8	(-80 , 338)	0.79	0.92
CARLISLE STREET & HOTHAM STREET, PORT PHILLIP	3183	B14	-5	(-82 , 395)	0.84	0.95
CHARMAN ROAD & PARK ROAD, KINGSTON	3192	A23	-52	(-94 , 313)	1.10	0.50
BAY ROAD & KAREN STREET, KINGSTON	3192	C16	-43	(-84 , 112)	0.67	0.40
NEPEAN HIGHWAY & WARRIGAL HIGHWAY, KINGSTON	3194	C19	-62	(-96 , 227)	1.09	0.38
KINGS WAY & PARK STREET, PORT PHILLIP	3205	C14	-70	(-93 , 33)	0.76	0.11
PRINCES HIGHWAY & THE BOULEVARD, GEELONG	3214	A55	3	(-89 , 856)	1.14	0.98
BELMONT-CORIO ROAD & NOBLE STREET, GEELONG	3220	A66	-100	(-100 , *)	11459.49	1.00
NEWTOWN-WHITTINGTON ROAD & PRINCES HIGHWAY, GEELONG	3220	A92	-100	(-100 , *)	11459.49	1.00
CALDER HIGHWAY & LODDON VALLEY HIGHWAY, BENDIGO	3550	A81	-100	(-100 , *)	11459.49	1.00
MURRAY VALLEY HIGHWAY & NORTHERN HIGHWAY, CAMPASPE	3564	A59	-55	(-96 , 421)	1.25	0.52
PRINCES HIGHWAY & WEBB STREET, CASEY	3805	A16	-50	(-87 , 87)	0.67	0.30

* standard error too high for estimate of upper confidence interval due to 0 treatment crashes in the after period.
Site A02, Terminal Drive and Centre Road, Melbourne Airport, PC 3045 was excluded from analysis.