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An Evaluation of Automated Traffic Enforcement Operations in Western Australia, 1995 - 2013

C-MARC

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Abstract

Like many other jurisdictions in Australia, road traffic enforcement in Western Australia is partly undertaken using a camera based automated system. Key elements of the W.A. system include a mobile (vehicle or tripod mounted) speed camera program, a system of fixed speed cameras located on freeways in Perth and combined speed and red light cameras placed at 29 signalised intersections across metropolitan Perth. The broad aim of this project was to develop and apply a comprehensive evaluation framework for the WA speed enforcement strategy. The framework consists of both analysis of camera operations in data from the years 1995 to 2013 and outcome evaluation components. Analysis of operations data aimed to quantify the implementation of the automated enforcement strategy to inform the outcome evaluation and future program directions. The outcome evaluation aimed to quantify what the program, as implemented, has contributed to reducing road trauma in Western Australia and assist in estimating likely future benefits.

Evaluation of the automated enforcement program in Western Australia has shown the program to be associated with statistically significant crash reductions with estimated effects highest for fatal and serious injury crashes, the target of the Western Australian road safety strategy. Contributions to crash reductions of each camera type of the automated enforcement program have been estimated. During 2012, the automated enforcement program was estimated to be associated with an overall reduction in serious casualty crashes in W.A. of 5.6%. Analysis showed significant potential for additional fatal and serious crash savings through expansion of the automated enforcement program.

Keywords
Speed Camera, Red Light Camera, Process Evaluation, Outcome Evaluation, Crash, Injury, Statistical analysis

Preface

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Ethics Statement

Ethics approval was not required for this project.

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Contents

EXECUTIVE SUMMARY

Like many other jurisdictions in Australia, road traffic enforcement in Western Australia is partly undertaken using a camera based automated system. Key elements of the W.A. system include a mobile (vehicle or tripod mounted) speed camera program, a system of fixed speed cameras located on freeways in Perth, and combined speed and red light cameras placed at 29 signalised intersections across metropolitan Perth. The broad aim of this project was to develop and apply a comprehensive evaluation framework for the WA speed enforcement strategy. The framework consists of both analysis of camera operations in data from the years 1995 to 2013 and outcome evaluation components. Analysis of operations data aimed to quantify the implementation of the automated enforcement strategy to inform the outcome evaluation and future program directions. The outcome evaluation aimed to quantify what the program, as implemented, has contributed to reducing road trauma in Western Australia and assist in estimating likely future benefits.

The evaluation was based on data identifying the placement and operation of automated enforcement technologies in operation in Western Australia for the years 1995 to 2013, and included the three key technologies utilised in Western Australia; mobile speed cameras; fixed intersection speed and red light cameras; and, fixed spot speed cameras used within the Perth freeway network. Evaluation of the automated enforcement program in Western Australia has shown the program to be associated with statistically significant crash reductions with estimated effects highest for fatal and serious injury crashes, the target of the Western Australian road safety strategy. Contributions to crash reductions of each camera type of the automated enforcement program have been estimated. Evaluation design was informed by the international literature on traffic camera enforcement evaluation as well as the specific operation practices in place in Western Australia. Operational practices have also been interrogated to guide interpretation of the estimated camera effects as well as to provide comment on how the automated enforcement program might be enhanced in the future to provide even greater crash savings.

Fixed Speed Cameras

Evaluation of the impact of 25 of the current 29 combined speed and red light camera installations at signalised intersections estimated a statistically significant 37% reduction in serious casualty crashes at enforced intersections associated with the cameras. Operations data showed a significant prevalence of speeding at these intersections suggesting the speed enforcement component to the cameras has been a significant contributor to their effectiveness.

Evaluation of the fixed freeway speed camera system focused on 4 of the current 5 camera locations in operation. Those sites evaluated were the original 4 sites which were operated with 1 speed camera being rotated between the 4 camera locations. Based on other evaluations in the literature, effects were measured within 1km of the camera site on the same road. However, evaluation results were somewhat inconclusive due to the limited time period of crash data available after installation of the cameras (3 to 13 months across the 4 sites evaluated). Although not statistically significant, the results did indicate that the estimated reductions in serious casualty crashes were consistent in magnitude to those estimated for the intersection cameras that had the speed monitoring upgrades. They were also generally consistent with estimates of effectiveness of the same camera type in other jurisdictions. Ongoing monitoring of the effectiveness of this camera type is recommended.

Mobile Speed Cameras

The mobile speed camera program in W.A. appears to have been operated on the principles of random road watch, using highly overt enforcement, at a large number of sites, with low site visitation frequency over most sites. Analysis of the operations data provided identified nearly 10,000 sites where the WA mobile camera program has used, more than 3 times that used under any other major mobile programs in Australia. W.A. Police report that up to 14,000 sites have been used over the program history with around 4,000 sites operational in recent times. The sites operated were within 500m of the majority of the identified crash population in metropolitan Perth. In regional areas the cameras are used predominantly in south-west areas of the state where crash densities are the highest. Operations are confined largely to the daytime hours of 6am to 8pm although can extend to 9pm with the shift ending at 10pm. Enforcement during night hours has increased since the period covered by the evaluation data. The number of mobile camera enforcement hours is relatively small compared to other Australian jurisdictions operating a mobile camera program. The number of mobile speed camera sessions delivered per month has also been highly variable over the life of the program.

Evaluation of the crash effects associated with the W.A. mobile camera program showed a strong relationship between the number of sessions undertaken in a month and reductions in fatal and serious casualty crashes within 500m of sites where a speed camera had been used. The association was stronger for fatal crashes and in regional W.A., compared to Perth. The relationship between the number of monthly sessions delivered and estimated fatal and serious casualty crash reductions for both a 500m and 1km radius are shown in Figures E1 and E2 for Perth and regional W.A. respectively.

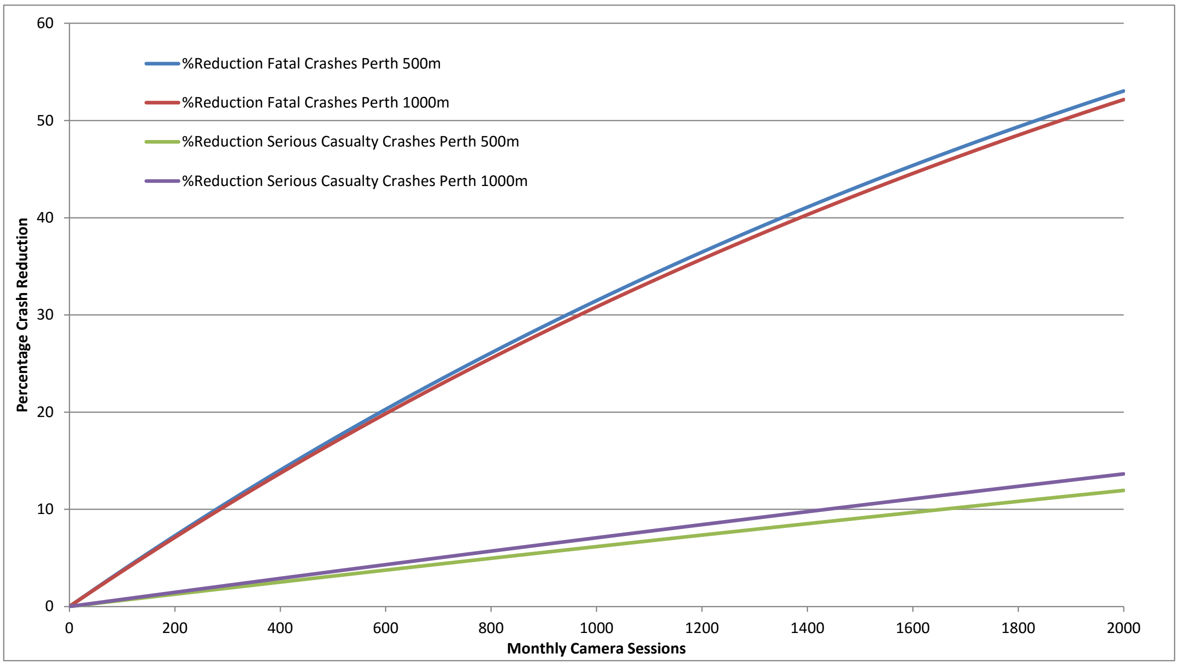


Figure E.1 *Percentage crash reduction by monthly number of mobile speed camera sessions and distance from mobile speed camera site: Perth*

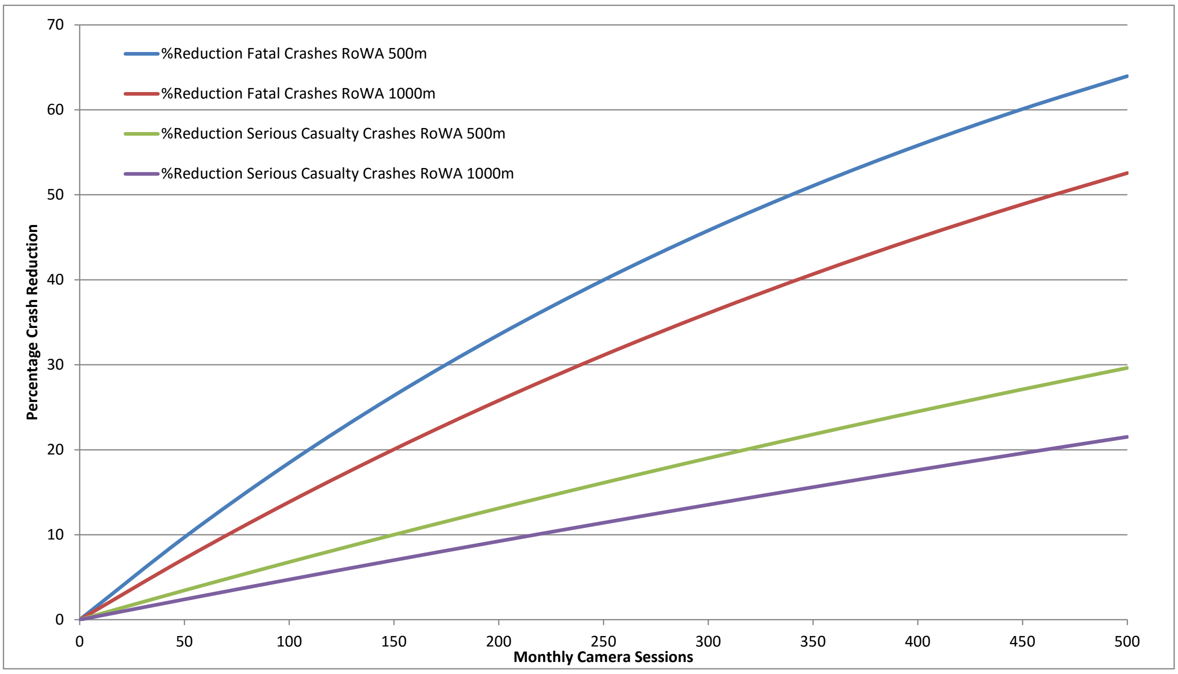


Figure E.2 *Percentage crash reduction by monthly number of mobile speed camera sessions and distance from mobile speed camera site: Rest of W.A.*

At the level of enforcement effort delivered in 2014, the program was associated with a 36% reduction in fatal crashes and a 7% reduction in all serious casualty crashes within 500m of a camera site in Perth. In regional W.A. the corresponding reductions were 36% for fatal crashes and 14% for serious casualty crashes.

Overall Program Crash Effects

Given the coverage and level of camera operations in 2012, the automated enforcement program was estimated to be associated with an overall reduction in serious casualty crashes in W.A. during 2012 of 5.6%. This comprised a 6.8% reduction in Perth and a 3.3% reduction in the rest of W.A. Total crash numbers and absolute and expected crash savings, overall and for each program element, are shown in Table E1. The mobile speed camera program was responsible for nearly 70% of this reduction, representing 100% of the reduction in regional areas and 61% in Perth. The contribution of the fixed freeway cameras was only 6.8% of the overall reduction (or a 0.4% reduction in total W.A. road trauma) or 8.3% (0.6% of total W.A. road trauma) in Perth. Intersection cameras made up the remainder of the reductions.

Table E.1 *Overall absolute and percentage savings in serious casualty crashes associated with the W.A. automated enforcement program and it's elements*

Region	Measure	Estimate
Perth	Observed Crashes	1437
	Savings Fixed Freeway	9
	Savings Intersection	33
	Savings Mobile Speed	64
	Expected Crashes with No Automated Enforcement	1542
	Total % Savings Automated Enforcement	6.84%
	% Savings Fixed Freeway	0.57%
	% Savings Intersection	2.11%
	% Savings Mobile Speed	4.15%
RoWA	Observed Crashes	725
	Savings Fixed Freeway	0
	Savings Intersection	0
	Savings Mobile Speed	25
	Expected Crashes with No Automated Enforcement	750
	Total % Savings Automated Enforcement	3.28%
	% Savings Fixed Freeway	0.00%
	% Savings Intersection	0.00%
	% Savings Mobile Speed	3.28%
All	Observed Crashes	2162
	Savings Fixed Freeway	9
	Savings Intersection	33
	Savings Mobile Speed	89
	Expected Crashes with No Automated Enforcement	2292
	Total % Savings Automated Enforcement	5.67%
	% Savings Fixed Freeway	0.38%
	% Savings Intersection	1.42%
	% Savings Mobile Speed	3.87%

Potential Future Program Benefits

Further analysis showed significant potential for additional fatal and serious crash savings through expansion of the automated enforcement program. Under the long term expansion targets for the program set by the W.A. Government, including major expansion of the fixed camera network and modest increases in mobile camera use in regional W.A., total serious casualty crash reductions could be increased to 11% (double the current level). Major expansion of the mobile speed camera program and increases in the fixed speed camera network, as recommended in independent strategic advice, would increase overall serious casualty crash reductions to 14%. Combining both strategies would increase serious casualty crash savings to over 16%. Evaluation shows that implementation of any of these strategies is justified on the basis of expected crash savings, although the optimum program based on economic benefits is yet to be determined. Significant increases in the use of mobile speed cameras would place higher demand on the processing system. W.A. Police report that there is no current limit on the processing system capacity with staffing able to be increased to meet demand.

Ongoing monitoring and evaluation of the program is recommended. To support this, improvements to data collection on program operations and enhancement of data accessibility is critical and should be implemented as soon as practicable.

BACKGROUND AND AIMS

Safe speeds are often considered the fourth pillar of the safe system framework for road safety management. Speed limit setting is integral in specifying a safe system to ensure human tolerances are not exceeded within the design parameters of the vehicle and road infrastructure elements of the system. Simply setting speed limits does not guarantee that road users will comply with the set limits. Consequently, in most jurisdictions, enforcement of speed limits by police is necessary to encourage road user compliance with set speed limits in order for safe system operation and outcomes to be realised.

Western Australia has developed a strategy for speed enforcement based on best practice derived from strong underlying scientific principles covering both manual and camera based automatic enforcement (Cameron, 2006; Cameron & Delaney, 2008). Although there is an expectation of the crash reduction outcomes from this strategy based on the prior experience from which the strategy was developed, actual effectiveness needed to be measured through comprehensive formal evaluation to ensure the strategy has been effective and to provide feedback for fine tuning its further implementation. There are two important elements required for the strategy to be effective. The first is that the strategy has been implemented as specified. The second is that the elements of the strategy implemented have been effective in reducing either the incidence of crashes or the severity of outcomes from crashes or a combination of both.

The broad aim of this project was to develop and apply a comprehensive evaluation framework for the WA speed enforcement strategy. The framework consists of both process and outcome evaluation components. The process component of the evaluation aimed to assess the effectiveness in implementing the strategy according to the best practice guidelines. The outcome evaluation aimed to quantify what the program as implemented has contributed to reducing road trauma in Western Australia.

To achieve these aims, the project has developed a speed enforcement evaluation framework for Western Australian covering both process and outcome evaluation. The process evaluation component of the study considers implementation progress of the full strategy and comment on potential for further enhancing strategy implementation. This has been achieved through analysis of the operations of automated speed enforcement technologies in Western Australia and review of these against the recommended operational levels and principles described in the speed enforcement strategy of Cameron and Delaney (2008). The outcome component of the evaluation framework includes methodology to estimate the crash effects associated with each element of the strategy as well as for the strategy overall.

Together the process and outcome evaluation ascertain whether strategy implementation has followed the recommended best practice path, assist in understanding where the process might be improved, and assess whether the crash reduction benefits predicted have been realised.

This report has been structured in three main sections. The first describes the process evaluation component in the form of an analysis of automated speed enforcement operation in Western Australia and an assessment of these against the strategy of Cameron and Delaney (2008). The second describes the outcome evaluation of the W.A. automated enforcement strategy in terms of its impact on crash frequency and severity. Section 3 draws the process and outcome evaluation results together and discusses the implications for future automated speed enforcement in W.A.

SECTION 1 AN ANALYSIS AND PROCESS REVIEW OF AUTOMATED TRAFFIC ENFORCEMENT IN WESTERN AUSTRALIA

1.1 CAMERA OPERATIONS DATA

Data on the placement and operation of automated enforcement technologies in operation in Western Australia were extracted from the information systems of the traffic camera management section of Western Australian Police for the full years 1995 to 2013. Information was obtained on the following three key technologies in use in Western Australia;

- Mobile speed cameras
- Fixed intersection speed and red light cameras
- Fixed spot speed cameras used within the Perth freeway network

Information about the location (placement) of the technology was a critical data source for the evaluation. For each fixed camera placement, a description of the camera location was provided along with latitude and longitude of the camera placement. Location information for mobile cameras was more problematic and a process for obtaining full information on mobile camera locations needed to be developed for the evaluation.

Location of Mobile camera sites

For the mobile speed camera program, each unique location in which a camera had been placed was provided with a location identifier code and a description of the site (typically road name and nearby intersecting road names or landmarks). Around one third of the mobile camera locations were also provided with latitude and longitude of the camera site. For the remaining sites the location latitude and longitude were identified using a hybrid methodology. An automated GIS process was first employed based on the described location of the camera. For those sites not having a latitude and longitude assigned through this process due to road names or landmarks not being recognised, manual identification of the latitude and longitude of the site was undertaken.

For the evaluation analysis it was important that the location of the speed camera deployment site could be identified using GPS co-ordinates. From the 210,824 deployment sessions there were 2,429 sessions that did not contain any information about the location of the deployment site (e.g. no street names or GPS details) these sessions were excluded from further analysis, leaving data for 208,395 deployment sessions.

Table 1.1 outlines the number of deployment sessions per year that were excluded from the analysis due to an inability to identify the deployment site location because of missing GPS and street data. Due to the lack of any locational data it was not possible to identify if this excluded data represented 2,429 unique mobile camera locations or less if some locations had been used multiple times. It is evident form the table that missing location data was more prevalent in the earlier years of the program with location data quality issues seeming to have been largely rectified from 2008 onwards.

Table 1.1 *Number of deployment sessions per year that were excluded from analysis due to missing GPS and location information*

Year	No. of Deployment sessions excluded due to missing location details and GPS	Year	No. of Deployment sessions excluded due to missing location details and GPS
1995	97	2005	181
1996	127	2006	152
1997	72	2007	101
1998	321	2008	0
1999	340	2009	0
2000	302	2010	0
2001	300	2011	0
2002	156	2012	0
2003	119	2013	0
2004	161	**Total excluded**	**2 429**

A large percentage of the data (88,209 out of the 208,395 remaining deployment sessions) was missing GPS coding. As analysis was focused on deployment site location the remaining 208,395 deployment sessions were screened according to their location code to identify unique deployment sites. This process identified that the 208,395 deployment sessions had all been conducted at 10,105 unique mobile speed camera deployment site locations. Of these unique locations 3,023 had GPS codes provided in the original dataset. The remaining 7,082 sites were missing GPS codes.

To support the inclusion of these sites that were missing location data in further data analysis, attempts were then made to assign the remaining 7,082 unique locations with accurate GPS location codes. Two methods were used in this process. Firstly, the street intersection data from each site was matched with intersection data obtained from the crash data sets and GPS codes from the crash data were extracted for any matching intersections found. This resulted in 1,771 sites matching with the crash data locations and having missing GPS data filled.

The remaining 5,311 sites still requiring GPS data were then searched manually using google maps. Of these 5,311 sites still requiring GPS coding a further 110 sites (356 sessions) were excluded from the final data for analysis because, although they did contain some location information, this information was insufficient to enable accurate identification of the location and therefore GPS coding could not be assigned. The GPS coding for the remaining 5,201 sites was sourced using manual google map searches. It is also worth noting that for these sites for which a GPS was allocated using one of the above two matching methods, the GPS was matched with the intersection location however, the actual mobile speed camera session may have occurred further down the road.

This process of mapping sites to the nearest intersection could result in a small GPS coding error within the urban Perth data where the nearest intersection may be 100-200 metres away from where the actual mobile camera session was situated however, the error distance may be greater for rural session sites. As shown in Table 1.2 a total of 9,995 mobile speed camera site locations were used in the final analysis.

Table 1.2 *GPS coding source for mobile speed camera sites used in final analysis*

GPS coding source	No. of unique deployment sites
Police original dataset	3023
Crash data matching	1771
Manual Google Maps search	5201
Total	**9995**

Camera Operations Data Fields

Camera operations data extracted contained a number of important fields for analysis. For fixed intersection cameras where the camera is in operation almost continuously (apart from repair and maintenance) the operation data included:

- Number of vehicles checked per time period
- Number of vehicles exceeding the speed limit
- Number of infringements issued in total and within speed bins (ranges of speeds)

For the freeway fixed speed cameras which are rotated through sites and for the mobile camera program additional information provided included:

- Camera identifier
- Location code
- Session start and end date and time

1.2 MOBILE SPEED CAMERA OPERATIONS

1.2.1 DEPLOYMENT SITES

To the end of 2013, mobile speed cameras in Western Australia have been used at 9995 distinct locations across the state although W.A. Police report that this number might be up to 14,000 with 4,000 in regular operation in recent years. This is more than for any other mobile camera program in Australia. For example in Victoria and Queensland typically only 2500-3500 distinct sites have been used, these are generally selected based on crash history or through recommendations from the community or local councils identifying a speeding problem.

WAPOL has 4 criteria that locations selected for camera enforcement must comply with. Before a new location is added to the database it is checked to ensure compliance with the following rules:

- Fatal/serious crashes at the location within 3 years
- Complaint/hoon locations
- Where 15% of vehicles are exceeding the posted speed limit
- School Zones

A weekly camera location roster is generated to direct camera placement. Camera operators must attend their allocated locations. Mobile speed cameras in WA are not operated by sworn police members but are operated by Police Staff who are public servants. This is in contrast to Victoria where camera operations have been contracted to a private operator.

Around 78% of mobile speed camera sites used are in the Metropolitan Perth area with the remaining sites situated in regional Western Australia. The spatial distribution of these sites will be described in a later section.

1.2.2 MOBILE SPEED CAMERA SESSIONS

The mobile speed camera dataset identified that 203,852 deployment sessions, where there was location information for the deployment, occurred over the nineteen year period (1995-2013). Table 1.3 lists the number of deployment sessions conducted per year. While there were less mobile speed camera sessions during the earlier years (1995-1997), from 1998 to 2006 the number of sessions conducted ranged from approximately 10,000 to 13,000. There were slight declines in deployment during 2007, 2008, and 2010, increasing to the current rates of around 17,000 sessions in 2012-13.

Table 1.3 *Number of mobile speed camera sessions per year 1995-2013*

Year of deployment	Number of sessions	% of total years
1995	4517	2.2
1996	6650	3.3
1997	2152	1.1
1998	10893	5.3
1999	12434	6.1
2000	12442	6.1
2001	13217	6.5
2002	13333	6.5
2003	12399	6.1
2004	11732	5.8
2005	10587	5.2
2006	9891	4.9
2007	8660	4.2
2008	8727	4.3
2009	9937	4.9
2010	8559	4.2
2011	13421	6.6
2012	16928	8.3
2013	17373	8.5
Total	**203852**	**100.0**

The month of the year in which the sites were operated is outlined in Table 1.4 and further per year detail is provided in Appendix A. While sites are regularly operated across all months of the year, overall more sites were operated in January (12.2%), followed by August (10.2%). In the latest five years (2009-2013) more sites were operated in August (10.6%), followed by October (9.9%), see Appendix A.

Table 1.4 *Number of mobile camera sites by month of the year*

Month of year	Number of sites	Percentage %
January	24796	12.2
February	19197	9.4
March	16502	8.1
April	14445	7.1
May	13932	6.8
June	11089	5.4
July	14494	7.1
August	20798	10.2
September	17583	8.6
October	18220	8.9
November	17914	8.8
December	14882	7.3
Total	**203852**	**100.0**

There has been a relatively even spread of mobile speed camera sites scheduled across all days of the week, over the nineteen years of data (see Table 1.5)

Table 1.5 *Year and Day of week of mobile speed camera sessions, 1995-2013*

Year of session	Day of week							Total sessions / year
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
1995	608	666	689	620	760	601	573	4517
1996	995	1006	953	921	986	937	852	6650
1997	300	293	313	284	380	299	283	2152
1998	1471	1519	1667	1565	1680	1486	1505	10893
1999	1661	1686	1863	1740	1925	1777	1782	12434
2000	1690	1710	1794	1752	1911	1790	1795	12442
2001	1849	1784	1916	1897	2104	1885	1782	13217
2002	1917	1905	1969	1855	1976	1863	1848	13333
2003	1754	1711	1904	1649	1791	1837	1753	12399
2004	1625	1647	1721	1689	1664	1741	1645	11732
2005	1500	1471	1600	1430	1439	1615	1532	10587
2006	1318	1337	1524	1433	1344	1476	1459	9891
2007	1290	1219	1323	1287	1225	1183	1133	8660
2008	1299	1185	1285	1169	1165	1317	1307	8727
2009	1398	1355	1518	1364	1391	1462	1449	9937
2010	1216	1181	1352	1198	1249	1236	1127	8559
2011	1824	1843	2123	1913	1886	2008	1824	13421
2012	2429	2218	2652	2282	2424	2515	2408	16928
2013	2540	2417	2814	2360	2389	2394	2459	17373
Total	**28684**	**28153**	**30980**	**28408**	**29689**	**29422**	**28516**	**203852**

As shown in Table 1.6 the majority of mobile camera sessions were deployed in the Perth metropolitan area. In the most current two years of data (2012-2013) the metropolitan/regional mobile speed camera sessions ratio was greater than 5:1 meaning that around 84% of operations were in Metropolitan Perth.

Table 1.6 *Broad region where mobile speed camera session was conducted by year*

Year	WA Region	
	Metropolitan	Regional
1995	4397	120
1996	6392	258
1997	2026	126
1998	10119	774
1999	11334	1100
2000	11540	902
2001	11794	1423
2002	11861	1472
2003	11074	1325
2004	10396	1336
2005	9245	1342
2006	8268	1623
2007	6328	2332
2008	6825	1902
2009	8043	1894
2010	6418	2141
2011	11118	2303
2012	14249	2679
2013	14582	2791
Total	**176009**	**27843**

Table 1.7 outlines the police district in which the mobile speed camera sessions were located. Further detail outlining the district by year is provided in Appendix B. Table 1.7 shows that use of the mobile camera program in remote areas of W.A. such as the Kimberley, Pilbara and Goldfields-Esperance areas is extremely limited.

Table 1.7 *District where mobile speed camera session was conducted*

District	Frequency	Percentage %
Central Metropolitan	28903	14.2
East Metropolitan	22021	10.8
Goldfields-Esperance	214	0.1
Great Southern	3465	1.7
Kimberley	132	0.1
Mid West-Gascoyne	3449	1.7
North West Metropolitan	23451	11.5
Peel	18713	9.2
Pilbara	306	0.2
South East Metropolitan	30041	14.7
South Metropolitan	20863	10.2
South West	13121	6.4
West Metropolitan	32017	15.7
Wheatbelt	7156	3.5
Total	**203852**	**100.0**

For the following analysis, some variables of interest had missing data, the final number of mobile camera sessions included in each of the specific analyses will be reported as "N=".

As shown in Table 1.8, over the 19 year period the majority of mobile speed camera sessions monitored up to 5,000 vehicles per session (190,591 sessions).

Table 1.8 *Number of vehicles monitored per mobile speed camera session by year (N= 193,602)*

Year of deployment	Number of vehicles monitored per session					Total sessions
	1 - 4999	5000 - 9999	10000 - 14999	15000 - 19999	20000 +	
1995	4449	8	0	0	0	4457
1996	6571	17	0	0	0	6588
1997	2135	3	0	0	0	2138
1998	10815	29	0	1	0	10845
1999	12169	115	4	0	2	12290
2000	12174	95	2	0	1	12272
2001	12997	67	3	0	0	13067
2002	13132	83	3	0	0	13218
2003	12058	210	35	3	8	12314
2004	11386	232	12	10	14	11654
2005	10288	238	5	1	2	10534
2006	9580	135	4	0	2	9721
2007	8344	175	5	0	0	8524
2008	8218	223	5	0	0	8446
2009	9445	173	8	0	0	9626
2010	6164	124	4	0	0	6292
2011	7888	189	14	0	0	8091
2012	16119	376	30	0	0	16525
2013	16659	314	21	0	6	17000
Total	**190591**	**2806**	**155**	**15**	**35**	**193602**

Table 1.9 outlines the speed limit zone in which each of the mobile speed camera sessions were located across the nineteen year data collection period and the percentage of sites scheduled within that zone across each year. Further yearly detail is provided in Appendix C. The majority of mobile speed camera sessions 85,710 (43.7%) were conducted within a 60km/h speed limit zone followed by the 70km/h zone 41,687 (21.3%). Further investigation would be necessary to identify if this was reflective of the general travel exposure in each speed zone or whether operations are weighted more highly towards particular speed zones.

Table 1.9 *Speed limit of site where mobile speed camera was located (N=195,978)*

Speed limit of site location	Frequency	Percent %
40	8024	4.1
50	5068	2.6
60	85710	43.7
70	41687	21.3
80	26279	13.4
90	9254	4.7
100	13172	6.7
110	6784	3.5
Total	**195978**	**100.0**

Offence count data represents the number of vehicles detected exceeding the posted speed limit however, for various reasons (e.g. tolerance limits, inability to locate vehicle driver etc.) not all offences detected result in an infringement. In the dataset both offence count and infringement data was available for 177,423 sessions from which 8,005,961 speeding offences were detected. From these 6,343,733 (79.2%) resulted in an infringement.

From the 178,482 mobile speed camera sessions with sufficient infringement data available for analysis (see Table 1.10), a speeding infringement was detected in 177,423 sessions (99.4% of the sessions) and there were 1,059 sessions (0.6% of the sessions) in which no speeding offences were detected and as mentioned above there was a total of 6,463,121 speeding infringements detected. The number of speeding offences detected per session ranged from 1-1,922 however in the majority of the sessions (77.3%) there were less than 50 infringements detected. The majority of sessions detected between 1-9 infringements (24.9%) followed by 10-19 infringements (19.9%). The number of infringements detected each session per year is presented in Appendix D.

Table 1.10 *Grouped number of infringements detected per mobile speed camera sessions (N=178,482)*

Infringements	No. of sessions	Percentage %
0	1059	.6
1-9	44452	24.9
10-19	35569	19.9
20-29	25168	14.1
30-39	18282	10.2
40-49	13411	7.5
50-59	9123	5.1
60-69	6970	3.9
70-79	5608	3.2
80-89	4253	2.4
90-99	3157	1.8
100-149	7139	4.0
150+	4201	2.4
Total	**178482**	**100.0**

Data identifying the number of kilometres per hour over the posted speed limit associated with each speeding infringement was reported in the data from July 2007, full year data was available from 2008 onwards. From the total 74,945 deployment sessions undertaken during the years 2008-2013, adequate infringement data was available for 67,350 sessions from which 2,519,342 speeding infringements resulted. Table 1.11 outlines the number of km/h (group) over the posted speed limit associated with these infringements.

Table 1.11 *km/h over the posted speed limit for mobile speed camera infringements (N=2,519,342)*

	km/h over speed limit				
	1-9	**10-19**	**20-29**	**30-40**	**41+**
Total	1295455	1098814	107660	15161	2252
% total infringement	51.4	43.6	4.3	0.6	0.1

* Note: Cell 30-40 not of equal range (should be 30-39), this is how the data was reported in the police dataset

As shown in Table 1.12, in relation to speeding infringements detected between 2008 and 2013, there has been a gradual decrease in the percentage of drivers detected for exceeding the speed limit by 10-40 km/h from 49.9% of the speeding infringements during 2008 to 46.4% in 2013. In accordance there has been a 3.6% increase in the percentage of infringements in the 1-9 km/h over the posted speed limit range from 2008 to 2013.

Table 1.12 *km/h over speed limit for mobile speed camera infringements by year (N=2,519,252)*

Year	km/h					Total
	1-9	10-19	20-29	30-40	41+	
2008	129905	115882	12330	1853	376	**260346**
%	49.9	44.5	4.7	0.7	0.1	**100.0**
2009	149003	131516	13880	2039	421	**296859**
%	50.2	44.3	4.7	0.7	0.1	**100.0**
2010	146328	130568	13993	1937	296	**293122**
%	49.9	44.5	4.8	0.7	0.1	**100.0**
2011	285686	258606	27062	3861	459	**575674**
%	49.6	44.9	4.7	0.7	0.1	**100.0**
2012	288642	228761	19970	2661	358	**540392**
%	53.4	42.3	3.7	0.5	0.1	**100.0**
2013	295891	233391	20425	2810	342	**552859**
%	53.5	42.2	3.7	0.5	0.1	**100.0**
Total	**1295455**	**1098724**	**107660**	**15161**	**2252**	**2519252**

* Note: Cell 30-40 not of equal range (should be 30-39), this is how the data was reported in the police dataset

1.2.3 OPERATIONAL HOURS

Metropolitan and Regional

Some of the session data provided by Police had anomalous session end times. It seems that when a session end time was not entered into the system it defaulted to midnight of the day in which the session started. This resulted in some apparently long session times of up to 20 hours. To correct this for analysis, where the session time was given as over 6 hours the average session time across the data period was assigned for analysis. This was considered a reasonable strategy to facilitate analysis although the analysis would be more accurate if the accurate start and end times were recorded for all mobile camera sessions. For this reason, the outcome analysis reported below has used 'number of sessions' as the mobile camera program output measure rather than 'hours enforced', noting the high degree of correlation between the two (see Figures 1.1 and 1.2).

From 1995 through 2013 there was in excess of 530,000 hours of mobile speed camera operation, distributed over 200,000 deployments across Western Australia (see Table 1.13). The majority of these were in metropolitan areas, which included the Central, West, North-West, East, South-East, South, and Peel districts. Around one in seven camera hours were in regional WA, which included the Great Southern, Goldfields-Esperance, South West, Mid-West Gascoyne, Wheatbelt, Pilbara, and Kimberley districts. The proportion of operational hours in regional WA has changed over time. It has grown steadily from generally less than 5% between 1995 and mid-1998, to around 27% in 2013.

Table 1.13 *Mobile speed camera deployments in Western Australia by region (1995 to 2013)*

Region	Hours of operation	Number of deployments
Metropolitan	440,000 (83%)	176,000 (86%)
Regional	90,000 (17%)	27,840 (14%)
Total	*530,000*	*203,840*

In the year 2013, there were approximately 31,700 hours of operation in metropolitan areas (2,640 per month). This is two and a half times the number reported in 1995, which saw 12,180 cameras hours (1,020 per month). Despite this, the rate of growth had varied during the period 1995 to 2013. More specifically, 1995 to 1998 saw a steady increase in the number of camera hours (~250% growth), which was followed by a gradual decrease in the number of hours from around the years 2000 through to 2010. In the most recent four year period (2010 to 2013), there was another period of growth. Figure 1.1 shows the number of operational hours and deployments across metropolitan WA per month.

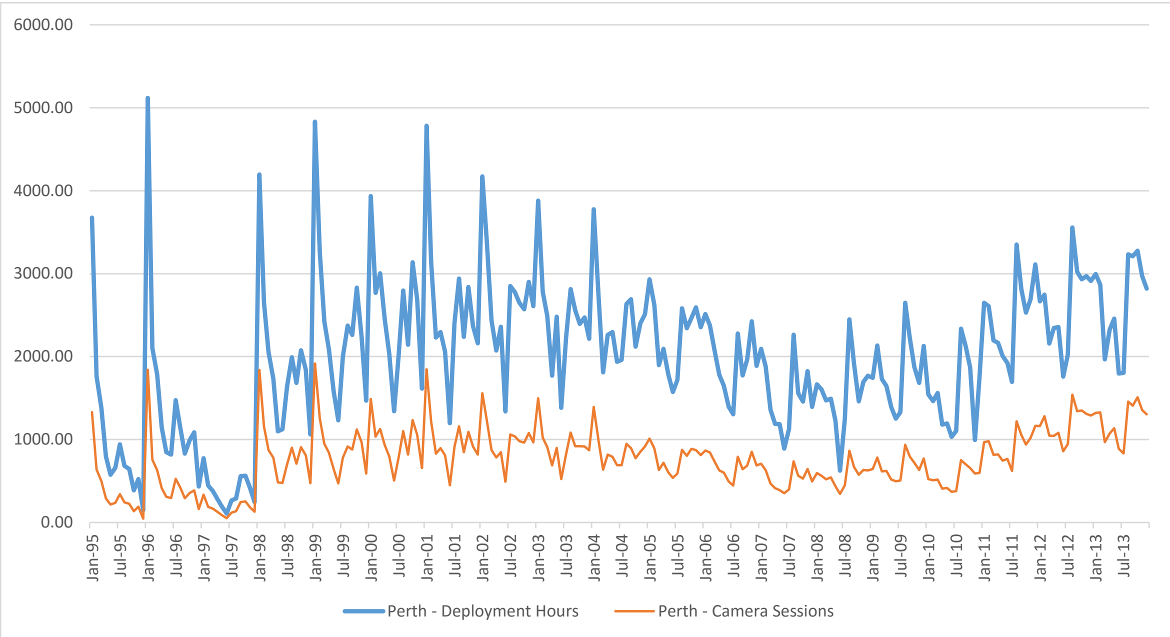


Figure 1.1 *Monthly mobile speed camera deployments and operation hours in metropolitan WA*

There has been similar growth in operational hours in regional areas since 1995. In 1995 there were fewer than 110 deployments and 300 camera hours reported (8.5 and 25 per month respectively), in contrast to nearly 2,300 deployments and 6,500 hours in 2013 (191 and 540 per month respectively). Unlike the metropolitan region, the rate of growth has been relatively steady over time (see Figure 1.2).

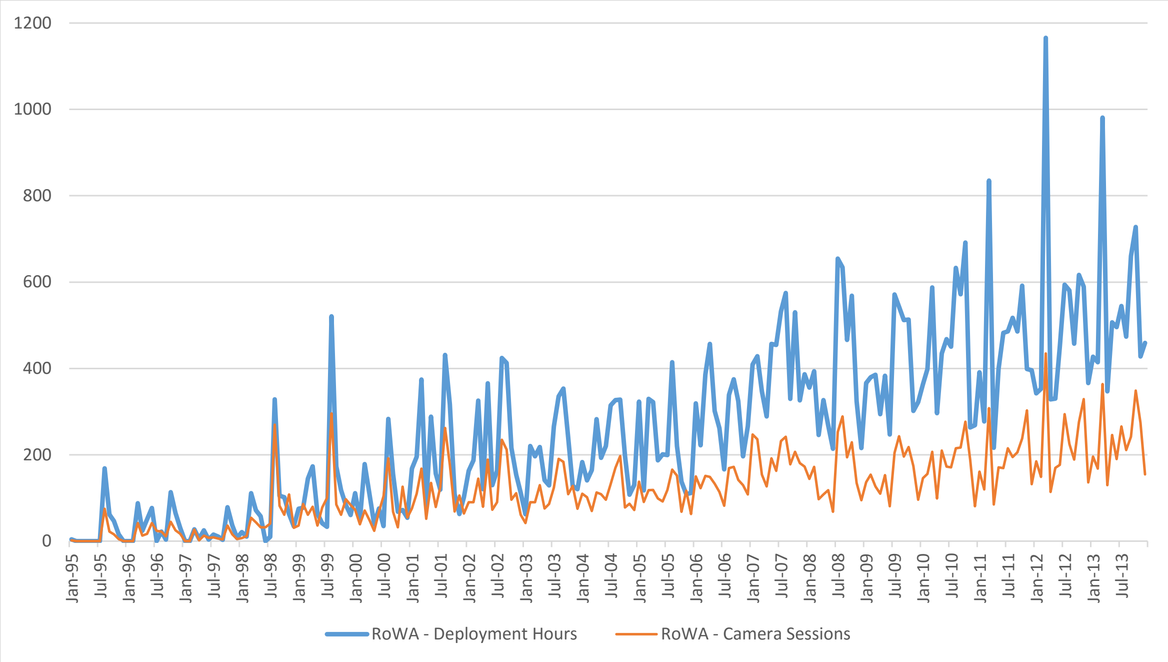


Figure 1.2 *Monthly mobile speed camera deployments and operation hours in regional WA*

The deployment time per session has been relatively consistent over time with sessions lasting between 2-3 hours on average, with session time averages in regional W.A. being similar to those in Perth at around 2.5 hours

Deployments across Districts

There are seven metropolitan districts in Western Australia, and the distribution of deployments (and operation hours) has remained relatively equal across these districts. In 2013, the number of deployments in each district ranged from around 1,230 in Peel to 2,850 in South-East Metropolitan. The change in the rate of deployments across time was also comparable across districts. This is characterised by a decline in deployments from 1998 to 2010, followed by growth from 2010 to 2013 (with the exception of the Peel district). Figure1.3 illustrates the monthly deployments for each district.

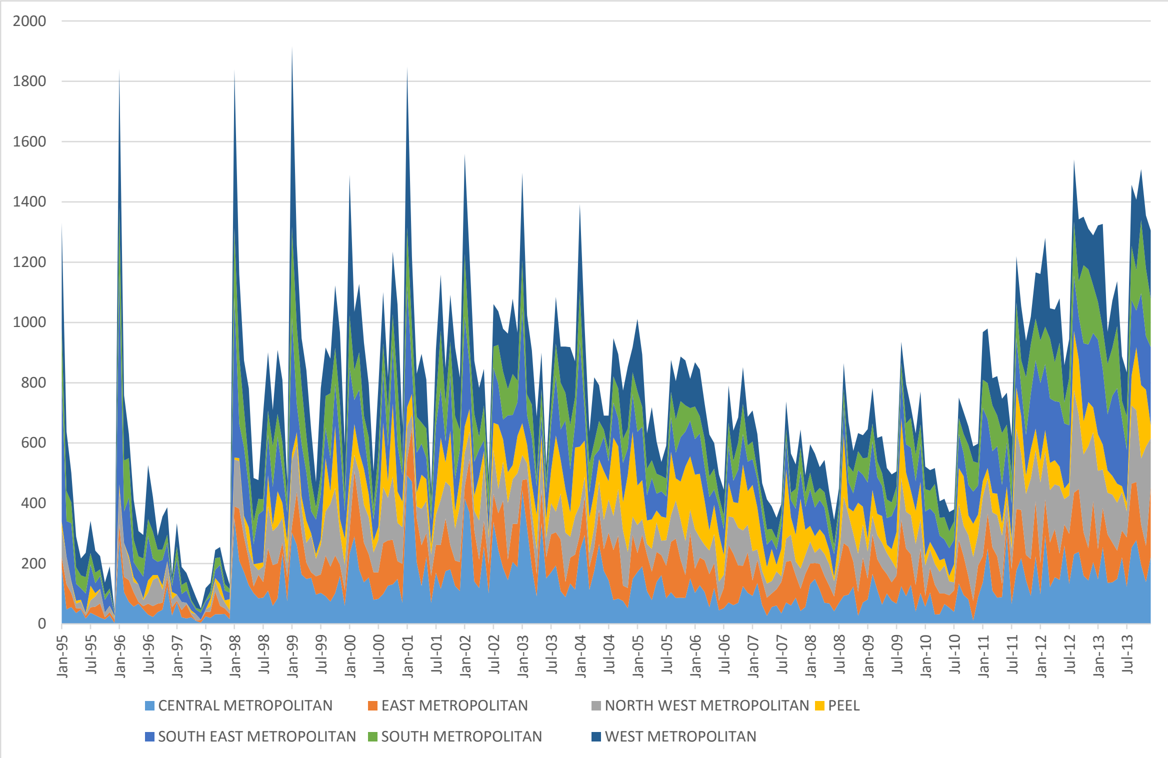


Figure 1.3 *Monthly deployments in Metropolitan Districts*

There are also 7 districts in regional Western Australia, Figure 1.4 illustrates the monthly deployments in each. Growth in the number of deployments over time has not been the same in each regional district with growth strongest in those divisions surrounding metropolitan Perth: Great Southern, Mid West-Gascoyne and South West. These three divisions plus the Wheatbelt accounted for 98% of regional camera deployments.

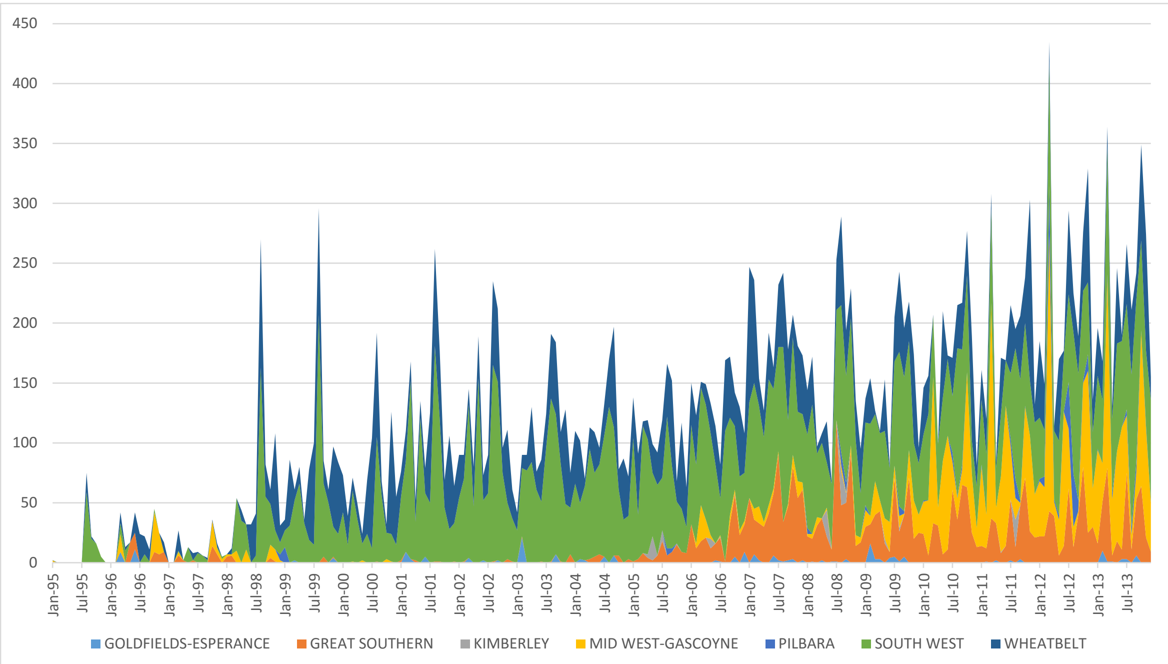


Figure 1.4 *Monthly deployments in Regional Districts*

1.2.4 CHARACTERISTICS OF MOBILE CAMERA DEPLOYMENTS

Day of Week and Start Time

Deployments in metropolitan and regional areas were evenly distributed across the days of the week (see Figure 1.5), yet the common start time varied between metropolitan and regional deployments. There were four more common start times for metropolitan deployments regardless of the day. These were between 7am and 8am, 10am and 11am, 3pm and 4pm, and 6pm and 7pm (see Figure 1.6). Regional deployments more commonly started between 2pm and 3pm, then between 7am and 8am, and 10am and 11am. Given the average session time for mobile cameras was between 2-3 hours, these results imply there is very little if any mobile speed camera enforcement between the hours of 9pm and 7am when traffic densities are light and the potential for speeding and speed related crashes is higher. W.A Police report that this has changed since the period of available data with camera operations now conducted on overtime from 2200-0600. W.A. Police report that in 2014-2015, 3500 camera hours were worked from 2200-0600

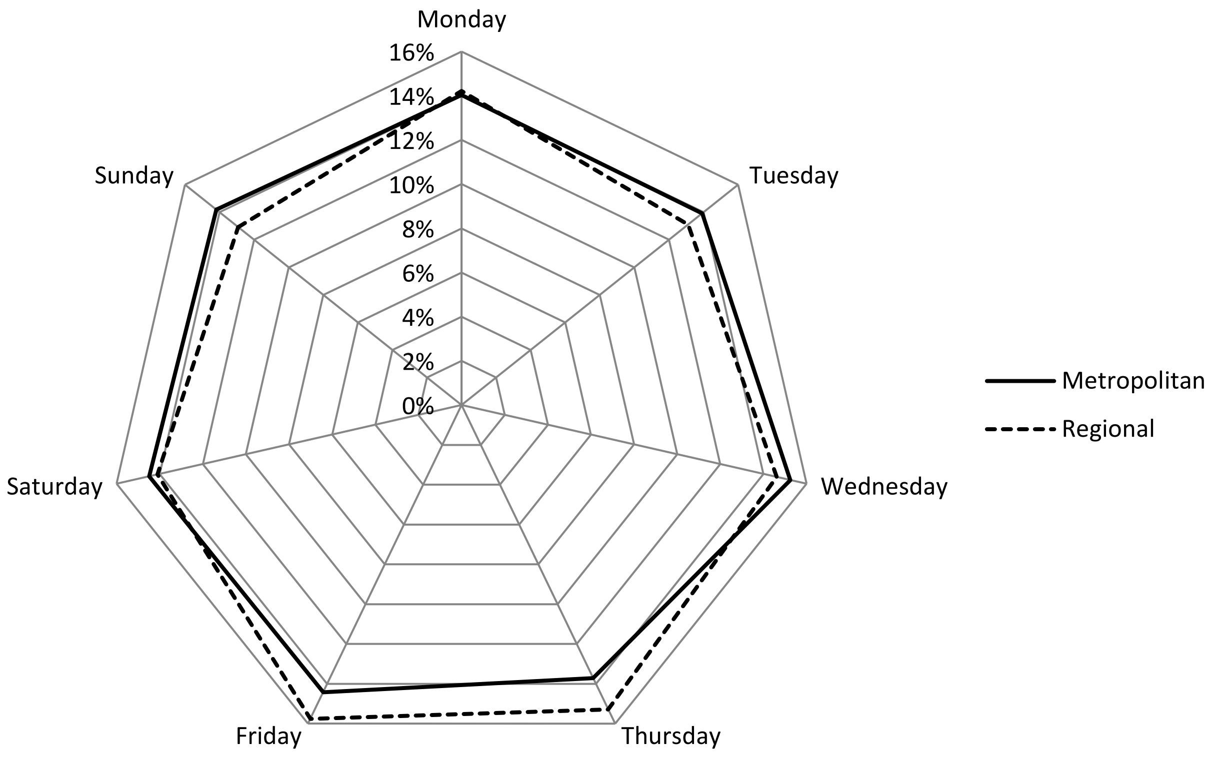


Figure 1.5 *Days of mobile speed camera deployments*

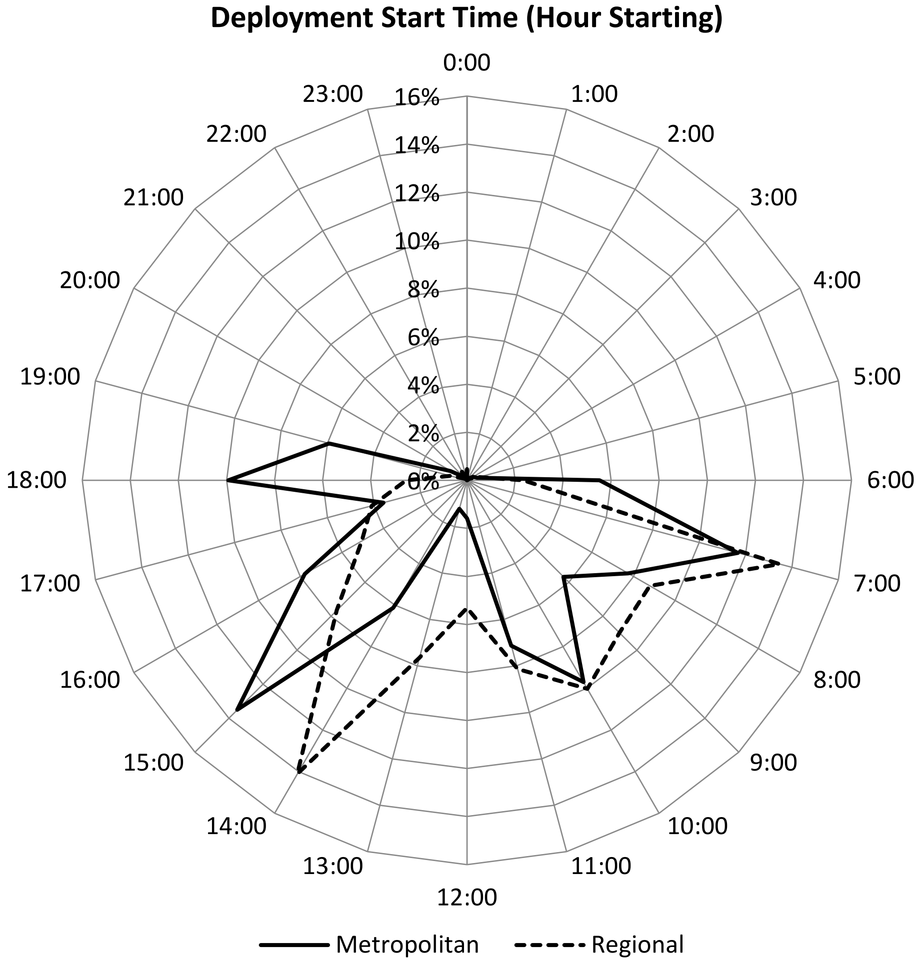


Figure 1.6 *Start time of mobile speed camera deployments*

Operational Hours in Speed Zones

Regions of Western Australia

The highest proportion of metropolitan operational hours was in 60 km/h speed zones, and this was particularly true in the years preceding 2006. In more recent years, the majority of metropolitan hours were located in 60 km/h and 70 km/h speed zones (around 55%). Prior to 2005, there were few hours in 40 km/h or 50 km/h speed zones. In 2013, around 13% of operational hours were in a 40 km/h or 50 km/h speed zone (see Figure 1.7).

There was a more even distribution of hours across speed zones in regional areas. Between 1995 and 2003, a much higher proportion of camera hours were in 60 km/h speed zones, yet more recently the highest proportion of hours are spent in higher speed zones (see Figure 1.8).

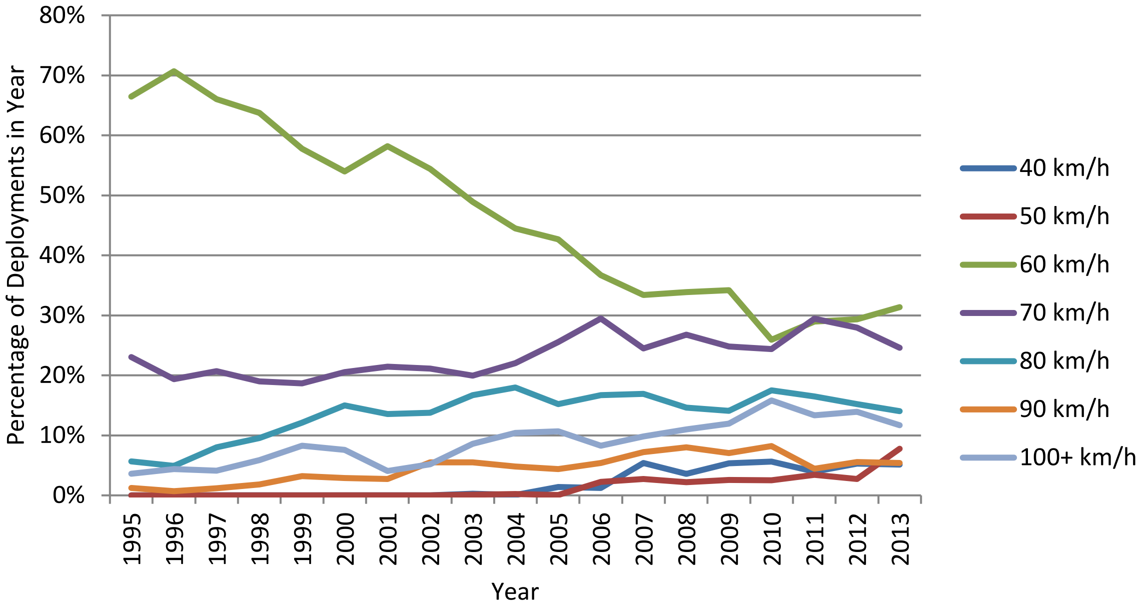


Figure 1.7 *Operational hours across different metropolitan speed zones*

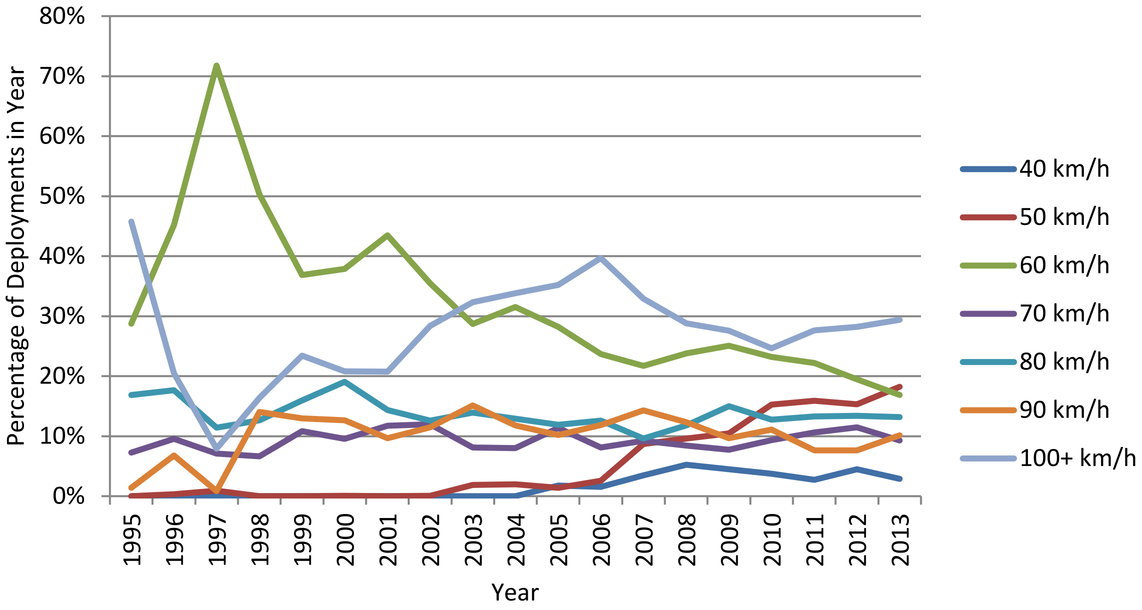


Figure 1.8 *Operational hours across different regional speed zones*

Operational Hours in High Speed Zones (Regional)

Approximately 27% of regional operational hours were on roads in high speed zones (100 and 110 km/h); an exception to this being deployments from 1995 through 1998 which saw greater variation. In 2013, there were around 2,500 operational hours on high speed roads, which was a significant increase on the annual average across the four year period 1995 through 1998. Through this period, there were approximately 170 operational hours reported each year. There has been slower growth in the number of operational hours since 2007, where it has stabilised at around 2,500 operational hours in the year (210 hours per month). Figure 1.9 shows the number of operational hours in high speed zones per month.

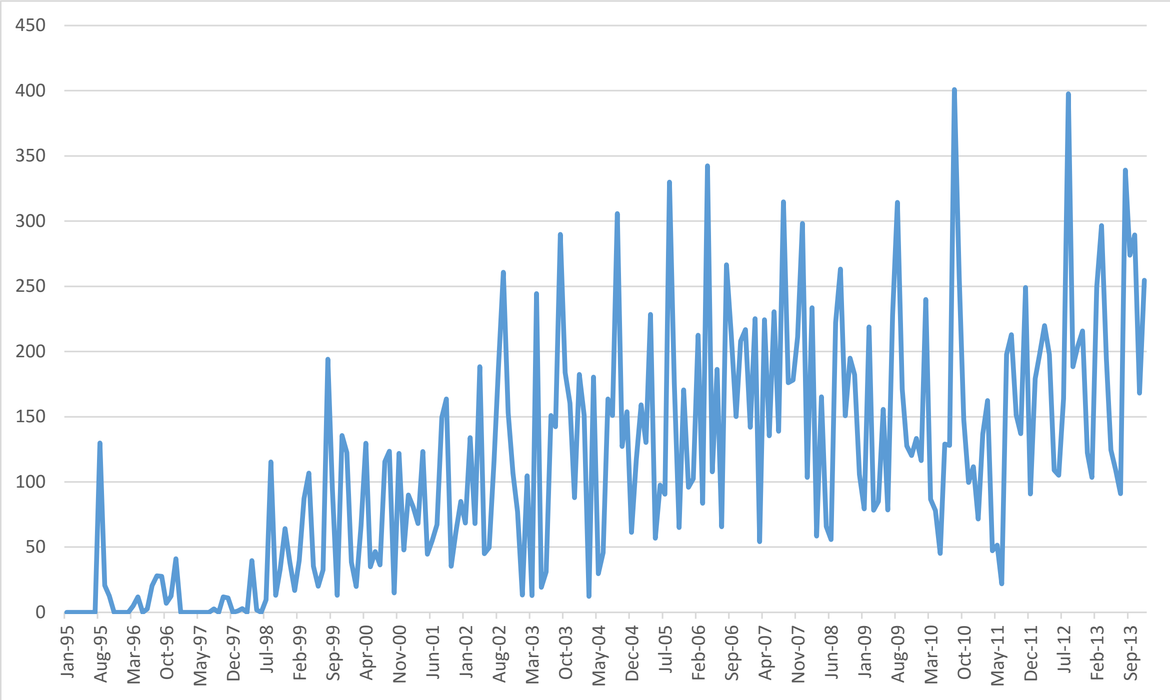


Figure 1.9 *Deployment hours per month in regional high speed zones*

Revisitation of Regional Sites

Revisitation of regional sites has been reviewed over two time periods, the first being 1995 to 2007 (inclusive), and the second 2008 to 2013 (inclusive).

From 1995 to 2007, half of the regional sites were visited either once or twice. This is not dissimilar to the period 2008 through 2013, where 44% of sites were visited once or twice. In both periods, there is a tendency for sites to be either visited infrequently (say fewer than 5 times), or often (say more than 10 times). A greater proportion of sites were visited more than 10 times in the latter period (25%), than the earlier period (16%). In both periods, the maximum number of times a site was visited was in excess of 300. This is shown in Figure 1.10. Figure 1.11 shows the frequency of revisitation for regional roads with speed zone 100 km/h or 110 km/h, where around 33% of sites were visited just once in the period 1995 to 2007, compared to 33% in the period 2008 to 2013.

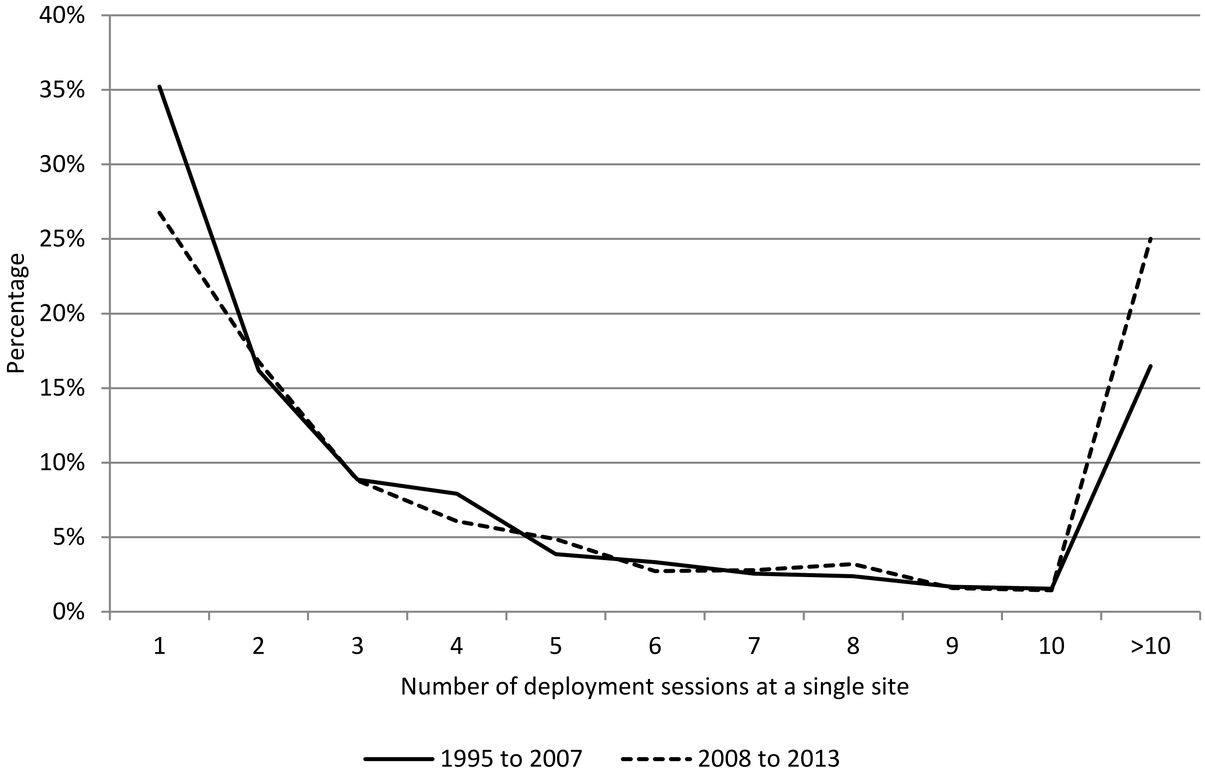


Figure 1.10 *Frequency of revisitation at regional sites*

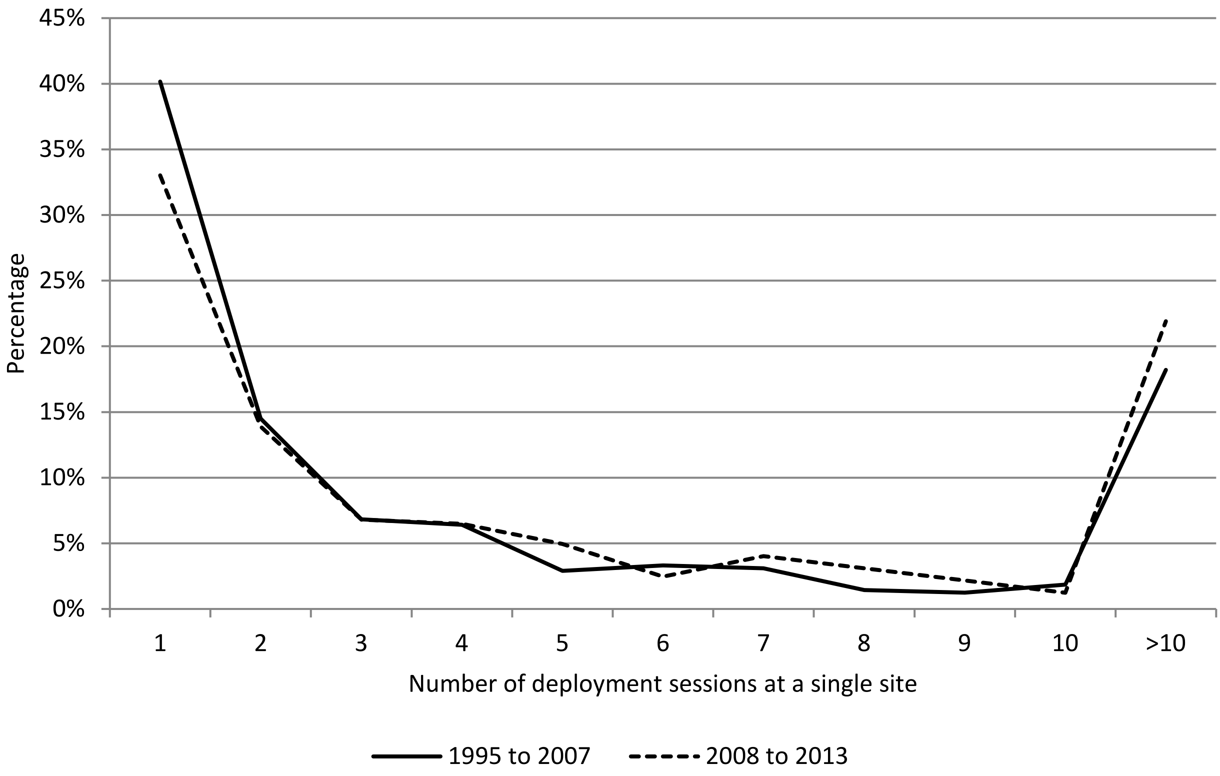


Figure 1.11 *Frequency of revisitation at regional sites: 100-110km/h zones*

The number of days between revisiting regional sites ranged from 0 (i.e. repeated on same day), to 12 years for the period 1995 and 2007, and just under 6 years between 2008 and 2013. Clearly this varied depending on the level of revisitation. Figure 1.12 shows the range of intervals between visits (interquartile range in days), based on the number of visits. It suggests there is less variation in the number of days between visits in the period 2008 to 2013, than the period 1995 to 2007 indicating scheduling has become more regular.

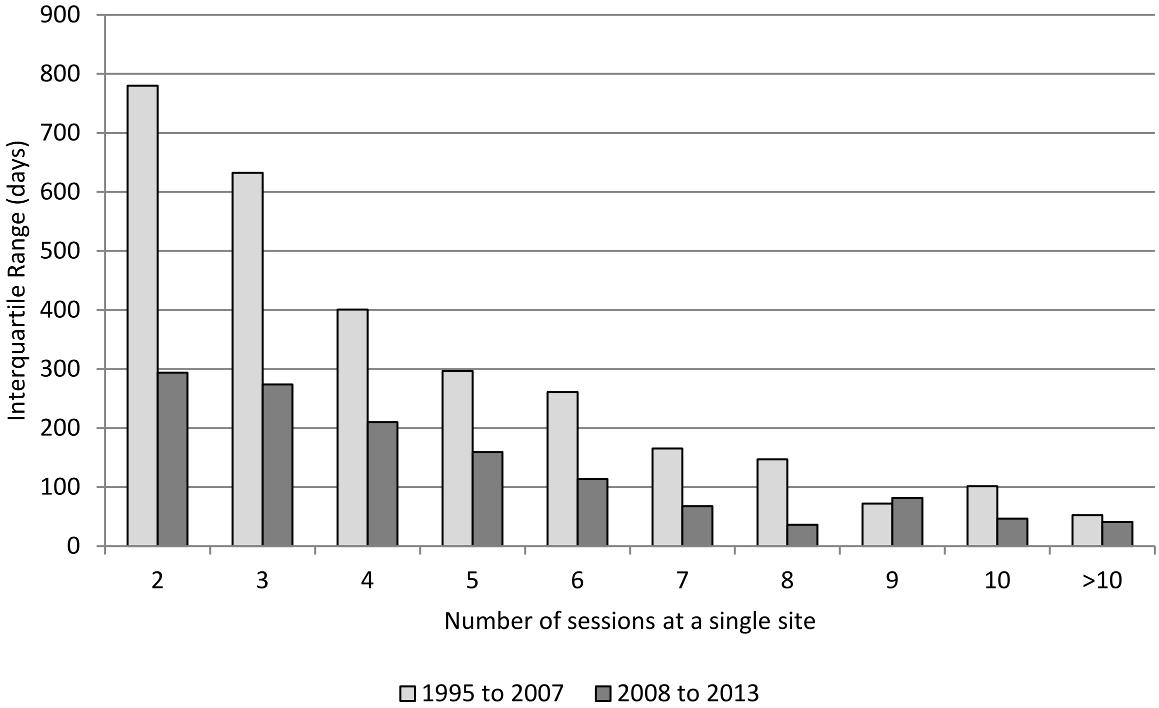


Figure 1.12 *Variation of interval between revisited sites*

1.2.5 SPATIAL CHARACTERISTICS OF DEPLOYMENTS

Spatial Distribution of the Number of Sessions per Site

The spatial distribution of metropolitan and regional deployments from 1995 to 2013 is shown in Figure 1.13, along with a sample of road-based crashes (from 2008 to 2012). Figure 1.14 also shows all locations where mobile speed cameras had been deployed across this period, scaled by the number of deployments at each location.

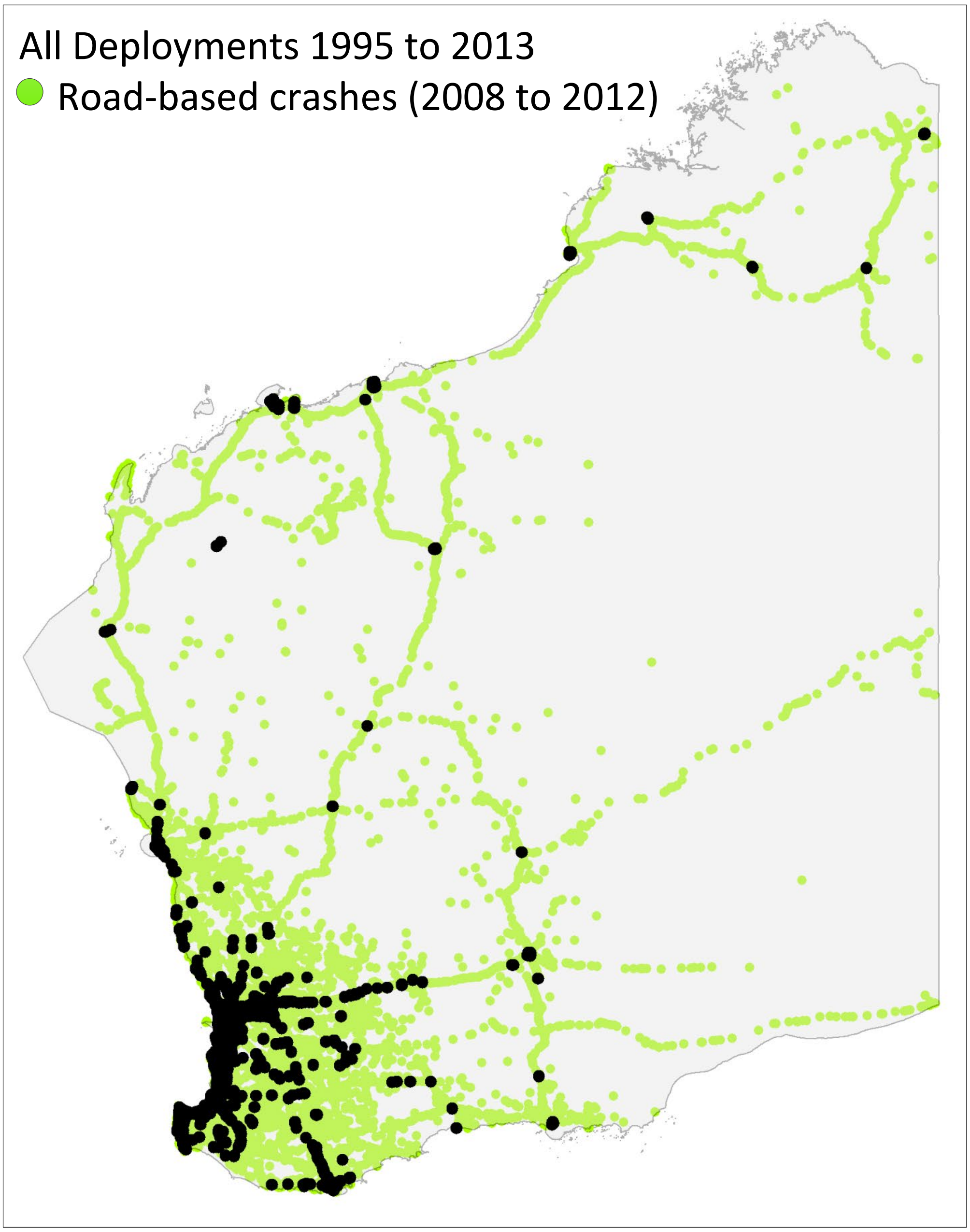


Figure 1.13 *All deployments and road-based crashes*

Figure 1.14 *Spatial distribution of deployments (1995 to 2013)*

As can be seen from Figure 1.14, the vast majority of deployments have taken place in the highly populated areas of Western Australia from Perth to Bunbury and around Albany and out from Perth towards Kalgoorlie.

1.3 FIXED CAMERA OPERATIONS

1.3.1 FREEWAY FIXED SPOT SPEED CAMERAS

Operational data and speed enforcement data was provided for four fixed speed camera sites listed below in Table 1.14.

Table 1.14 *List of fixed speed cameras*

Location Code	Street/Road 1	Street/Road 2	Suburb	District
F00001	Mitchell Fwy	Karrinyup Rd	Innaloo	West Metropolitan
F00002	Kwinana Fwy	Eric St	Como	South East Metropolitan
F00003	Roe Hwy	South St	Willetton	South East Metropolitan
F00004	Mitchell Fwy	Erindale Rd	Stirling	West Metropolitan

Since receipt of the speed camera data, another fixed speed camera location has become operational on the Kwinana Freeway at Murdoch. Five fixed speed cameras are now operational on Perth Freeways 24 hours a day whereas previously cameras had been rotated between sites. Table 1.15 displays the activation dates, dates of first infringement notice issued and hours of speed camera operations for each of the four fixed camera sites. Overall the fixed speed cameras have been in operation for 8,841 hours from 23rd December 2011 until March 2014.

Table 1.15 *Fixed Speed Cameras on Perth Highways/Freeways: Hours of operations: December 2011-March 2014.*

Fixed Camera Location	Site Activation Date	Date of first infringement	Date of last infringement*	No. of sessions	No. of hours of operation
Mitchell Fwy & Karrinyup Rd, Innaloo	23 December 2011	13 January 2012	6 March 2014	253	4,963
Kwinana Fwy & Eric St, Como	12 July 2012	24 July 2012	6 December 2013	94	1,847
Roe Hwy & South St, Willetton	11 September 2012	25 September 2012	19 February 2014	90	1,179
Mitchell Fwy & Erindale Rd, Stirling	3 October 2012	11 October 2012	20 February 2014	41	852
All Fixed cameras				**478**	**8,841**

*From receipt of speed camera enforcement data in April 2014

For the time period 23 December 2011 until 6 March 2014, the number of vehicles monitored; vehicles exceeding the speed limit and the number of speeding infringements issued is shown in Table 1.16.

For all fixed speed cameras combined 723,123 vehicles exceeded the speed limit or 8.3% of all vehicles monitored. The total number of speed infringements issued was 46,431 (10% of all vehicles that were found to exceed the speed limit, and 0.5% of all vehicles monitored).

Table 1.16 *Fixed Speed Cameras on Perth Highways/Freeways: Number of vehicles monitored and infringements issued*

Fixed Camera Location	No. of vehicles monitored	Vehicles exceeding speed limit	No. of offences	No. of infringements issued	% exceeding speed limit	Infringements issued as % of vehicles exceeding limit	Offences as % of vehicles exceeding limit
Mitchell Fwy & Karrinyup Rd, Innaloo	4,884,099	388,685	37,505	23,037	7.96%	5.93%	9.65%
Kwinana Fwy & Eric St, Como	1,986,032	109,051	9,391	5,424	5.49%	4.97%	8.61%
Roe Hwy & South St, Willetton	1,040,326	143,771	14,893	9,885	13.82%	6.88%	10.36%
Mitchell Fwy & Erindale Rd, Stirling	835,780	81,616	10,849	8,085	9.77%	9.91%	13.3%
All Fixed cameras	**8,746,237**	**723,123**	**72,638**	**46,431**	**8.27%**	**6.42%**	**10.0%**

For the period 13 January 2012 to 6 March 2014, a total of 46,431 speeding infringement notices were issued from the fixed speed camera operations – on average, approximately 1,800 per month. This amount is considerably less than the 10,000 infringements issued per month estimated by Cameron (2008) assuming fixed speed cameras were operated intermittently at 24 sites but is broadly consistent with that expected from the operation of 4 camera sites.

Table 1.17 gives a breakdown of the speed infringements issued according to the amount by which the speed limit was exceeded. The majority of speeding infringements issued were for vehicles exceeding the speed limit by 1-9 km/h (60.6%), whilst 0.15% was found to be excessively speeding over 40 km/h.

Table 1.17 *Fixed Speed Cameras on Perth Highways/Freeways: Percentage of infringements issued exceeding speed limit at different thresholds*

Fixed Camera Location	Total infringements	Exceeding 1-9 km/h	Exceeding 10-19 km/h	Exceeding 20-29 km/h	Exceeding 30-40 km/h	Exceeding 41km/h
Mitchell Fwy & Karrinyup Rd, Innaloo	23,037	14,147 (61.4%)	7,394 (34.4%)	775 (3.4%)	145 (0.63%)	36 (0.16%)
Kwinana Fwy & Eric St, Como	5,424	3,179 (58.6%)	1,979 (36.5%)	204 (3.8%)	48 (0.88%)	14 (0.26%)
Roe Hwy & South St, Willetton	9,885	5,760 (58.3%)	3,709 (37.5%)	329 (3.3%)	72 (0.73%)	15 (0.51%)
Mitchell Fwy & Erindale Rd, Stirling	8,085	5,056 (62.5%)	2,745 (33.9%)	235 (2.9%)	44 (0.54%)	5 (0.06%)
All Fixed cameras	**46,431**	**28,142 (60.6%)**	**16,367 (32.2%)**	**1,543 (3.3%)**	**309 (0.67%)**	**70 (0.15%)**

1.3.2 COMBINED RED-LIGHT/SPEED CAMERAS

Operational data and speed enforcement data was provided for 25 combined red-light and speed (SRL) camera sites listed below in Table 1.18. Activation Dates were derived from the operations data.

There were also 21 listed Red Light Speed Camera sites for which the activation date of the camera was not available at the time of analysis. In addition, operations data for these sites was not received. Furthermore, the W.A. police camera website only lists 29 currently operational speed and red light camera sites meaning only 4 of the additional 21 listed might currently be operational. It is possible that the remainder were legacy red light camera only sites which have been decommissioned. These 21 additional sites were excluded from the analysis results presented in the following chapters (either as treated or control sites). A list of these sites is provided in Table 1.19.

Table 1.18 *List of combined Red-Light/Speed Cameras in Western Australia*

Camera Location	Suburb	Intersection	Activation Date
R00019	South Perth	Canning Hwy & Douglas Ave	14 July 2010
R00022	Victoria Park	Great Eastern Hwy & Shepperton Rd	26 July 2010
R00027	Dianella	Alexander Drive & Grand Promenade	20 Dec 2011
R00029	Bentley	Albany Hwy & Leach Hwy	15 July 2010
R00030	Hamilton Hill	Winterfold Rd & Stock Rd	13 July 2010
R00031	Hamersley	Wanneroo Rd & Beach Rd	8 August 2010
R00033	Wilson	Leach Hwy & Bungaree Rd	13 July 2010
R00035	Booragoon	Riseley St & Marmion St	20 Dec 2010
R00036	Mirrabooka	Mirrabooka Ave & Ravenswood Drive	18 April 2011
R00037	Piara Waters	Armadale Rd & Nicholson Rd	14 April 2011
R00040	Balga	Beach Rd & Mirrabooka Ave	13 July 2010
R00041	Morley	Beechboro Rd Nth & Morley Drive	20 Dec 2010
R00043	High Wycombe	Roe Hwy & Kalamunda Rd	15 July 2010
R00046	Madeley	Wanneroo Rd & Hepburn Ave	9 Aug 2011
R00047	Padbury	Hepburn Ave & Marmion Ave	27 July 2010
R00049	Dianella	Morley Drive & Alexander Drive	15 July 2010
R00050	Balcatta	Reid Hwy & Balcatta Rd	18 April 2011
R00051	Bayswater	Guildford Rd & Garratt Rd	10 Aug 2011
R00052	Hazelmere	Great Eastern Hwy Bypass & Stirling Cres	8 Sep 2011
R00054	Malaga	Reid Hwy & Malaga Drive	5 July 2011
R00059	Joondalup	Joondalup Drive & Shenton Ave	14 April 2011
R00061	East Rockingham	Mandurah Rd & Dixon Rd	21 Dec 2010
R00062	Canningvale	Bannister Rd & Willeri Ave	15 April 2011
R00063	Canningvale	South St & Roe Hwy	15 April 2011
R00064	Welshpool	Orrong Rd & Pilbara St	9 Aug 2011

Table 1.19 *List of combined Red-Light/Speed Camera Locations in Western Australia with unknown activation dates (excluded from analysis)*

Camera Location	Suburb	Intersection	Local Government Area
R00020	South Perth	Canning Hwy & Way Rd	South Perth
R00021	Applecross	Canning Hwy & Kintail Rd	Melville
R00023	East Victoria Park	Shepperton Rd & Oats St	Victoria Park
R00024	East Fremantle	Stirling Hwy & Canning Hwy	East Fremantle
R00025	Innaloo	Scarborough Beach Rd & Liege St	Stirling
R00026	Osborne Park	Royal St & Main St	Stirling
R00028	Dianella	Walter Rd West & Coode St	Stirling
R00032	Como	Canning Hwy & Henley St	South Perth
R00034	West Perth	James St & Fitzgerald St	Perth
R00038	East Perth	Causeway & Riverside Drive	Perth
R00039	Fremantle	Hampton Rd & South St	Fremantle
R00042	Carine	Beach Rd & Davallia Rd	Stirling
R00044	Bayswater	Tonkin Hwy & Collier Rd	Bayswater
R00045	Bayswater	Tonkin Hwy & Collier Rd	Bayswater
R00048	Redcliffe	Great Eastern Hwy & Tonkin Hwy	Belmont
R00053	Heathridge	Ocean Reef Rd & Eddystone Ave	Joondalup
R00055	Balga	Mirrabooka Ave & Reid Hwy	Stirling
R00056	Balga	Reid Hwy & Mirrabooka Ave	Stirling
R00057	Mirrabooka	Reid Hwy & Mirrabooka Ave	Stirling
R00058	Edgewater	Hodges Drive & Joondalup Drive	Joondalup
R00060	Welshpool	Orrong Rd & Roe Hwy Off Ramp	Canning

A report (CamComp, 2010) giving policy advice to the WA Office of Road Safety on the placement of fixed speed cameras in WA identified that in 2010, 60 of the 860 signalised intersections (7%) in WA currently had red-light camera infrastructure, through which the 30 wet-film red-light cameras have been rotated for many years. The report identified the top 60 signalised intersections, ranked in order of the expected savings in social costs of crashes if an SRL was installed. Four intersections that had red-light camera infrastructure at the time were ranked in these top 60. The report identified those sites where the installation of a red light speed camera at the intersection was expected to yield economic benefits. A list of the top 17 sites recommended for treatment is given in Table 1.20 along with an indication of whether the site was treated as at 2013. As indicated, around 10 of the 17 sites recommended for treatment in CamComp (2010) have been treated.

Table 1.20 *Priority sites for Red-Light/Speed Cameras installation in Western Australia identified by CamComp (2010)*

Inter-sect-ion No.	**Intersection Description**	**Local Govt. Area**	**Social Cost Saving p.a. ($)**	**BCR of SRL** (estimate without RLC)	**Treated as at 2013**
50615 (RLC)	BEAUFORT ST & NEWCASTLE ST	Perth (C)	252,459 (336,612)*	**2.48 (3.31)***	**No**
55527	FLINDERS ST & NOLLAMARA AV	Stirling (C)	214,770	**2.23**	**No**
37789	BEECHBORO RD NORTH & MORLEY DR	Bayswater (C)	298,266	**2.22**	**Yes**
56046	MIRRABOOKA AV & RAVENSWOOD DR & YIRRIGAN DR	Stirling (C)	275,362	**2.18**	**Yes**
114893	GILMORE AV & MANDURAH RD & DIXON RD	Kwinana (T)	185,953	**1.93**	**Yes**
50560	BARRACK ST & WELLINGTON ST & BEAUFORT ST	Perth (C)	276,348	**1.80**	**No**
63192	SHENTON AV & JOONDALUP DR	Joondalup (C)	286,205	**1.74**	**Yes**
4061	ARMADALE RD & NICHOLSON RD	Armadale (C)	167,977	**1.65**	**Yes**
40435 (RTS)	WILLERI DR & BANNISTER RD	Canning (C)	213,148	**1.62**	**Yes**
65270	BLAIR ST & SANDRIDGE RD & ALBERT RD	Bunbury (C)	190,881	**1.51**	**No**
3642 (RTS)	REID HWY & REID HWY - MITCHELL FWY STH ON & H016 STH BOUND - REID HWY OFF & BALC	Stirling (C)	258,672	**1.47**	**Yes**
47019	RISELEY ST & MARMION ST	Melville (C)	226,598	**1.42**	**Yes**
56042	MIRRABOOKA AV & BEACH RD	Stirling (C)	198,766	**1.42**	**Yes**
82300	REID HWY (WEST BND) & MIRRABOOKA AV	Stirling (C)	195,809	**1.37**	**No**
14106	SOUTH ST & H015 STH BOUND - SOUTH ST WEST	Melville (C)	379,791	**1.37**	**No**
68098	KARRINYUP - MORLEY HWY & ALEXANDER DR (NTH BND)	Stirling (C)	166,006	**1.34**	**Yes**
76283 (RLC)	GUILDFORD RD & EAST PDE - LORD ST & H020 WEST BOUND - EAST PDE OFF	Perth (C)	202,709 (270,278)*	**1.27 (1.69)***	**No**

RTS – indicates full right turn control required

RLC – indicated existing Red light camera site

From 13 July 2010 to early 2014 248,085,204 vehicles were monitored by SRL cameras with 4,933,646 exceeding the speed limit and 424,353 offences recorded. A total of 258,425 speeding infringements were issued at the 25 sites from 13 July 2010 to February 2014. Table 1.21 lists the number of speeding infringements by the range over the speed limit.

Table 1.21 *Speeding Infringements issued at Red-Light Speed Camera Sites in Perth, Western Australia, by level of speeding over speed limit: July 2010-February 2014*

Level of speeding over speed limit	No. of infringements	Percentage over speed limit
1-9 km/h over speed limit	157,345	60.9%
10-19 km/h over speed limit	94,801	36.7%
20-29 km/h over speed limit	5,503	2.1%
30-40 km/h over speed limit	667	0.26%
41 km/h or more over speed limit	109	0.04%
All	**258,425**	

Figures in Appendix E show the percentage of speeding offences that were over the speed limit at each level of speeding for each of the Red Light Speed Camera sites. It should be noted that for Site R00022 (Great Eastern Hwy and Shepperton Rd, Victoria Park), operations data was only provided for four speeding offences hence information for R00022 is not presented in Figures 17 to 21.

For each RLSC site the percentage of speeding offences issued that were 1-9 km/h over the speed limit ranged from 49% (R00043: Roe Hwy and Kalamunda Rd, High Wycombe) to 65% (R00051: Guildford Rd and Garratt Rd, Bayswater). For each RLSC site the percentage of speeding offences issued that were 10-19 km/h over the speed limit were lowest (33%) at sites R00035 (Riseley St and Marmion St, Booragoon) and R00043 (Roe Hwy and Kalamunda Rd, High Wycombe), and highest at R00051 (Guildford Rd and Garratt Rd, Bayswater), i.e. 65% of all speeding offences. The percentage of speeding offences issued that were 20-29 km/h over the speed limit ranged from 1.2% (site R00027: Alexander Drive & Grand Promenade, Dianella) to 4.0% of all speeding offences (site R00061: Mandurah Rd and Dixon Rd, East Rockingham). For each RLSC site the percentage of speeding offences issued that were 30-40 km/h over the speed limit ranged from 0.08% (site R00041: Beechboro Rd North and Morley Drive, Morley) to 1.04% of all speeding offences (at site R00061: Mandurah Rd and Dixon Rd, East Rockingham).

Six of the combined Red Light Speed Camera sites had no speeding offences issued that were more than 40 km/h over the speed limit (i.e. Sites R00036, R00040, R00043, R00059, R00061 and R00062). Sites R00031 and R00049 had the highest percentage of offences that were more than 40 km/h over the speed limit (0.12% and 0.11%, respectively).

1.4 ASSESSMENT OF OPERATIONS AGAINST THE RECOMMENDATIONS

1.4.1 MOBILE CAMERA OPERATIONS

The review of mobile speed camera deployments from 1995 to 2013 indicated that over time the number of operational hours across Western Australia has grown, both in metropolitan and regional areas. In the most recent year of data (2013), there were around 31,700 operational hours in metropolitan areas in a year, across 14,580 deployments. This equates to an average of 2,640 hours in a month. Regionally in 2013, there were around 6,460 operational hours across 2,800 deployments in the year, or an average of 540 hours in a month.

Mobile speed camera deployments across this period were evenly distributed across the days of the week. Deployments almost always commenced between the hours of 7am and 6pm in metropolitan areas and between 7am and 4pm in regional areas. There has been a tendency for operational hours in metropolitan areas to be focused around 60 km/h speed zones; which may reflect the relative frequency of this type of speed zone. This tendency has become less pronounced in recent years, although hours spent in 60 km/h or 70 km/h speed zones form the majority (56%). Regional operational hours were more evenly distributed across speed zones, with around 29% of hours in high speed zoned roads (around 210 hours per month; 2,500 per year).

The majority of sites in regional areas were visited fewer than 5 times, although there was a tendency for some sites to be visited frequently. This was also true for regional roads with high speed limits (100 km/h or 110 km/h). In the period 2007 to 2013, some sites were visited more than 300 times (over 40 times a year). The variation in the number of days between visits to the same site was less in the period 2007 to 2013, than 1995 to 2007.

There is a clear concentration of mobile camera deployments around Greater Perth, southward towards Busselton, Geraldton, and Albany. Fewer deployments were located on major roads and highways radiating from Perth (e.g. National Highway 95, National Highway 1). Similarly, sites within metropolitan regions were more often revisited than regional sites.

Although not identified in the operational data, there are some other pertinent features of the W.A. mobile speed camera program. The W.A. mobile speed camera program is an overt program with camera vehicles in operation at the roadside being clearly marked with a sign to identify them to passing traffic. W.A. Police report that since 2011 the sign has no longer been used. Further reinforcing the overt nature of the program, camera locations are advertised by W.A. Police weekly with information published including the road name and suburb on which the operation will occur. It is understood that media also frequently broadcast the locations of mobile cameras on any particular day. Until 2010 all mobile speed cameras in W.A. operated exclusively in front facing mode (i.e. photographing the front of the vehicles when detecting a speeding offence). Rearward facing operation of the mobile camera program commenced in 2010 although it is not clear if all cameras can operate in rearward facing mode. Rearward facing operation is likely to be more effective in deterring and fining speeding motorcyclists since motorcyclists are only required to display rear license plates. However, rearward operation is potentially problematic because WA does not have full owner onus legislation for mobile camera infringements (where the owner is liable unless the infringing driver can be nominated). So if W.A. Police cannot produce a photo of the driver and the driver is unable to nominate who was driving the vehicle, then the penalty cannot be applied. W.A. Police report that it cannot determine how many hours of MOBILE camera operation have been undertaken or TINS have been issued in the rearward *versus* forward facing mode for the mobile camera program.

Recommended Operational Characteristics

The road environment of Western Australia is characteristically vast and comprised of light traffic density. In this type of environment, reductions in speed-related road trauma are best achieved through a package of speed enforcement programs, including overt and covert mobile speed camera programs. Strategies for best practice in enforcement using mobile speed cameras for Western Australia recommended in Cameron and Delaney (2006) include:

1. Covert mobile speed cameras on urban highways, equivalent to 9,000 operational hours per month; and
2. Overt mobile speed cameras on randomly scheduled rural highways, equivalent to 3,000 operational hours per month.

Operational Hours

In recent years, the number of hours per month of mobile speed camera operation in metropolitan areas has stabilised at around 2,640. The majority of camera hours were on roads with a speed zone of either 60 km/h or 70 km/h, and only around 30% were on roads with speed zones of 80 km/h or more. The recommended 9,000 operational hours on urban highways is 3.75 times more than the current operation across all metropolitan roads, and over 12 times that on roads with speed limits indicative of urban highways (80 km/h or over). A significant increase in the number of operational hours on urban highways is required to achieve the targets set in Cameron and Delaney (2006).

The number of operational hours in regional WA has growth since 1995, and currently stands at around 540 in a month. Around 29% of these hours (165 hours) are on roads of high speed zones (100 or 110 km/h). The recommended 3,000 operational hours on rural highways is nearly 6 times more than the current operation across all regional roads, and over 18 times that on roads with high speed limits. A significant increase in the number of operational hours on rural highways is required to achieve the targets set in the recommended strategy.

Time and Location Based Scheduling

Speed camera deployments in WA are evenly distributed across the days of the week. There is, however, a clear pattern in scheduling across the time of day with most deployments commencing between 7am and 6pm. Importantly, this indicates that up to 2013 there has been essentially no camera based enforcement in the hours between the hours of 8pm and 7am, a time of day where speeding related crash risk is often highest due to lower traffic densities. As noted, W.A. Police report that cameras are now used in these hours on overtime with 3,500 hours worked during these times during 2014-15

A high number of mobile speed camera sites are used in Western Australia compared to other jurisdiction in Australia meaning the average number of hours of enforcement undertaken per site is necessarily lower than other jurisdictions. In regional areas over the period 2008 to 2013, there were a high proportion of regional sites being visited just once. This was also true for high speed regional roads, where 33% were visited just once, and 60% fewer than 5 times. Although the cameras a placed according to criteria based on the evidence of crashes and speeding, there is some degree of randomness in the spatial distribution of camera deployments although there is a clear focus around greater Perth and the surrounding regions appropriately reflecting the population, travel and associated crash concentrations around these areas.

Whether specifically intended or not, this indicates that mobile speed camera scheduling in WA is approximating a random regime which was recommended by Cameron and Delaney (2006) to maximise the general effectiveness of the program in time and space. Although site selection is based on crash-history amongst other criteria for mobile speed camera deployments in WA, Cameron and Delaney (2006) indicated this is not necessary if the objective of the program is to portray an 'anywhere at any time' picture of camera operations to the public, designed to maximise deterrence. A focus on randomly scheduling deployments across the time of day and sites of operation, as currently used, is required. In addition, some review of the practice of repeated scheduling at the 20-25% of sites commonly used in regional areas should also be considered.

Cameron and Delaney (2006) also recommended covert use of the mobile speed cameras in metropolitan Perth where currently the program is highly overt. Moving to covert operations would require removing the signs and markings from camera vehicles, as well as refraining from advertisement of planned mobile camera locations by W.A. Police and the media.

1.4.2 FIXED CAMERAS

Freeway Speed Cameras

For fixed speed cameras Cameron and Delaney's (2006) speed enforcement package for Western Australia recommended that an estimated 24 overt fixed speed camera units (*continuously operated)* should be installed on Perth freeways. This recommendation was somewhat modified in Cameron (2008) where it was proposed that the 24 fixed speed cameras for Perth freeways should be operated intermittently without causing any reduction in effectiveness on road crashes. This recommendation was based on experience in Sweden where operation of overt fixed speed cameras occurs intermittently on designated routes.

Currently there are only 5 fixed speed camera sites on Perth freeways which is significantly less than the number recommended.

Combined Red-Light/Speed Cameras

For red light camera/speed camera combinations the research presented in Newstead (2013) recommended that fixed speed cameras at intersections mainly target blackspot locations and a broader coverage of the road network. This reflects findings that the crash reduction effects of fixed speed cameras are largely localised to the site of operation hence the proportion of the road network and crash population that can be targeted by fixed cameras is relatively small compared to mobile cameras. Newstead (2013) identified that in Queensland, 95% of the crash reduction benefits achieved by the camera detected offence program were attributable to the mobile camera program.

Despite this, CamComp (2010) identified that there are economic benefits achievable by the strategic placement of intersection speed and red light cameras at high risk intersections, particularly in combination with the implementation of full control right turn signal phases where appropriate. From the list of the 17 highest priority sites for these cameras, 10 sites have had cameras installed to date showing significant progress toward the strategic recommendations. Further installations at the remaining high priority sites could produce additional benefits.

1.4.3 PLANNED EXPANSION OF THE WA PROGRAM

The WA Road Safety Commission has documented further expansion to the automated speed enforcement program in WA that is being considered in the categories of immediate and medium term opportunities.

Immediate opportunities identified and implemented during 2014-15 include:

- All fixed freeway camera sites being fitted with a camera operating at all times through the purchase of an additional five cameras, and enhancement of back-room processing capacity (scheduled to be completed by last quarter of 2014/15)
- Increase of 300 additional mobile speed camera hours per month and increase in back-office processing capacity.

In the medium term, priorities identified were:

- Increase the capacity for automated speed enforcement in WA to levels that are comparable on a population basis to that in the best performing jurisdictions. This requires a significant increase in the number of fixed speed and red light speed cameras and a marginal increase in mobile camera capacity.
- Ultimately to increase the levels of automated speed enforcement in Western Australia over the next 5 years to:

Table 1.22 *Existing and Desired Automated Speed Enforcement levels*

Type of Enforcement	Existing enforcement level	Desired enforcement level
Mobile Speed Cameras	3,200 hours (2,300 metro, 900 country) per month	3,800 hours (2,500 metro, 1300 country) per month
Fixed Cameras	1 camera over five sites	30 cameras over 30 sites
Red Light Intersection Cameras	30 sites	90 sites
Point-to-point cameras	Nil	One length, initially as a trial (non-enforcing)

Various models of delivery of the expanded program are being considered including the review of the back room processing procedures and capacity.

Although these planned expansions of the WA automated speed enforcement program bring the program closer to the targets recommended by Cameron and Delaney (2006) they still do not fully meet these targets or are consistent with the recommendations on mode of operation. The desired enforcement levels for mobile speed cameras are less than half that recommended by Cameron and Delaney overall and less than one third that proposed in regional areas. Furthermore, there is no mention of a move to covert camera operation as recommended, possibly due to the limited capacity of back office processing of infringements mentioned below.

The planned fixed camera expansion exceeds that recommended by Cameron (2008) but does not capitalise on the potential savings in equipment possible by continuing the rotation system between sites. The fixed intersection speed and red light camera expansion goes beyond that recommended and exceeds the number of sites that CamComp (2010) identified as being cost beneficial, which is around 30 sites. Additional sites may be warranted if economies of scale in installation and fine processing can be implemented, although the evidence suggests that investment of funds in the mobile program may be preferable to the significant expansion of the intersection camera program.

Overseas research suggests that a point to point speed camera system can be effective in enforcing highly trafficked arterial roads and freeways with limited entry and egress points. As yet there is no Australian evidence on the effectiveness of point to point camera systems. Experience in Victoria has shown a number of operational challenges with the system due to issues such as camera synchronisation and interference due to roadworks and speed limit changes symptomatic of poor co-ordination of information between agencies. The proposed trial in WA would identify such operational challenges. Assessment of road safety benefits could only happen if the system also enforced speed compliance.

A key element in the future plan is the expansion of the capacity for back-room processing of camera infringements. This appears to be a limiting factor in the expansion of the WA automated enforcement network and should be urgently addressed in order to ultimately allow the expansion of the program to the levels recommended by Cameron and Delaney (2006).

Further consideration of the planned expansion against strategic recommendations is made in Section 3, following presentation of evidence on the current effectiveness of the W.A. automated enforcement program on reducing road trauma presented in Section 2.

SECTION 2 CRASH EFFECTS OF AUTOMATED ENFORCEMENT IN WESTERN AUSTRALIA

2.1 CRASH DATA

Crash data covering the full years 1995 to 2012 was provided to MUARC by the Western Australian Department Main Roads for use in the evaluation. The data provided included records on 691,422 reported crashes in W.A. involving 1,446,926 traffic units (vehicle, pedestrian, cyclist, motorcyclist etc.). Data fields provided included:

- Unique accident identifier
- Date and time of crash
- Crash location details including LGA, postcode, road name, intersecting road name, latitude and longitude of crash site
- Crash severity (severity of most severe injury resulting from crash: Fatal, Hospital Admission, Medical Attention, PDO Major, PDO Minor)
- Crash characteristics (crash configuration, number of vehicles involved, etc.)
- Crash environment details (road conditions, weather conditions etc.)
- Vehicle details
- Traffic unit controller details (age, gender, license status, etc.)

In order to conduct the evaluation of the automated enforcement program in W.A., it was necessary to be able to relate the location of reported crashes to the location of both mobile and fixed traffic enforcement cameras. Using the reported latitude and longitude of each crash location, each reported crash in the data supplied was mapped using a GIS. Within the GIS, crash locations were then mapped against locations of automated enforcement cameras for analysis. From this it was possible to identify the crashes which were within the defined areas of influence of each camera, by camera type, as detailed in the next section specifying study design. Dates of each crash were then related to the dates of installation and operation of each camera to further inform the preparation of data to support the evaluation framework specified.

2.2 OUTCOME EVALUATION DESIGN

Development of the evaluation framework for the assessmet of the overall impact of the automated enforcement program on road trauma outcomes in Western Australia considered the likely mechanisms and scope of influence for each camera type currently in use. The most appropriate evaluation designs and statistical analysis techniques were considered. The evaluation framework developed includes methodology to estimate the effectiveness of each camera type, primarily in terms of percentage crash savings. Methodology to convert this to absolute crash savings has also been considered, in order that the relative contribution of each camera type in reducing overall road trauma can be compared.

Another consideration in designing the evaluation framework was how to effectively control for the influence of other factors apart from the camera program, on crash outcomes. These included such factors as other road safety programs, socio-economic, environmental and travel exposure.

2.2.1 FIXED FREEWAY SPEED CAMERAS

There are relatively few published evaluations of the crash effects of fixed speed cameras located in non-intersection locations from which to glean information on likely effects. From those that are published, it appears that fixed speed cameras are generally used as a black spot type treatment at locations where speeding has been identified as a primary driver of identified elevated crash risk (M.H. Cameron & Delaney, 2006; C. Wilson, C. Willis, J. K. Hendrikz, R. Le Brocque, & R. Bellamy, 2010).

The most relevant evaluation for the Australian context of fixed speed cameras is that of the NSW fixed speed camera program (ARRB, 2005). Effects estimated for the NSW program are highly localised to within 3km of the camera site, possibly reflecting the high visibility signage used in conjunction with the cameras as part of this program. Although not specifically evaluated, the high visibility of the NSW program also suggests the primary mechanism of deterrence is the presence of the camera, with infringement notices issued acting as a secondary deterrence for infringing drivers. Deterrence related to camera visibility is also demonstrated in the Norwegian program (Elvik, 1997) where, similar to Western Australia, speed cameras are not always present in the fixed roadside boxes. Whether strongly localised deterrence is maintained when accompanying signage of the cameras is not used is unknown but considered likely. Freeway cameras in W.A. are signed so it is likely that the hypothesis of crash effects localised to the site applies.

One of the few other evaluations of fixed speed cameras was conducted for the U.K. camera program (Gains, 2005). Installation of the cameras in the U.K. program being evaluated was carried out in large numbers at relatively close proximity (within 0.5km). Unlike the other programs evaluated, there was some suggestion that the U.K. program may have achieved generalised effects (that is effects beyond the areas local to the camera sites) across the trial regions in which the cameras were situated. Whether this was a true generalised effect or simply a reflection of the density of camera operations is hard to identify. Furthermore, the generalised effects were only identified in early evaluations and not in the latest evaluation, suggesting that the population may learn and adapt to the specific locations of the fixed cameras over time.

Based on these previous evaluations, it is likely that fixed speed cameras in W.A. will have strongly localised crash effects at the camera site with deterrence primarily driven by the presence of the camera. Given the fixed speed cameras in W.A. are all located on the urban freeway network and signed, it is also likely that the effects will be limited to the freeway network itself.

The presence of localised effects, along with the need to control for the influence of other factors affecting crash outcomes at the camera sites, dictates the evaluation designs which could be considered for fixed cameras. Excluding the randomised controlled trial which is generally not a viable evaluation design for targeted road safety programs such as speed cameras, there are two potential evaluation designs which are commonly used for the evaluation of programs with localised crash effects: the simple before after design and the before after design with comparison group (quasi experiment) (Hauer, 1997).

Of the two designs considered for the outcome evaluation of road safety programs with localised effects, the quasi experiment is the design that often offers the most useful approach with a reasonable degree of scientific rigour. It is also the one that is most often used in practice reflecting its applicability. Unlike the fully randomised controlled trial, it is consistent with the implementation strategies typically used for road safety programs. It does not require broad reaching exposure data that are often difficult to obtain, particularly for programs with a wide geographical influence. Compared to the simple before-after comparison, the quasi experiment offers an additional level of scientific rigor by providing the facility to correct for biases in the estimated treatment effect caused by the simultaneous effects of non-treatment factors in the outcome measure. Furthermore, it eliminates the need to have explicit measures of confounding factors and to assume relationship forms between these and the outcome measure to undertake corrected before-after comparisons through some form of covariate analysis.

Use of the quasi experiment comes with some cautions. Control groups within the design must be carefully selected to adequately reflect the influence of non-treatment related factors at treated sites but not so narrowly as to compromise statistical power. The issue of regression to the mean must also be considered both from the likelihood of it representing a problem based on the selection regime for site treatment, and adopting a strategy to either minimise potential regression to the mean effects or estimate the magnitude of the regression to the mean bias.

Use of the quasi-experimental design requires consideration of how to specify the area over which the camera program will influence crashes (the ‘treatment area’) and the area which will be used as a comparison in the design (the ‘control’ or ‘comparison’ area).

Specifying the treatment area in the quasi experimental design for fixed spot speed cameras requires the halo of influence around the camera site to be defined. Hypothesising the size of the halo of influence is informed by the summary of halo sizes reported in previous speed camera evaluation studies summarised in Table 2.1. In urban areas the most commonly assumed halo of influence used was a distance of 0.5km from the camera site on the same road, although one study used a halo of 2km. In rural areas, the halo identified has extended up to 10km from the camera on the same road. The extent of the halo is likely to be driven partly by the placement of signs advising of the presence of a camera.

As noted, in W.A. signage is used with the spot speed cameras before the location of the camera. This practice, in conjunction with the findings from previous studies and noting the high speed limit of the W.A. sites, suggests that a halo of 1km from the camera site on the same road would be reasonable to use. Consequently, the treatment area is defined as areas on the same road as the camera is placed, within a 1km distance of the camera and on the same road. Crashes occurring in this area are hypothesised as being influenced by the presence of the camera. Under the initial W.A. implementation of fixed freeway speed cameras there are fewer cameras than sites and cameras are rotated amongst sites. Since the public are likely to be unaware of which sites have active cameras at any point in time, the speeding deterrence value of the cameras was considered to be unrelated to the camera being present.

Table 2.1 *Summary of estimated localised effects measured at camera sites, by affected crash/injury severity (reported by Wilson et. al., 2010)*

				Severity of crashes or injuries reduced by camera system								
Evaluation study (Wilson et al's terminology)	Speed camera type	Location type	Distance halo	Fatal	Hosp-ital	KSI	Med treat-ment	PIC	Other injury	Non-injury	Any sever-ity	Notes
				F	H	F+H	M	F+H+M	O	N	F to N	
AU VIC 1 Ph.3	covert mobile	Melbourne	1 km					8.4%				HAH crashes for 2 weeks
AU VIC 1 Ph.5	covert mobile	Melbourne	1 km					6.2%				HAH crashes for 2 weeks
AU VIC 1 Ph.5	covert mobile	Melbourne	1 km					14.6%				All crashes for 3 weeks
Average effect	**Covert**	**Urban**						**9.7%**				
GB Nationwide	overt fixed	Urban	0.5 km	20%		46.8%		22.4%				
GB Nationwide	overt mobile	Urban	0.5 km	45%		34.9%		22.4%				
GB Nationwide	overt fixed	Urban	0.5 km			23.5%		16.6%				
GB Nationwide	overt mobile	Urban	0.5 km			17.6%		19.4%				
GB 30mph Nation	overt fixed	Urban 30	1 km			13.0%		24.0%				
US Arizona 1	overt fixed	Urban fwy	6.5 mile					43.0%			47.0%	6.5 mile section
Average effect	**Overt**	**Urban**						**24.6%**				
AU VIC 1 Ph.5	covert mobile	Rural hwy	15 km					23.2%				HAH crashes for 1 week
AU VIC 1 Ph.5	covert mobile	Rural hwy	15 km					8.9%				LAH crashes for 2 weeks
Average effect	**Covert**	**Rural**						**16.1%**				
GB Nationwide	overt fixed	Rural	0.5 km	65%		62.4%		33.2%				
GB Nationwide	overt mobile	Rural	0.5 km	22%		33.8%		15.5%				
GB Norfolk	overt mobile	Rural 60	3 km			44.0%		19.0%				3 km long sections
Average effect	**Overt**	**Rural**						**22.6%**				
AU QLD 2	overt mobile	All State	2 km	45.3%	30.5%		39.0%	36.3%	19.3%	21.4%	28.4%	
GB South Wales	overt mobile	All types	0.5 km					50.0%				
GB Cambridge	overt fixed	All types	2 km					20.9%				
Average effect	**Overt**	**All**						**35.7%**				

Comparison sites for the evaluation were chosen using a very specific matching protocol which defines the comparison area as the same road as the camera is placed on, within the same statistical local area (SLA), limiting the selection to parts of the same road with the same speed limit and physical characteristics. This provided close matching on local factors affecting crash rates, as well as potentially ensuring similar traffic volumes on treatment and control sites.

Before and after treatment periods in the evaluation design were dictated by the date of installation and operationalization of the camera, in addition to the available data. To control for regression to the mean effects, a minimum of 3 years prior treatment crash history was aimed for. Matching of control sites by pre-treatment crash history to control for regression to the mean effects will not be feasible in this case since the control area road lengths were significantly longer than the treatment area for each matched pair.

2.2.2 INTERSECTION SPEED AND RED LIGHT CAMERAS

Cameras at signalised intersections which detect both red-light running and speeding infringements are a recent technology. The principal reasons for installing these combination cameras is to reduce red-light running crashes and also to reduce the risk and severity of the remaining crashes. The first objective is the same as that of traditional red-light cameras and in addition it could also be expected that the threat of detection for speeding by the cameras may encourage a proportion of motorists to travel at lower speeds through the intersection. As such the cameras appear to be consistent in objective with both the red light and fixed spot-speed cameras. Geographical reach in effectiveness and likely deterrence mechanism is likely to be similar to both single function camera types.

The only two published evaluations of the effects of this enforcement method is for three such cameras in Canberra (Brinson, 2002) and the Victorian intersection combined red light and speed camera program (Budd, Scully, & Newstead, 2011). Results of the Canberra study, in terms of changes in speeds and reductions in crashes, varied from site to site and results from the analysis were deemed inconclusive. The Victorian study focused only on crash effects and found the installations to be highly effective at reducing crashes in the area local to the intersection on which they were installed.

Information on red light only cameras is also informative in designing the evaluation framework for the dual function intersection cameras. Most of the existing evaluation studies, which are summarised by Retting and colleagues (Retting, Ferguson, & Hakkert, 2003), assume the effects of red light only cameras to be localised at or within close proximity of the camera site. Whether the effects of the camera are localised to the intersection leg on which it is placed or spill over to the whole intersection are not clear. The spill over effects may be related to the use of accompanying signage on other legs warning of the presence of a camera, as is applied in Victoria, or the visibility of the cameras from other legs. Primary mechanisms of deterrence associated with red light cameras identified in the evaluation studies are the overt physical presence of the camera and accompanying signage and the receipt of a traffic infringement by offending motorists. Given the overt nature of the program, the former is likely to be stronger.

For the purpose of this study then, it is likely that the effects of the combined red light and speed cameras will be highly localised to the intersection and perhaps the leg on which the camera is installed.

It was originally understood that the combined speed and red light camera installations in W.A. were are all upgrades of sites that previously had a red light camera installed with the red light cameras having been installed for many years before the upgrade. Precise installation dates of the original red light camera were not available. However, W.A. Police report that the majority of combined speed and red light camera sites are in fact new installations at previously unenforced locations.

Given the similarity in anticipated localised effects of the intersection cameras to the freeway spot speed cameras, a quasi-experimental design was also used for the evaluation of the intersection cameras. The key to getting the most robust and unbiased estimates of intersection camera crash effects under this framework is the appropriate choice of comparison sites for the quasi experiment. The control sites should accurately reflect the effects on crashes of factors other than the red light camera including socio-economic, environmental and other road safety programs. These other factors might be state-wide in their influence or very local with the control sites needing to reflect both extremes.

Control sites were matched on a range of criteria that describe the site at which the red light camera is located. Primary matching criteria for control sites for the evaluation of intersection cameras were:

1. Statistical Local Area (SLA)
2. Intersection control
3. Speed Limit

These matching criteria will likely capture other local influences on crash risk such as traffic exposure, and local road safety programs on road infrastructure that is the same as that where the intersection cameras are installed. In order to control for regression to the mean effects, as far as possible comparison sites were also matched by similar prior treatment crash history. Assuming that crash frequency counts at each treatment site follow approximately a Poisson distribution (Nicholson, 1985), whenever possible control sites with a similar prior treatment crash frequency were defined as those that had a prior treatment crash count within two standard deviations of the treatment prior crash count.

2.2.3 MOBILE SPEED CAMERAS

The use of mobile speed cameras in W.A. can generally be described as overt in nature as cameras operate with accompanying signs advising motorists of the camera and camera locations are routinely advertised to the public. The mobile speed camera program in W.A. commenced in 1995. Sites for camera location are based on a number of criteria. As reported by W.A. Police, mobile cameras can be operated from the roadside on a tripod, mounted in a vehicle or located in a fixed security cabinet. The criteria for the selection of all mobile speed camera locations is:

- speed related fatal or serious crashes zones
- 'speed related complaints' derived from the Hoon Hotline
- school zones
- locations where more than 15% of road users exceed the posted speed limit.

These criteria are reasonably broad as evidenced by the nearly 10,000 sites at which mobile cameras have been operated in W.A. (see Section 1). How the daily scheduling of sites is managed is unclear however analysis of operations data in Section 1 suggests that there is no systematic basis for camera scheduling. Some sites are used reasonably commonly however the majority of sites are visited relatively irregularly.

Generating a hypothesis for the likely effects of the W.A. mobile speed camera program is informed by the evaluation of the mobile speed camera program in Queensland, which is also run largely in overt mode. Evaluation of the Queensland mobile speed camera program (S. Newstead & Cameron, 2003; S. V. Newstead, 2006) have identified a strong spatial correlation with the mobile camera zones of operation and the bulk of crash effects being measured in areas within 1 kilometre of the operational camera zone centroids. This is in contrast to the Victorian mobile speed camera program where crash effects are largely generalised in space, due to the covert nature of the program (M.H. Cameron, Cavallo, & Gilbert, 1992; S. V. Newstead, Mullan, & Cameron, 1995; Rogerson, Newstead, & Cameron, 1994). Given the similarity between the Queensland and W.A. mobile speed camera programs of overt operations at chosen sites, evaluation of the W.A. program was also based on the principle of general deterrence facilitated through overt operation via marked vehicles. Reflecting this, the evaluation design for W.A. mobile speed camera has focused on detecting crash effects of the program at areas local to the sites where cameras have been operated over the life of the program.

Designing an evaluation methodology for the W.A. mobile camera program posed a number of challenges. Primary amongst these was that the available crash data for analysis started at the same time the camera program was introduced, meaning there was no pre-program crash history for analysis. This issue immediately precluded the application of the quasi-experimental design used for the fixed cameras. Instead, the evaluation framework used capitalised on the natural monthly variation in number of mobile camera sessions undertaken in both Perth and the rest of W.A. over the history of the program, as demonstrated in Figures 1.1 and 1.2. The aim of the evaluation framework was to measure the association between monthly cameras sessions undertaken, and observed crash frequency and severity in each month. Camera sessions rather than enforcement hours were favoured as the operational outcome measure due to the reporting of session numbers being more accurate in the data supplied. Based on a measured average of 2.5 hours of enforcement per session undertaken it is possible to convert between the two in the evaluation.

In line with the hypothesis of crash effects localised to the site of camera operations, areas of influence were hypothesised around each site of camera operation. Drawing from the Queensland mobile camera evaluation and other previous research and noting the highly overt operation of the W.A. cameras, an area of influence of radius 1km from the camera site was defined. Influence within a 500m radius was also considered to establish whether crash effects diminished with distance from the camera site. The same radius of influence was defined for operations regardless of area of the state.

In relating the number of monthly mobile speed camera sessions to crash outcomes, it was necessary to control for the effects of other factors potentially influencing crash outcomes at speed camera sites. In the evaluation of the Queensland mobile speed camera program, areas outside of the hypothesised areas of camera influence were used as an effective comparison to control for confounding effects. Examination of the spatial distribution of camera sites in metropolitan Perth identified that a similar strategy could not be used in the W.A. evaluation. This was because the number of sites used in Metropolitan Perth was so large that large tracts of inner Perth were effectively totally covered by camera operations, meaning there would be a significant geographical mismatch between treated and untreated sites. This was considered likely to compromise the use of the untreated areas as controls since they would not represent the influence of factors local to the camera sites. Instead, it was decided to use a multivariate time series modelling approach to control for the effects of major non-camera factors on crash outcomes. Factors included in the models included:

- Population
- Vehicle travel
- Unemployment rate
- Alcohol sales

Each of these factors have been identified as being important in influencing road trauma outcomes in previous research in both Western Australia and other jurisdiction (D'Elia, 2014; Scuffham & Langley, 2002). Furthermore, these previous studies have demonstrated the consideration of these factors in conjunction with a measure of road safety program output to measure the effectiveness of the road safety program. In additional to the above factors, a general yearly level (trend) as well as seasonality were also included in the model to account for the effects of any un-measured confounding factors.

A further means of controlling the evaluation design for confounding was also identified from the operations data. Figure 1.6 shows that the vast majority of mobile speed camera sessions took place between the hours of 6am and 8pm meaning the remaining hours of the day are essentially un-enforced. This presented the opportunity to stratify the monthly crash data into enforced and un-enforced times based with the modelling relating monthly variation in the enforced time crashes to the speed camera session data and the un-enforced time crashes only to the confounding factors. This process strengthened the ability of the analysis to detect relationships between crashes and the measures of the confounding variables, effectively using the un-enforced time crashes as a type of control.

To ensure adequate statistical power in the analysis, the crash data was stratified into two geographical areas: metropolitan Perth and the Rest of W.A. As well as using monthly crash counts as the principle measure of outcome, analysis also considered the average severity of crashes defined by the proportion of all casualty crashes that were fatal and serious injury and the proportion of all casualty crashes that were fatal.

2.3 ANALYSIS METHODS

2.2.1 FIXED FREEWAY SPEED CAMERAS AND INTERSECTION SPEED AND RED LIGHT CAMERAS

Statistical methods to support the analyses of quasi-experimental designs, as described for the fixed camera elements, are the same for both fixed freeway cameras as well as intersection cameras. Each design has the similarity of assessing the change in crash counts from a period before treatment implementation to a period after treatment implementation against parallel changes at the defined control or comparison areas. Because the treatments being considered are highly localised, the crash data in the before and after periods was too small to facilitate a time series based analysis. Hence, the statistical analysis was performed on aggregated data in the form of total crash counts in each of the before and after periods.

To outline the basic statistical analysis methodology, first the case of a single treatment site assessed against aggregated data across the chosen control areas is considered. The accident data for a particular treatment site and control site in a simultaneous before and after comparison can be summarised in a 2x2 contingency table, shown in Table 2.2. The before and after treatment crash counts are taken over the entire before and after treatment periods defined in the study. Often the before and after crash periods are of different duration although, as will become evident, this has no bearing on the analysis method.

Table 2.2 *Contingency table representation of crash counts in the quasi experiment*

	Before treatment crash count	After treatment crash count
Control group	n_{00}	n_{01}
Treatment group	n_{10}	n_{11}

The assessment of the treatment effect in the quasi experiment is made by comparing changes in the crash frequency at the treatment site from before to after treatment, with parallel changes in crash frequency at the control site, over the same time period. If there is no treatment effect the ratio of crashes after treatment to before treatment, at the treated site, will be the same as the ratio at the control site (within chance variation). A treatment producing an effect at the treatment site will result in different after to before crash ratios between treatment and control sites. In terms of the contingency table representation of crashes in Table 2.2, a treatment crash effect will be reflected in an interactive effect on cell counts between the rows and columns of the table.

To assess this interactive effect a regression model framework was used to test for the statistical significance of an interactive effect in the contingency table. The model is defined as:

$$\ln(n_{tb}) = \alpha + \beta_t + \gamma_b + \delta_{tb} + \varepsilon_{tb} \quad \text{(Equation 2.1)}$$

where:

t is the index for treatment or control group (0=control, 1=treatment)

b is the index for before or after treatment (0=before treatment, 1=after treatment)

α, β, γ, δ are parameters of the model

ε is a random error term

n_{tb} is the observed crash count

The structure of the linear form of parameters in the above model can be thought of as including the base effects and first order interaction of two categorical variables, each with two levels. Parameterisation of the 2 level categorical variables in the model is most convenient for interpretation using a simple contrast scheme where the design matrix elements are represented only as a combination of zeros and ones. Because the model includes an intercept, one level of each of the categorical variables must be aliased through setting the associated parameter to zero. The choice of the aliased parameter in the model is critical for ease of interpretation of the remaining parameters. It turns out to be most convenient to alias the parameters corresponding to the zero levels of the before and after treatment indicator, which is the before level, and the treatment control indicator, which is the control indicator. Correspondingly, three out of the four interaction parameters, where either the before-after or treatment-control indicators are at their zero level, are also aliased. Symbolically, this is:

$$\beta_0 = \gamma_0 = 0 \quad and$$
$$\delta_{00} = \delta_{01} = \delta_{10} = 0$$

Parameter β_1 then represents the difference in the number of crashes between the treatment and control groups in the before treatment period and parameter γ_1 represents the change in crash frequency in the control group from before to after treatment. Most importantly, parameter δ_{11} represents the differential crash change in the treatment group from before to after treatment compared to the control group as shown in Table 2.2. In other words, parameter δ_{11} is a direct measure of the crash effect of the treatment being assessed. It is straightforward to show that the ratio of after to before treatment crashes at the treatment site, relative to the control site, is simply the exponent of parameter δ_{11}. This leads to the estimated percentage crash reduction at the treatment site attributable to the treatment, after parallel adjustment for changes in the control series crashes, being given as:

$$\Delta = (1 - \exp(\delta_{11})) \times 100\% \qquad \text{(Equation 2.2)}$$

Table 2.3 *Expected values contingency table representation of crash counts in the quasi-experiment*

	Before treatment crash count	After treatment crash count
Control group	$\exp(\alpha)$	$\exp(\alpha + \gamma_1)$
Treatment group	$\exp(\alpha + \beta_1)$	$\exp(\alpha + \beta_1 + \gamma_1 + \delta_{11})$

A log link function is chosen for the regression model as is assumes the countermeasure acts on crash frequency in a multiplicative rather than an additive way. The assumption of multiplicative effects within the model can be sustained because a road safety countermeasure will generally reduce the frequency of accidents by a certain proportion and not by a certain number. The multiplicative structure also ensures that the crash counts predicted from the regression model are non-negative, a clearly desirable property for models of crash counts.

A test of the statistical significance of the estimated treatment effect can be made using the parameter estimate for δ_{11} and its standard error, SE(δ_{11}). The generic null hypothesis being tested is that the treatment had no effect on observed crash frequency after implementation relative to the control. This is tested against the two sided alternative hypothesis that the treatment resulted in some change in observed crashes. Existing evidence of speed camera effectiveness suggests that it could be expected that each camera system would reduce, but not increase, crashes to some degree and, because of this, it would be appropriate to test against a one sided alternative hypothesis in each case in order to maximise statistical power. However, it is possible that drivers may react to visible camera equipment by speeding up after slowing very temporarily in response to a perceived short-distance threat, and hence increasing crashes or their severity on road sections adjacent to areas around the camera sites. Because of this unintended possibility, it is considered that two sided alternative hypotheses are appropriate in most circumstances in this study.

In relation to the parameter δ_{11}, the null and alternative hypotheses can be phrased in the following way:

$$H_o : \delta_{11} = 0$$
$$H_1 : \delta_{11} \neq 0$$

Having both the parameter estimate and its standard error, calculation of the Type I error probability for acceptance or rejection of the null hypothesis can be made using a standard normal quantity, *Z*, defined as:

$$Z = \frac{\delta_{11}}{SE(\delta_{11})} \quad \text{(Equation 2.3)}$$

The significance probability for assessment of the null hypothesis is calculated by comparing Z to the standard normal distribution in the usual way. Similarly, (1-k) 100% confidence limits can be calculated for the treatment effect parameter δ_{11} from the following:

$$\delta_{11} \pm Z_{k/2} SE(\delta_{11}) \qquad \text{(Equation 2.4)}$$

Here Z_k is the k^{th} percentile of the standard normal distribution. The confidence limit for the parameter estimate can be transformed into a confidence limit for the estimated percentage crash reduction by applying Equation 2.4 to each bound of the parameter confidence limit.

A final important consideration in specifying the analysis regression model is the error structure which is assumed for the crash count data. The most commonly assumed error structure is a Poisson distribution (Nicholson, 1985, 1986) although when data are aggregated across a number of sites, which might be the case when control data is taken across a range of eligible sites, other distributions arise. The most common of these is the Negative Binomial distribution which accounts for over or under dispersion of the data as well as cases where there is a surplus of zero crash counts (Hilbe, 2007). The general strategy in choosing the most appropriate analysis error structure was to either start with the negative binomial error structure and assess the relationship between the estimated mean and variance parameters, or to start with the Poisson distribution and examine for evidence of over dispersion. Goodness of fit statistics such as the Akaike Information Criteria (AIC) were used to inform the choice (Wood, 2002).

Presentation of the analysis model above has considered estimating the treatment crash effect at one treatment site using corresponding control site information for that treatment. Cameras with localised crash influence are implemented across a number of sites and it is of interest to assess the treatment effectiveness at each of these sites individually as well as in aggregate across all sites. The above model is readily extended to simultaneously estimate the effect of *L* treatments from *L* treatment and control pairs with before and after treatment data.

For L treatment and control pairs, the before and after crash count data may be summarised in a 2x2xL contingency table as shown in Table 2.4.

Table 2.4 *Contingency table representation of crash counts from L individual treatment and control pairs*

Site No.	Control Group		Treatment Group	
	Before	After	Before	After
1	n_{111}	n_{112}	n_{121}	n_{122}
2	n_{211}	n_{212}	n_{221}	n_{222}
.	.	.	.	.
.	.	.	.	.
L	n_{L11}	n_{L22}	n_{L21}	n_{L22}

The regression model for analysis of the treatment crash effects at the *L* sites in Table 2.4 is an extension of that described by Equation 2.1. The extended model is given by Equation 2.5 and is essentially Equation 2.1 with each term interacted with a site indicator variable.

$$\ln(n_{stb}) = \alpha + \lambda_s + \beta_{st} + \gamma_{sb} + \delta_{stb} + \varepsilon_{stb} \qquad \text{(Equation 2.5)}$$

The definition of terms in Equation 2.5 is the same as for Equation 2.1 with the addition of the following.

S is the indicator for treatment site (*1, 2,..., L*)

λ_s are model parameters indicating differences in the number of crashes between sites.

Appropriate aliasing of indicator variable levels in the extended model is again critical for obtaining direct estimate of the crash effects of the treatment at each treated site. The following parameters are aliased in the model to achieve this

$$\beta_{s0} = \gamma_{s0} = 0 \ \forall s \ \ and$$
$$\delta_{s00} = \delta_{s01} = \delta_{s10} = 0 \ \ \forall s$$

Which of the λ_s are aliased is not important.

Aliasing in this way leaves the parameters δ_{s11} as direct estimates of the treatment effect at each treatment site. The percentage crash reduction at treatment site s is given by Equation 2.6, being analogous to Equation 2.6 for the single treatment case.

$$\Delta_s = (1 - \exp(\delta_{s11})) \times 100\% \qquad \text{(Equation 2.6)}$$

Tests of the statistical significance of each treatment effect parameter and corresponding confidence limits follow through obvious modification to Equations 2.3 and 2.4.

One of the advantages of using a single model to estimate treatment effects across a number of treatment sites is that the model of Equation 2.5 can be modified subtly to provide an average treatment effect across all *L* treatments being assessed. The modifications to the model involve a modification to Equation 2.5 replacing the *L* 3-way interaction terms δ_{s11} with a single global 2-way interaction term as indicated in Equation 2.7.

$$\ln(n_{stb}) = \alpha + \lambda_s + \beta_{st} + \gamma_{sb} + \delta_{tb} + \varepsilon_{stb} \qquad \text{(Equation 2.7)}$$

Aliasing is as before except with all but δ_{11} of the δ parameters aliased. The non-aliased parameter δ_{11} represents the average net treatment crash effect across the *L* treated sites. Calculation of the overall percentage treatment crash reduction, significance probabilities, and confidence limits are as before based on the overall treatment effect parameter, δ_{11} in Equation 2.7, and its estimated standard error.

There are specific benefits to using the formulation of Equation 2.7 rather than aggregating data across treatment and control sites to produce an overall effect estimate. Firstly, it avoids the potential for the occurrence of Simpson's paradox which can occur when data are aggregated across a confounding variable (Jarrett, 1997; Simpson, 1951). If the treatment effect is confounded with site then aggregation of the data across sites may lead to a biased overall treatment effect estimate.

2.2.2 MOBILE SPEED CAMERAS

The objective of the analysis to measure the crash effects of the mobile speed camera program was to relate monthly variation in observed crashes to the monthly number of camera sessions undertaken whilst controlling for the influence of a range of other factors on crash outcomes. The analysis also needed to simultaneously model these relationships for crashes in enforced times and unenforced times. A Negative-Binomial Generalised Estimating Equation (NB GEE) was identified as the most appropriate analysis technique to meet these requirements. The NB GEE is readily able to accommodate over or under dispersion of the crash data which is possible in the time series count data. It is also able to effectively account for serial correlation of the time series data hence providing more accurate estimates of parameter standard errors. Under the GEE model framework, the repeated measures block is represented by the treated (daytime) and untreated (nigh-time) analysis stratum. For this analysis, the working correlation matrix, which represents the inter-correlation between data points, is most appropriately set as an autoregressive form to reflect the time series nature of the data. Fitted values from the model are constrained to be non-negative through the log link function which also reflects the assumption that both the camera program and external factors, such as road safety campaigns, affect crash numbers in a proportionate way.

The form of the model fitted to the crash data count time series data is given by Equation 2.8. Separate models were fitted to data series in Perth and the Rest of W.A.

$$\ln(y_{tg}) = \alpha_g + \beta X_t + \delta_{mg} + \gamma_{rg} + \phi s_{tg} \quad \text{… (Equation 2.8)}$$

where:

y_{tg} is the monthly crash count in analysis series g and month t

S_{tg} is the camera sessions in month t and analysis series g (this will be zero for all months in the night crash series).

X_t is the vector of measures of other factors (population, unemployment, vehicle travel and alcohol sales) in month t.

g is an indicator for day (6am-8pm times) or night (8pm-6am) data series

t is the month from January 1995

m is the month of year indicator (1, 2, …,12)

c is the year of crash indicator (1995, 1996, … , 2012)

$\alpha, \beta, \delta, \gamma, \phi$ are parameters of the model

The key parameter in the model giving the relationship between the number of speed camera sessions undertaken in a month and observed crash outcomes in the month is ϕ. The quantity shown in Equation 2.9 gives the percentage change in expected crashes for each unit change in the number of speed camera sessions. From Equation 2.9, the impact on crashes of changing the level of mobile camera enforcement can be estimated as well as inferring the expected number of crashes if no camera enforcement had taken place.

$$(1-\exp(\phi))\times 100\% \qquad \ldots \text{ (Equation 2.9)}$$

The variance of ϕ from the modelling output can be used to compute confidence limits on the estimated change in crash frequency and to test the statistical significance of the association between camera sessions and crash outcomes. Separate models were fitted for the different crash severity levels considered.

2.4 RESULTS: EVALUATION OF CRASH EFFECTS

2.4.1 FIXED FREEWAY SPEED CAMERAS

Using GIS based matching techniques crashes were identified in the defined treatment area which was areas on the same road as the camera is placed within a 1km distance of the camera. Crashes occurring in this area were hypothesised as being influenced by the presence of the camera. Four camera sites were available for analysis and are listed in Table 2.5 along with the LGA in which control crashes were matched and the date of activation of the camera. Before and after study periods were determined according to the activation date of each fixed speed camera.

Table 2.5 *Fixed freeway speed camera sites used in the evaluation*

Fixed Speed Camera Location	LGA	Fixed Speed Camera Site Activation Date
F00001: Mitchell Fwy & Karrinyup Rd, Innaloo	Stirling	23 Dec 2011
F00002: Kwinana Fwy & Eric St, Como	South Perth	12 July 2012
F00003: Roe Hwy & South St, Willetton	Canning & Melville	11 Sept 2012
F00004:Mitchell Fwy & Erindale Rd, Stirling	Stirling	3 Oct 2012

Crashes occurring on or after the activation date of the fixed speed camera were defined as 'after' crashes with the after period ending in December 2012, the latest date for which crash data was available for the study. Hence the after period of crashes ranged from approximately 3 months to 13 months. Those crashes occurring 5 years before each camera's activation date were defined as 'before' crashes. A 5 years prior treatment crash history was considered adequate to control for potential regression to the mean effects. The potential for regression to the mean to be a problem for the study was unclear since it was unknown on what basis sites were chosen for camera placement.

To account for the influence of factors other than the fixed speed cameras that may have occurred during the evaluation period, a suitable control or comparison group of crashes had to be chosen. For this study, crashes occurring on the same roads and in the same Local Government Area but outside of the 1 km radius of the camera were chosen as the control group of crashes. Crashes occurring in the same before and after periods as the treatment group were identified for each matched control group.

Crash Frequencies at Fixed Camera Sites

The number of crashes (all injury and property damage crashes) occurring at each of the four fixed speed camera sites before and after activation of each camera together with the corresponding control crashes are shown in Table 2.6

Crashes were also presented by the following levels of crash severity:

- Fatalities, hospital admissions and medical attention – defined as All Casualty Crashes, and
- Fatalities and hospital admissions – defined as Serious Casualty Crashes.

The crash frequencies for the All Casualty and Serious Casualty groups of crashes are presented in Tables 2.7 and 2.8 respectively.

Table 2.6 *Injury & Property Damage Crashes at Fixed Speed Camera Locations in W.A. by Study Period and Camera Site*

Fixed Speed Camera Location	LGA of crash	Fixed Speed Camera Site Activation Date	Within 1km radius of fixed speed camera site (Treatment)		Outside 1 km radius of fixed speed camera on same roads and in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
F00001: Mitchell Fwy & Karrinyup Rd, Innaloo	Stirling	23 Dec 2011	765	160	727	144
F00002: Kwinana Fwy & Eric St, Como	South Perth	12 July 2012	590	37	1921	113
F00003: Roe Hwy & South St, Willetton	Canning & Melville	11 Sept 2012	728	52	1016	68
F00004:Mitchell Fwy & Erindale Rd, Stirling	Stirling	3 Oct 2012	534	19	834	37

Table 2.7 *All Casualty Crashes at Fixed Speed Camera Locations in W.A. by Study Period and Camera Site*

Fixed Speed Camera Location	LGA of crash	Fixed Speed Camera Site Activation Date	Within 1km radius of fixed speed camera site (Treatment)		Outside 1 km radius of fixed speed camera on same road and in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
F00001: Mitchell Fwy & Karrinyup Rd, Innaloo	Stirling	23 Dec 2011	182	48	173	29
F00002: Kwinana Fwy & Eric St, Como	South Perth	12 July 2012	112	8	348	23
F00003: Roe Hwy & South St, Willetton	Canning & Melville	11 Sept 2012	140	6	195	16
F00004:Mitchell Fwy & Erindale Rd, Stirling	Stirling	3 Oct 2012	116	1	194	8

Table 2.8 *Serious Casualty Crashes at Fixed Speed Camera Locations in W.A. by Study Period and Camera Site*

Fixed Speed Camera Location	LGA of crash	Fixed Speed Camera Site Activation Date	Within 1km radius of fixed speed camera site (Treatment)		Outside 1 km radius of fixed speed camera on same road and in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
F00001: Mitchell Fwy & Karrinyup Rd, Innaloo	Stirling	23 Dec 2011	35	5	35	4
F00002: Kwinana Fwy & Eric St, Como	South Perth	12 July 2012	25	0	51	4
F00003: Roe Hwy & South St, Willetton	Canning & Melville	11 Sept 2012	23	0	47	1
F00004:Mitchell Fwy & Erindale Rd, Stirling	Stirling	3 Oct 2012	29	0	38	1

Analysis Results

Data presented in Tables 2.6 to 2.8 was used in the regression models described in Section 2.2.1 to estimate the net crash effects associated with installation of the fixed speed cameras on the Perth freeway network. Results are presented in Table 2.9 for each site as well as on average across the four sites evaluated for the three crash severity levels considered. The relative risk measure (RR) in Table 2.9 is the relative crash risk after camera installation compared to before camera installation after correcting for parallel changes in the comparison group from before to after installation. For example, a relative risk of 0.608 indicates the average crash risk after camera installation is 60.8 percent of the pre installation risk, or a 39.2% crash reduction. Also presented in Table 2.9 is the significance probability of the estimated relative risk (the probability of obtaining the estimated relative risk given no real effect of the camera – low significance probabilities indicate a likely real effect of the camera) and the 95% confidence limit on the relative risk estimate (the interval the real crash reduction associated with the camera installation lies with 95% certainty – confidence limits that do not overlap indicate a significant crash effect associated with camera installation).

Table 2.9 *Estimated relative crash risk at sites with fixed speed cameras compared to sites with no speed cameras*

Serious Casualty Crashes				
Site	**RR**	**p-value**	**95% LCL**	**95% UCL**
F0001	1.250	.754	.310	5.048
F0002	N/A	N/A	N/A	N/A
F0003	N/A	N/A	N/A	N/A
F0004	N/A	N/A	N/A	N/A
Average	**.608**	**.392**	**.195**	**1.899**
All Casualty Crashes				
Site	**RR**	**p-value**	**95% LCL**	**95% UCL**
F0001	1.573	.079	.949	2.609
F0002	1.081	.855	.470	2.484
F0003	.522	.186	.199	1.368
F0004	.209	.142	.026	1.693
Average	**1.078**	**.688**	**.746**	**1.558**
All Reported Crashes				
Site	**RR**	**p-value**	**95% LCL**	**95% UCL**
F0001	1.056	.666	.825	1.352
F0002	1.066	.743	.727	1.563
F0003	1.067	.733	.735	1.550
F0004	.802	.443	.456	1.409
Average	**1.033**	**.716**	**.869**	**1.227**

N/A = not result available due to inadequate post implementation crash data

Results presented in Table 2.9 do not indicate any statistically significant crash effects associated with implementation of the fixed speed cameras. In this instance, this result does not indicate that the speed cameras have no effect on crashes. Lack of statistical significance is a result of the limited ‘after implementation period’ for which crash data was available for analysis. As noted, across the four sites assessed, there was only between 3 and 13 months post implementation crash data available for analysis. Results show this is clearly inadequate for robust analysis of the crash effects associated with the fixed cameras. This is particularly the case for serious casualty crashes where 3 of the 4 sites analysed have no observed crashes in the after implementation period.

Whilst the point estimates of camera effects on all crashes and all casualty crashes make no indication of any particular crash effects, the point estimate for serious casualty crashes suggests a crash reduction benefit associated with the camera, although this result is not robust as mentioned. As will be seen in the analysis of crash effects for other camera types, speed enforcement in particular seems to have a greater impact on higher severity crashes than lower severity crashes, consistent with the results suggested here. Consequently it would be highly valuable to revisit the analysis of the effects of fixed freeway speed cameras on crash risk when a longer ‘after implementation period’ of crash data is available for analysis.

2.4.2 COMBINED RED LIGHT SPEED CAMERA SITES.

Crashes occurring at each of the 25 RLSC sites were identified using the mapped GIS data locations for crashes and intersection camera sites. Data were further filtered by cross checking the location name of the crash in the crash data to make sure the name of the intersection matched the name where the camera location was described. Only crashes occurring at the intersection, as described in the crash data, were selected for analysis. Crashes at road mid-blocks adjoining the intersection were excluded from analysis.

The 'before period' for analysis was defined to be that occurring five years before each RLSC activation date (see Table 2.10). The 'after treatment period' was defined as the date of the camera activation until December 2012, the last month of available data. It should be noted again here that the cameras being evaluated here are not new installations but upgrades of existing red light only camera sites. Consequently the evaluation is measuring the benefits of the camera upgrade rather than a new installation of a combine speed red light camera. Installation dates for the original red light cameras were not available so evaluation could not consider the crash effects of the original camera installation. Furthermore, no new installations of red light and speed cameras had been undertaken at previously un-enforced intersections to assess the impact of this treatment.

A suitable group of crashes had to be chosen as the control group to account for factors other than the combined Red Light Speed Cameras that may have been of influence on crash frequencies during the evaluation period. Crashes occurring during the same before and after periods as the treatment crashes (i.e. the RLSC sites) at signalised intersections in the same Local Government Areas (LGAs) as the RLSC sites, were chosen as control crashes. It should be noted that some of the sites had to share a common control set since the camera sites were located in the same LGA. For example, sites R00027, R00036, R00049 & R00050 were located in the LGA of Stirling so these sites shared the same control group. In this case the before period became 5 years prior to the first camera activation in the LGA whilst the after period was the date of the last camera activation up to December 2012.

Crash Frequencies at Intersection Camera Sites

The number of crashes of all severity levels occurring at each of combined Red Light Speed Camera sites and at each control set both before and after camera activation are shown in Table 2.10.

The crash frequencies for the All Casualty and Serious Casualty groups of crashes are presented in Tables 2.11 and 2.12 respectively. Crash severity aggregations are as defined for the fixed freeway camera analysis in the previous section. There were insufficient fatal crashes at the intersection site being studied to undertake an analysis of effects on fatal crashes. Where a number of sites were compared against a single control LGA, the aggregate crashes across the intersection sites in the same LGA have been given in Tables 2.11-2.12. Before and after treatment crash frequencies for the sites individually can be found in Tables 2.13-2.15 below.

Table 2.10 *All Reported Crashes at combined Red Light Speed Camera Locations in W.A. by study period*

Location ID	LGA where crash occurred	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	14 Jul 2010	80	36	862	401
R00022	Victoria Park	26 Jul 2010	24	21	1256	641
R00030	Cockburn	13 Jul 2010	53	18	1174	683
R00035	Melville	20 Dec 2010	111	32	2611	1104
R00037	Armadale	14 Apr 2011	90	44	273	93
R00043	Kalamunda	15 Jul 2010	180	85	590	355
R00027 & R00036 & R00049 & R00050 (grouped)	Stirling	15 Jul 2010	676	197	5244	2506
R00029 & R00033 & R00062 & R00063 & R00064 (grouped)	Canning	13 Jul 2010	369	152	2797	1482
R00041 & R00051 (grouped)	Bayswater	20 Dec 2010	182	70	1794	803
R00047 & R00059 (grouped)	Joondalup	27 Jul 2010	377	144	2161	1023
R00052 & R00054 (grouped)	Swan	5 Jul 2011	259	121	1759	582
R00061	Kwinana & Rockingham	21 Dec 2010	53	20	1339	488
R00031	Wanneroo	8 Aug 2010	108	68	1051	598
R00040	Stirling	13 Jul 2010	93	49	5244	2506
R00046	Joondalup	9 Aug 2011	242	68	2161	1023

Table 2.11 *All Casualty Crashes at combined Red Light Speed Camera Locations in W.A. by study period*

Location ID	LGA where crash occurred	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	14 Jul 2010	17	4	135	84
R00022	Victoria Park	26 Jul 2010	4	4	266	110
R00030	Cockburn	13 Jul 2010	12	5	267	144
R00035	Melville	20 Dec 2010	23	11	513	224
R00037	Armadale	14 Apr 2011	24	15	59	25
R00043	Kalamunda	15 Jul 2010	32	16	120	70
R00027 & R00036 & R00049 & R00050 (grouped)	Stirling	15 Jul 2010	131	41	1085	541
R00029 & R00033 & R00062 & R00063 & R00064 (grouped)	Canning	13 Jul 2010	86	32	525	273
R00041 & R00051 (grouped)	Bayswater	20 Dec 2010	54	14	407	165
R00047 & R00059 (grouped)	Joondalup	27 Jul 2010	79	33	508	220
R00052 & R00054 (grouped)	Swan	5 Jul 2011	51	14	380	1200
R00061	Kwinana & Rockingham	21 Dec 2010	11	5	313	97
R00031	Wanneroo	8 Aug 2010	21	15	235	135
R00040	Stirling	13 Jul 2010	27	7	1085	54
R00046	Joondalup	9 Aug 2011	59	14	508	220

Table 2.12 *Serious Casualty Crashes at combined Red Light Speed Camera Locations in W.A. by study period*

Location ID	LGA where crash occurred	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
			5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	14 Jul 2010	2	1	30	12
R00022	Victoria Park	26 Jul 2010	1	2	49	16
R00030	Cockburn	13 Jul 2010	1	0	58	20
R00035	Melville	20 Dec 2010	5	2	92	17
R00037	Armadale	14 Apr 2011	8	1	16	3
R00043	Kalamunda	15 Jul 2010	6	1	25	13
R00027 & R00036 & R00049 & R00050 (grouped)	Stirling	15 Jul 2010	29	5	189	94
R00029 & R00033 & R00062 & R00063 & R00064 (grouped)	Canning	13 Jul 2010	22	3	80	36
R00041 & R00051 (grouped)	Bayswater	20 Dec 2010	18	7	91	25
R00047 & R00059 (grouped)	Joondalup	27 Jul 2010	17	6	98	40
R00052 & R00054 (grouped)	Swan	5 July 2011	11	0	78	22
R00061	Kwinana & Rockingham	21 Dec 2010	5	2	89	24
R00031	Wanneroo	8 Aug 2010	3	0	44	24
R00040	Stirling	13 Jul 2010	7	2	189	94
R00046	Joondalup	9 Aug 2011	6	2	98	40

Analysis Results

Using the analysis methods described in Section 2.2.1, the crash effects associated with upgrading red light only cameras to combined speed and red light cameras at the 25 studied was estimated. Results of the analysis are given in Table 2.13 which is presented in a similar format to the analysis of fixed freeway speed cameras in the previous section. For each crash severity grouping considered, a relative risk is presented which represents the proportion of crashes expected at camera sites compared to only a red light camera being in place. Estimates are corrected for the effects of other factors influencing crash outcomes through adjusting the change in crashes at the camera sites from before to after treatment for similar changes at the chosen comparison sites via the analysis model. Table 2.13 also gives the statistical significance value and 95% confidence limit for the estimated relative risk.

Table 2.13 *Estimated average crash effects of upgrading red light only cameras to combined speed and red light cameras in W.A.*

Crash Severity	Relative Risk	Sig.	95% Lower Confidence Interval	95% Upper Confidence Interval
All Crashes	0.823	<0.001	.765	.885
Casualty Crashes	0.823	0.018	.700	.967
Serious Casualty Crashes	0.633	0.024	.426	.943

Table 2.13 shows statistically significant crash reductions associated with the intersection speed and red light camera upgrades in W.A. for all of the crash severity groupings considered. The magnitude of the estimated crash reductions were also greater for serious casualty crashes (36.7%) compared to all casualty crashes and all reported crashes (17.7%) although these differences are not statistically significant as demonstrated by the overlapping 95% confidence intervals.

Investigation of Regression-to-the-mean

One concern in evaluating the effects of non-randomly chosen sites for safety treatments, such as intersection camera upgrades, is the potential for the phenomenon known as regression to the mean (RTM). RTM can occur when sites are chosen for treatment based on a high prior crash history amongst similar sites and can lead to overestimation of the crash effects of the safety treatment. As noted in discussing the evaluation methodology in Section 2.2, RTM can be overcome by using a long pre-treatment crash history as well as potentially choosing comparison sites in the evaluation which are matched by pre-treatment crash history, meaning they are potentially equally susceptible to RTM effects.

It is not known whether the intersection camera sites in W.A. were chosen for upgrade from red light only, to red light and speed camera based on crash history or some other criteria. Since the treatment being evaluated is an upgrade of existing cameras rather than new installations, the potential for RTM effects is likely lower than for completely new installations. Despite this, an analysis to investigate the potential for RTM effects in the intersection camera analysis was undertaken.

To allow for a potential regression-to-the-mean effect, sub-groups of the control crashes used for the uncorrected analysis were chosen that had a similar prior crash history as those at the treated sites. They were chosen to be within 10% of the prior crash history frequencies at RLSC sites – i.e. crashes that occurred at signalised intersections in the same LGA as the RLSC site but within 10% of the treated site's prior crash history. It should be noted that at some of the control sites the prior crash history was more than 10% different from the treated site (ranging from 20% to 50%) due to the inability to find any appropriately matched sites.

The crash frequencies for the RLSC treatment and RTM-matched control sites are presented in Table 2.14 (all crashes); Table 2.15 (casualty crashes) and Table 2.16 (serious casualty crashes).

Table 2.14 *All Reported Crashes at combined Red Light Speed Camera Locations in W.A. by study period with controls matched by prior crash history at camera sites*

RLSC Location ID	LGA of crash	Suburb of RLSC Camera	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
				5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	South Perth	14 Jul 2010	80	36	160	75
R00022	Victoria Park	Victoria Park	26 Jul 2010	24	21	47	25
R00030	Cockburn	Hamilton Hill	13 Jul 2010	53	18	469	205
R00035	Melville	Booragoon	20 Dec 2010	111	32	889	333
R00037*	Armadale	Piara Waters	14 Apr 2011	90	44	47	15
R00043*	Kalamunda	High Wycombe	15 July 2010	180	85	118	62
R00027	Stirling	Dianella	20 Dec 2011	121	30	365	71
R00036	Stirling	Mirrabooka	18 Apr 2011	139	37	133	51
R00049	Stirling	Dianella	15 Jul 2010	72	24	651	341
R00050*	Stirling	Balcatta	18 Apr 2011	344	106	175	97
R00029	Canning	Bentley	15 Jul 2010	98	53	303	152
R00033	Canning	Wilson	13 Jul 2010	44	24	259	121
R00062	Canning	Canningvale	15 Apr 2011	115	21	227	86
R00063	Canning	Canningvale	15 Apr 2011	48	25	241	99
R00064	Canning	Welshpool	9 Aug 2011	64	29	196	66
R00041	Bayswater	Morley	20 Dec 2010	101	38	90	36
R00051	Bayswater	Bayswater	10 Aug 2011	81	32	88	27
R00047*	Joondalup	Padbury	27 Jul 2010	190	69	103	24
R00059*	Joondalup	Joondalup	14 Apr 2011	187	75	154	43
R00052	Swan	Hazelmere	8 Sep 2011	35	11	65	13
R00054*	Swan	Malaga	5 Jul 2011	224	110	132	30
R00061	Kwinana & Rockingham	East Rockingham	21 Dec 2010	53	20	58	17
R00031*	Wanneroo	Hamersley	8 Aug 2010	108	68	177	96
R00040	Stirling	Balga	13 Jul 2010	93	49	653	267
R00046*	Joondalup	Madely	9 Aug 2011	242	68	142	36
ALL				2897	1125	5942	2388

**More than 10% of treatment prior crash frequency (within 20% to 50%)*

Table 2.15 *All Casualty Crashes at combined Red Light Speed Camera Locations in W.A. by study period with controls matched by prior crash history at camera sites*

RLSC Location ID	LGA of crash	Suburb of RLSC Camera	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
				5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	South Perth	14 Jul 2010	17	4	19	19
R00022	Victoria Park	Victoria Park	26 Jul 2010	4	4	4	3
R00030	Cockburn	Hamilton Hill	13 Jul 2010	12	5	108	39
R00035	Melville	Booragoon	20 Dec 2010	23	11	173	64
R00037*	Armadale	Piara Waters	14 Apr 2011	24	15	11	3
R00043*	Kalamunda	High Wycombe	15 July 2010	32	16	23	10
R00027	Stirling	Dianella	20 Dec 2011	29	8	77	9
R00036	Stirling	Mirrabooka	18 Apr 2011	23	10	28	15
R00049	Stirling	Dianella	15 Jul 2010	17	3	140	69
R00050*	Stirling	Balcatta	18 Apr 2011	62	20	31	17
R00029	Canning	Bentley	15 Jul 2010	15	15	44	27
R00033	Canning	Wilson	13 Jul 2010	10	4	52	24
R00062	Canning	Canningvale	15 Apr 2011	35	3	44	16
R00063	Canning	Canningvale	15 Apr 2011	12	5	42	17
R00064	Canning	Welshpool	9 Aug 2011	14	5	34	11
R00041	Bayswater	Morley	20 Dec 2010	29	5	19	7
R00051	Bayswater	Bayswater	10 Aug 2011	25	9	29	4
R00047*	Joondalup	Padbury	27 Jul 2010	39	14	23	6
R00059*	Joondalup	Joondalup	14 Apr 2011	40	19	26	8
R00052	Swan	Hazelmere	8 Sep 2011	11	0	19	6
R00054*	Swan	Malaga	5 Jul 2011	40	14	32	5
R00061	Kwinana & Rockingham	East Rockingham	21 Dec 2010	11	5	19	7
R00031*	Wanneroo	Hamersley	8 Aug 2010	21	15	33	25
R00040	Stirling	Balga	13 Jul 2010	27	7	116	44
R00046*	Joondalup	Madely	9 Aug 2011	59	14	27	6
ALL				631	230	1173	461

**More than 10% of treatment prior crash frequency (within 20% to 50%)*

Table 2.16 *Serious Casualty Crashes at combined Red Light Speed Camera Locations in W.A. by study period with controls matched by prior crash history at camera sites*

RLSC Location ID	LGA of crash	Suburb of RLSC Camera	Red Light Speed Camera (RLSC) Activation Date	At RLSC Sites (Treatment)		At Signalised Intersections in same LGA (Control)	
				5 years before Activation date	On or After Activation Date	5 years before activation date	On or After Activation Date
R00019	South Perth	South Perth	14 Jul 2010	2	1	3	2
R00022	Victoria Park	Victoria Park	26 Jul 2010	1	2	0	0
R00030	Cockburn	Hamilton Hill	13 Jul 2010	1	0	23	3
R00035	Melville	Booragoon	20 Dec 2010	5	2	19	4
R00037*	Armadale	Piara Waters	14 Apr 2011	8	1	4	0
R00043*	Kalamunda	High Wycombe	15 July 2010	6	1	1	1
R00027	Stirling	Dianella	20 Dec 2011	1	1	8	1
R00036	Stirling	Mirrabooka	18 Apr 2011	9	2	1	1
R00049	Stirling	Dianella	15 Jul 2010	7	0	22	11
R00050*	Stirling	Balcatta	18 Apr 2011	12	2	3	0
R00029	Canning	Bentley	15 Jul 2010	5	2	3	3
R00033	Canning	Wilson	13 Jul 2010	1	0	10	4
R00062	Canning	Canningvale	15 Apr 2011	10	0	4	1
R00063	Canning	Canningvale	15 Apr 2011	1	0	8	5
R00064	Canning	Welshpool	9 Aug 2011	5	1	5	1
R00041	Bayswater	Morley	20 Dec 2010	11	2	3	0
R00051	Bayswater	Bayswater	10 Aug 2011	7	5	14	0
R00047*	Joondalup	Padbury	27 Jul 2010	5	1	4	1
R00059*	Joondalup	Joondalup	14 Apr 2011	12	5	3	2
R00052	Swan	Hazelmere	8 Sep 2011	3	0	5	2
R00054*	Swan	Malaga	5 Jul 2011	8	0	7	1
R00061	Kwinana & Rockingham	East Rockingham	21 Dec 2010	5	2	3	4
R00031*	Wanneroo	Hamersley	8 Aug 2010	3	0	9	4
R00040	Stirling	Balga	13 Jul 2010	7	2	20	9
R00046*	Joondalup	Madely	9 Aug 2011	6	2	6	0
ALL				141	34	188	60

**More than 10% of treatment prior crash frequency (within 20% to 50%)*

Using the same analysis techniques as for the analysis not-corrected for RTM effects, estimates of crash effects associated with the intersection camera upgrades were obtained using the pre-treatment control data matched on crash frequency. The resulting estimates are given in Table 2.17.

Table 2.17 *Estimated average crash effects of upgrading red light only cameras to combined speed and red light cameras in W.A. with Regression to the Mean Correction*

Crash Severity	Relative Risk	Sig.	95% Lower Confidence Interval	95% Upper Confidence Interval
All Crashes	1.087	.096	.985	1.200
Casualty Crashes	.923	.441	.752	1.132
Serious Casualty Crashes	.660	.461	.219	1.990

Comparison of results in Table 2.17 with those in Table 2.13 give an indication of the likely RTM bias in the original estimates of Table 2.13. Estimates of serious casualty crash effects associated with the intersection camera upgrades are very similar under the two control matching protocols, suggesting RTM effects are minimal for this crash severity. Differences in estimates for the two other crash severity groupings are more substantial, suggesting RTM effects are greater for lower severity crashes.

One difficulty in interpreting the RTM analysis is the much smaller quantity of control data available for analysis when matching by prior crash history. None of the results in Table 2.17 reached statistical significance due to the smaller quantities of data. Reflected in the wider confidence limits, the RTM corrected estimates are not statistically different from the uncorrected estimates presented in Table 2.13 with the measured RTM effects for less serious crashes possibly being an artefact of random variation in the data. It is difficult to differentiate the two effects in this instance.

In summary, the RTM analysis has identified that the estimated effects of the intersection camera upgrades presented in the main analysis of Table 2.13 are likely robust, estimating a serious casualty crash reduction of around 36%. This result is the most important of those obtained given it relates directly to the target of the W.A. road safety strategy to reduce serious injury. It also points to any expansion of the intersection camera program likely having additional benefits in reducing serious casualty crashes. It is also likely that new camera installations would have crash benefits that are greater than those estimated for camera upgrades here. Crash effects of the upgrades on more minor crashes are more difficult to determine and require further evaluation when greater after treatment crash data has accumulated or when additional camera installations have been completed, if planned.

2.4.3 MOBILE SPEED CAMERAS

Analysis crash data

Using the mapped crash and mobile speed camera locations, GIS methods were used to relate the location of each crash to the location of each mobile speed camera location that had been used over the period January 1995 to December 2012. Based on the spatial relationships between crashes and speed cameras identified in the literature, crashes were the categorised based on their proximity to a mobile speed camera site using the categories up to 500m and up to 1000m. Note that the first category is a subset of the second. The resulting number of crashes in each category by crash severity grouping (fatal, serious casualty, all casualty and all reported crashes), time of day (6am-8pm – camera enforced time, and 8pm-6am – unenforced time) and region of W.A. (Perth, Rest of W.A.) are shown in Table 2.18. Table 2.18 shows the total number of crashes over the period 1995-2012 as well as the average monthly crash count over this period.

As reflected in Table 2.18, analysis has only been stratified by Perth and the rest of W.A. There were insufficient crash numbers to stratify rural crashes into regions whilst there was a mismatch between regions recorded in the crash data and those used in the speed camera data to allow effective stratification of the Perth area.

Table 2.18 *Total and average monthly number of crashes within specified proximity of a mobile camera site by crash severity, time of day and region of W.A.: 1995-2012*

				Distance to Camera Site		
Region	**Time**	**Crash Severity**	**Measure**	**<500m**	**<1000m**	**All**
Perth	**6am-8pm**	**Fatal**	**Total**	719	777	886
			Av. Month	3	4	4
		Serious Casualty	**Total**	15347	16201	17100
			Av. Month	71	75	79
		All Casualty	**Total**	70390	73095	75589
			Av. Month	326	338	350
		All Crashes	**Total**	340183	353024	363353
			Av. Month	1575	1634	1682
	8pm-6am	**Fatal**	**Total**	427	452	503
			Av. Month	2	2	2
		Serious Casualty	**Total**	9051	9544	10049
			Av. Month	42	44	47
		All Casualty	**Total**	149210	41853	43315
			Av. Month	691	194	201
		All Crashes	**Total**	194498	202059	207957
			Av. Month	900	935	963
RoWA	**6am-8pm**	**Fatal**	**Total**	254	334	1178
			Av. Month	1	2	5
		Serious Casualty	**Total**	2845	3579	8845
			Av. Month	13	17	41
		All Casualty	**Total**	7730	9285	19072
			Av. Month	36	43	88
		All Crashes	**Total**	38086	45541	76579
			Av. Month	176	211	355
	8pm-6am	**Fatal**	**Total**	138	178	649
			Av. Month	1	1	3
		Serious Casualty	**Total**	1654	2074	5026
			Av. Month	8	10	23
		All Casualty	**Total**	4473	5407	10862
			Av. Month	21	25	50
		All Crashes	**Total**	21728	26019	43533
			Av. Month	101	120	202

Table 2.18 shows that around 65% of all reported crash occur in the mobile camera enforced hours of 6am-8pm in both Perth and the rest of W.A. It also shows that in Perth sites used under the mobile speed camera program cover a large proportion of the crash population. Around 88 of all fatal crashes during enforced times occurred within 1000m of a camera site whilst around 81% have occurred within 500m of a camera site. This coverage rises steadily with crash severity with 97% of all reported crashes being within 1000m of a camera site or 94% within 500m. The similarity of crash coverage between the 500m radius and 1000m radius of the camera sites reflects the high density of camera operations sites in the Perth area with nearly 10,000 locations having been used until the end of 2012.

The coverage of the crash population outside of Perth was not so high. During the enforced hours, 28% of fatal crashes occurred within 1000m of a camera site falling to 22% within 500m. This rose to 59% of all reported crashes within 1000m with 50% within 500m. The lower density of camera operations in regional areas is also reflected in the larger difference between the 100m radius coverage and the 500m radius coverage.

Monthly mobile camera session data used in the analysis is shown in Figures 2.1 and 2.2. In addition to the camera sessions data, a number of other exposure and socio-economic factors were considered in the analysis models that have been found to be related to observed monthly crash numbers in W.A. from previous research (D'Elia, 2014). These were Perth and RoWA resident population (Figure 2.1), vehicle kilometres travelled derived from fuel sales data (Figure 2.1), unemployment rate in Perth and RoWA collected by the Australian Bureau of Statistics (Figure 2.2) and retail alcohol sales also collected by the ABS (Figure 2.3). D'Elia et al., (2014) describes the sourcing and derivation of each of these measures. Where possible the measures were collected separately for Perth and the rest of W.A.

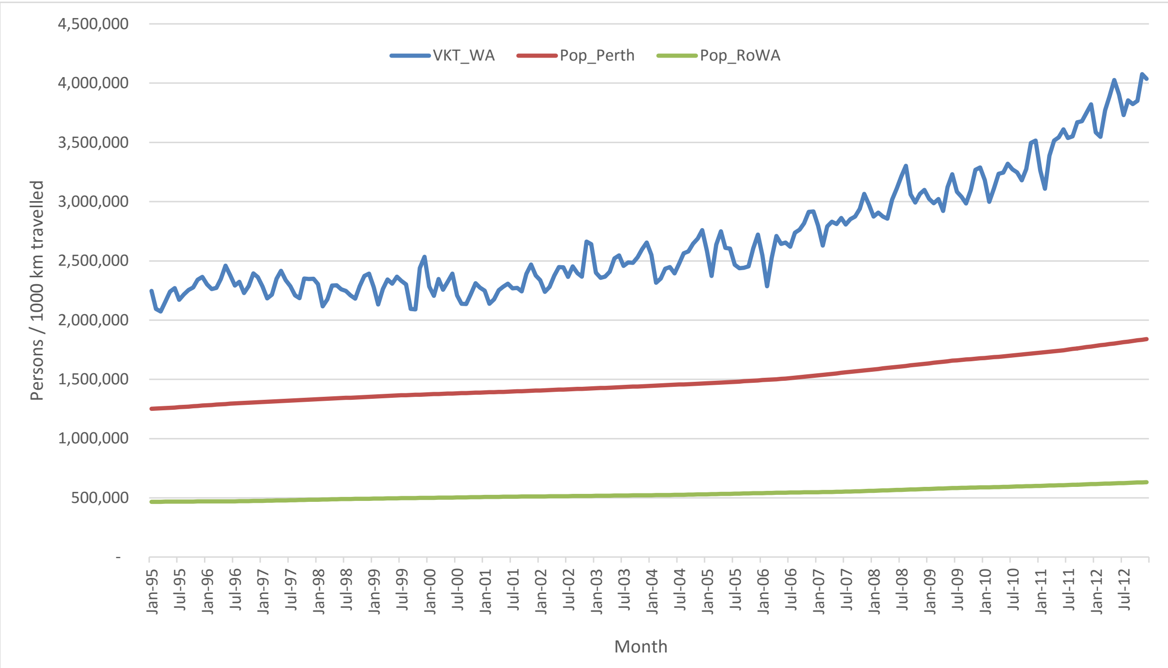


Figure 2.1 *Monthly population (Pop) and vehicle travel (VKT) trends in W.A. 1995-2012*

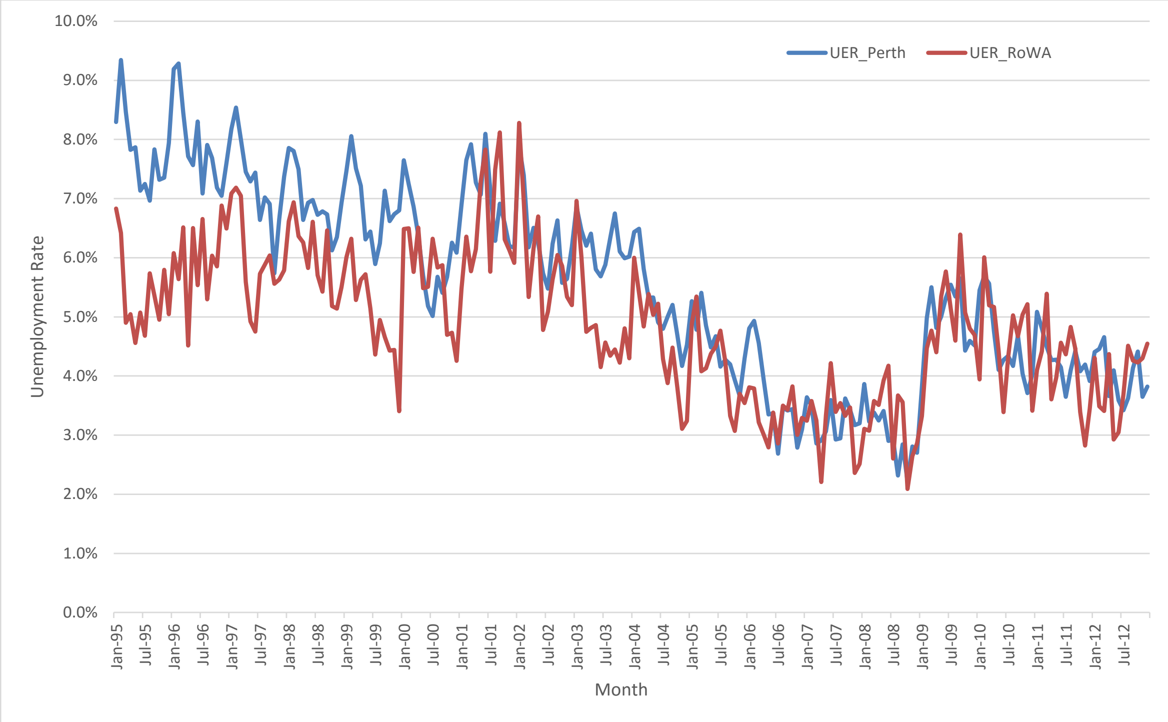


Figure 2.2 *Monthly unemployment rates in Perth and Rest of W.A. (RoWA) 1995-2012*

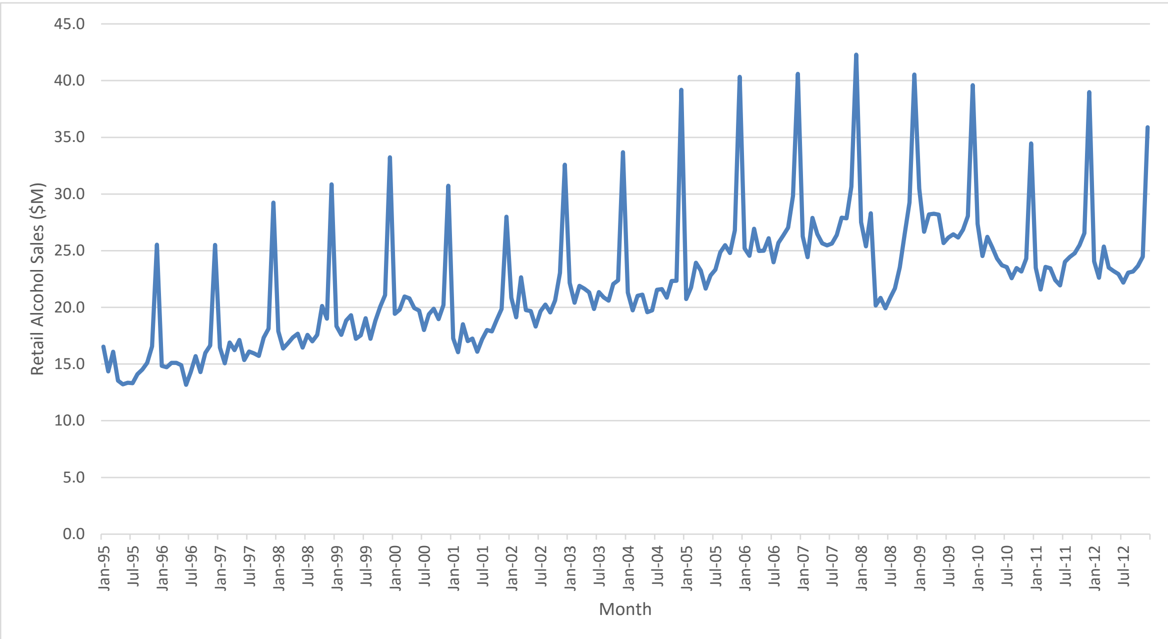


Figure 2.3 *Monthly retail alcohol sales in W.A. 1995-2012*

Time Series Analysis

Using the methodology of Section 2.2.2, the relationship between the number of mobile speed camera sessions in a month and the number of crashes observed was established as a measure of program effectiveness. As noted, there was no pre-implementation crash data available for evaluation of the mobile speed camera program, so the evaluation relied on establishing the relationship described through the estimation of a time series model describing the data. In order to capitalise on natural monthly variation in the number of mobile speed camera sessions undertaken, and particularly significant variation over the study time period of 1995 to 2012, monthly crash frequency counts were analysed in the model. The relationship between camera sessions and monthly road trauma was also adjusted for the confounding effects of the other factors shown in Figures 2.1 to 2.3. In order to establish models that well described the data, annual level variables as well as a seasonal component were also included in the model as general terms. These general terms represent the effect of other unmeasured factors besides the mobile camera program that have influenced road trauma trends.

Separate analysis models were estimated for Perth and the rest of W.A. and by the same crash severity groupings as considered in the analysis of other camera types: serious casualty, all casualty, and all reported crashes. There was also sufficient data to consider fatal crashes on their own. Separate models were also estimated for crashes within 500m and within 1000m of the mobile camera sites to see if there was evidence of diminishing effects by distance from camera site which would add weight to the causal argument of the relationship between camera placement and crash outcome. As described in Section 2.2.2, night crashes (8pm to 6am) were used as an effective comparison group since mobile camera operations are almost never scheduled in these hours. They were included to add analytical strength in establishing the relationship between monthly crash counts and the non-camera based measures included in the models.

A number of model formulations were investigated to describe the time series data being modelled. Investigation of model fit criteria showed that a Negative Binomial GEE model formulation using auto-regressive correlation between the time series elements was the most parsimonious model formation to describe the data. Table 2.19 summarises the estimated relative risks associated with the number of mobile speed camera sessions derived from the results of the modelling, along with the statistical significance of the estimated relative risk and 95% confidence limits. The relative risk is interpreted as the proportionate change in crash rate for each additional 100 mobile speed camera sessions undertaken. For example, the modelling results estimated a reduction in fatal crashes within 500m of a camera site in Perth of 3.7% ((1-0.963) x100%) for each 100 mobile speed camera sessions undertaken per month. The mobile speed camera measure was scaled to units of 100 sessions in order to assist in making the magnitude of the estimated effects easier to present and interpret.

Table 2.19 *Crash effects associated with the mobile speed camera program in W.A. by region, crash severity and distance from nearest speed camera*

					95% Confidence Interval for RR	
Region	**Severity**	**Distance**	**Statistical Significance**	**RR (per 100 Mobile Camera Sessions)**	**Lower**	**Upper**
Perth	**Fatal**	**<500m**	<0.001	0.96291	0.96079	0.96504
		<1000m	<0.001	0.96381	0.96126	0.96636
	Serious Casualty	**<500m**	<0.001	0.99366	0.99334	0.99398
		<1000m	<0.001	0.99269	0.99241	0.99298
	All Casualty	**<500m**	<0.001	1.00495	1.00483	1.00507
		<1000m	<0.001	1.00372	1.00369	1.00375
RoWA	**Fatal**	**<500m**	<0.001	0.81536	0.80121	0.82976
		<1000m	<0.001	0.86145	0.86058	0.86232
	Serious Casualty	**<500m**	<0.001	0.93214	0.93178	0.93250
		<1000m	<0.001	0.95270	0.95174	0.95367
	All Casualty	**<500m**	0.46575	0.99917	0.99696	1.00140
		<1000m	<0.001	0.98837	0.98573	0.99102

Table 2.19 shows statistically significant fatal and serious casualty crash reductions associated with the speed camera program in W.A. in both Perth and the rest of W.A. In general, crash reductions reduced with reductions in crash severity with evidence of a small but statistically significant increase in minor crashes in areas local to the mobile speed camera sites in Perth. Although this may be considered a negative impact of the program, these effects were more than offset by the large reductions in serious crashes measured. Crash effects by distance from speed camera site were similar in Perth reflecting that the majority of crashes are with 500m, and hence also 1000m, of a camera site. Effects diminished with distance from camera in the rest of W.A. reflecting the smaller crash coverage of the crash population outside of Perth. This result is important for suggesting a causal relationship between camera operations and crashes. Finally, associated effects on crashes were stronger in regional areas compared to Perth, perhaps reflecting the greater role speed might play on crash causation and injury severity outside of the built up environment.

Fit of the model to the data is important to ensure the validity of the estimated program effects presented in Table 2.19. Figures 2.4 and 2.5 show the observed data and model fits for the models fitted to serious casualty crashes in Perth and the rest of W.A. respectively. The models used have included a number of general parameters including monthly seasonal and annual level to ensure model fit is adequate. As can be observed in Figures 2.4 and 2.5 this strategy ensured good fit of the model to the trend in the observed data. The figures also show that the random variation in the data was relatively high, particularly in regional areas, justifying the use of the Negative Binomial model to adequately represent this.

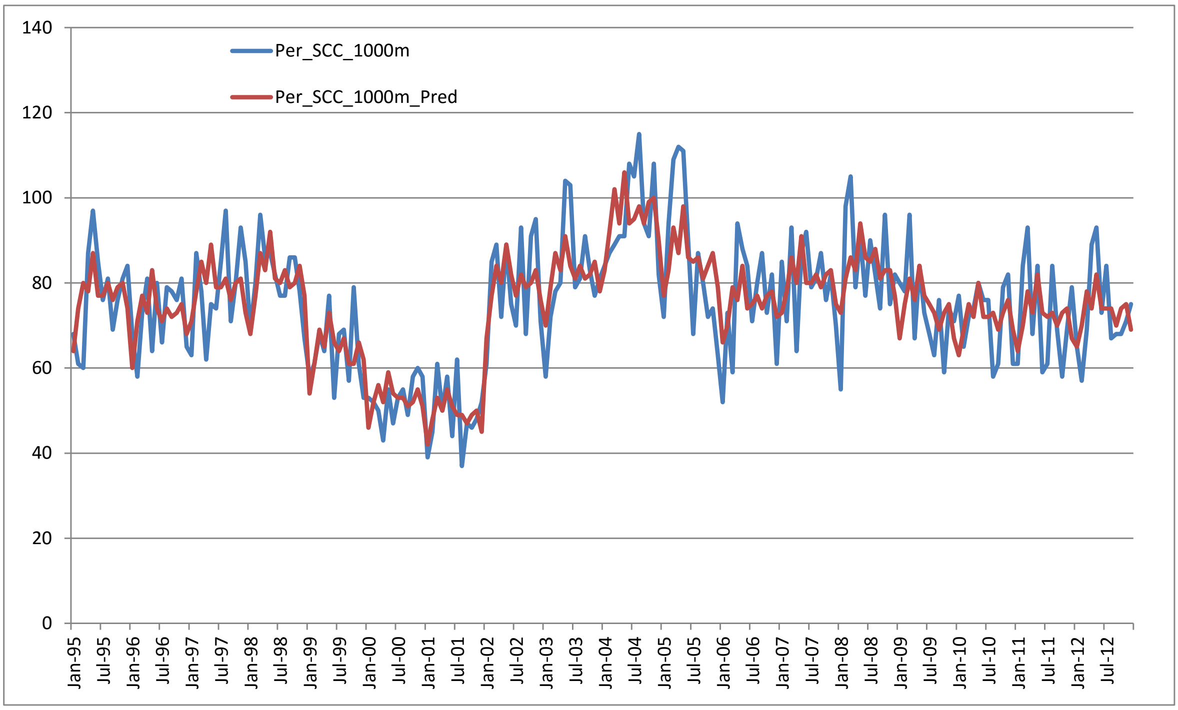


Figure 2.4 *Observed and modelled (Pred) monthly serious casualty crashes within 1000m of a mobile speed camera site: Perth*

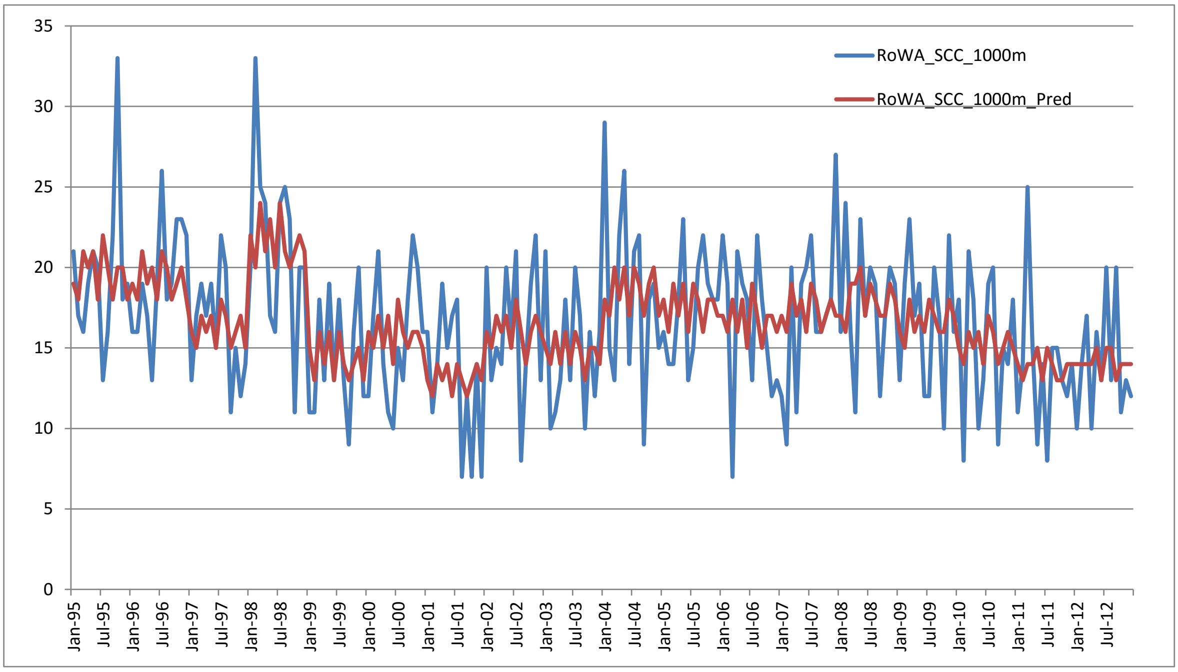


Figure 2.5 *Observed and modelled (Pred) monthly serious casualty crashes within 1000m of a mobile speed camera site: Rest of W.A.*

Severity Analysis

Analysis of crash frequency in the previous section identified increasing crash reduction effects with increasing severity of crash. This suggests that the mobile speed camera program in W.A. is associated with a reduction in average crash severity. As a confirmation of the results of the crash frequency time series analysis, a second analysis was undertaken examining the association between measures of average crash severity in each month related to mobile camera session undertaken. Analysis was again undertaken separately for metropolitan Perth and the rest of W.A. by distance groups from the mobile speed camera sites. The model structure used was the same as for the crash frequency analysis being a GEE incorporating the same adjustment for confounding effects of exposure and socio-economic factors and including a seasonal and annual level trend component. The severity model GEE used a logistic link function with binomial error structure with autocorrelation covariance structure of order 1 being used to represent the relationship between the time series observations.

The following measures of crash severity were considered, each being a probability, reflecting the logistic GEE model structure chosen:

- The probability of any reported crash being fatal
- The probability of any reported casualty crash being fatal
- The probability of any reported crash being a serious casualty
- The probability of any reported casualty crash being a serious casualty

Results of modelling of the injury severity measures are presented in Table 2.20. The key model parameter given in the table is the proportionate change in the odds of the severity metric for each 100 additional speed camera sessions undertaken (labelled Relative Odds in the table). The statistical significant of the relative odds estimate along with the 95% confidence interval are also given in the table.

Results presented in Table 2.20 are highly consistent with the crash frequency analysis results presented in Table 2.19. Reductions in each of the severity measures were estimated to be associated with increases in the monthly number of mobile speed camera sessions undertaken. Each of the estimated reductions were highly statistically significant. Like the crash frequency analysis, there were greater severity reductions associated with fatal crashes compared to serious casualty crashes and severity reductions were greater in the rest of W.A. compared to Perth. Furthermore, there was evidence in the rest of W.A. of reducing severity reductions with distance from speed camera site. This was not observed in Perth due to the vast majority of crashes being within 500m of a speed camera site (and hence also within 100m of a speed camera site).

The severity analysis provided good confirmation of the results in the crash frequency analysis in a less demanding modelling environment. Since the severity analysis was inherently controlling for the effects of confounding effects due to the severity measure being a ration of crash frequencies in the same month and area. The inherent control of confounding within the analysis design was evidenced through the covariates in the models, apart from speed camera sessions, not being statistically significantly associated with the crash severity measure. The consistency between the severity analyses and the crash frequency analyses shows confounding in the crash frequency models was effectively controlled through the model structures utilised.

Table 2.20 *Crash severity effects associated with the mobile speed camera program in W.A. by region, crash severity and distance from nearest speed camera*

					95% Wald Confidence Interval for Exp(B)	
Region	**Severity Measure**	**Distance**	**Statistical Significance**	**Relative Odds (per 100 Mobile Camera Sessions)**	**Lower**	**Upper**
Perth	**SCC / ACC**	<500m	<0.0001	0.987	0.986	0.987
		<1000m	<0.0001	0.985	0.985	0.986
	SCC / All Crashes	<500m	<0.0001	0.988	0.988	0.988
		<1000m	<0.0001	0.987	0.987	0.988
	Fatal / ACC	<500m	<0.0001	0.970	0.968	0.972
		<1000m	<0.0001	0.972	0.970	0.975
	Fatal / All Crashes	<500m	<0.0001	0.969	0.967	0.972
		<1000m	<0.0001	0.972	0.969	0.974
RoWA	**SCC / ACC**	<500m	<0.0001	0.916	0.912	0.920
		<1000m	<0.0001	0.960	0.955	0.964
	SCC / All Crashes	<500m	<0.0001	0.943	0.940	0.946
		<1000m	<0.0001	0.958	0.956	0.961
	Fatal / ACC	<500m	<0.0001	0.849	0.839	0.859
		<1000m	<0.0001	0.904	0.902	0.907
	Fatal / All Crashes	<500m	<0.0001	0.836	0.824	0.847
		<1000m	<0.0001	0.886	0.884	0.887

Crash Savings Associated With the Mobile Speed Camera Program

Having established the robustness of the crash frequency models through comparison with the crash severity analysis, results from the crash frequency analysis were then interpreted to estimate the influence of the mobile speed camera program on monthly crash counts in W.A. over time. The relationship between the monthly number of speed camera sessions and expected crash reductions can be estimated from the model parameters shown in Table 2.19. The resulting relationships are shown for Perth and the rest of W.A. in Figures 2.6 and 2.7 respectively for fatal crash reductions and serious casualty crash reductions by distance from mobile speed camera location. The range of monthly speed camera hours considered reflects the range that has been used in each area of the state over the history of the program.

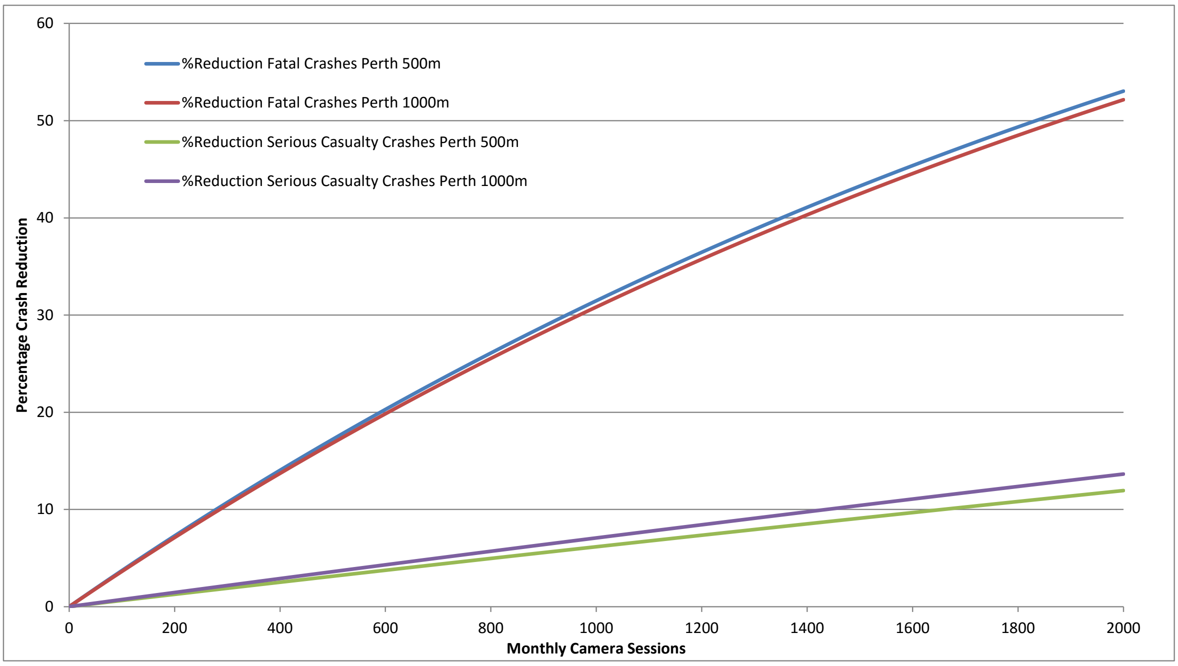


Figure 2.6 *Percentage crash reduction by monthly number of mobile speed camera sessions and distance from mobile speed camera site: Perth.*

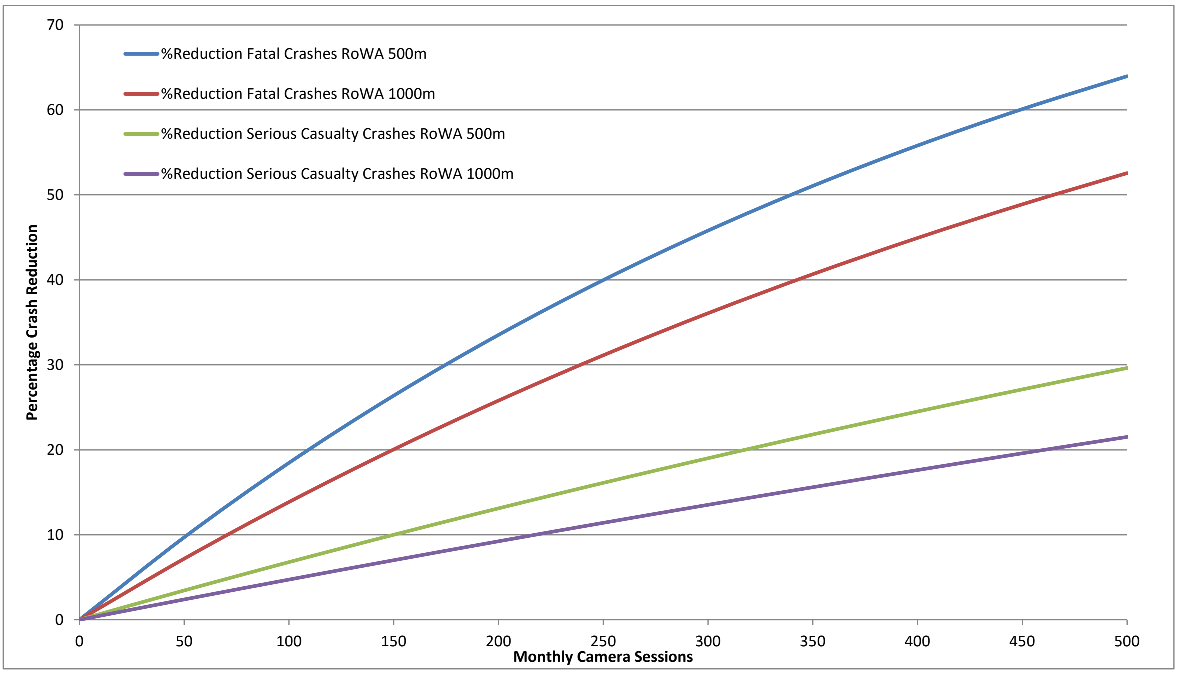


Figure 2.7 *Percentage crash reduction by monthly number of mobile speed camera sessions and distance from mobile speed camera site: Rest of W.A.*

Some of the key relevant attributes from Figure 2.6 and 2.7are summarised in Table 2.21 which gives the range of monthly crash reductions, average over the life of the program (1995-2012) and average over the most recent year of data analysed (2012) in both Perth and the rest of W.A. In Perth, monthly fatal crash reductions ranged from around 2% to 50% with an average of around 24% from the 747 average monthly mobile speed camera sessions. Corresponding estimates for serious casualty crashes were 0.3% to 13% with an average around 5%. Estimates in Perth did not differ by distance from camera site given the majority of crashes were within 500m of a camera site. The average monthly number of sessions in 2012 was higher than the long term average at 1187 being associated with fatal crash reductions of about 36% and serious casualty crash reductions of about 8%.

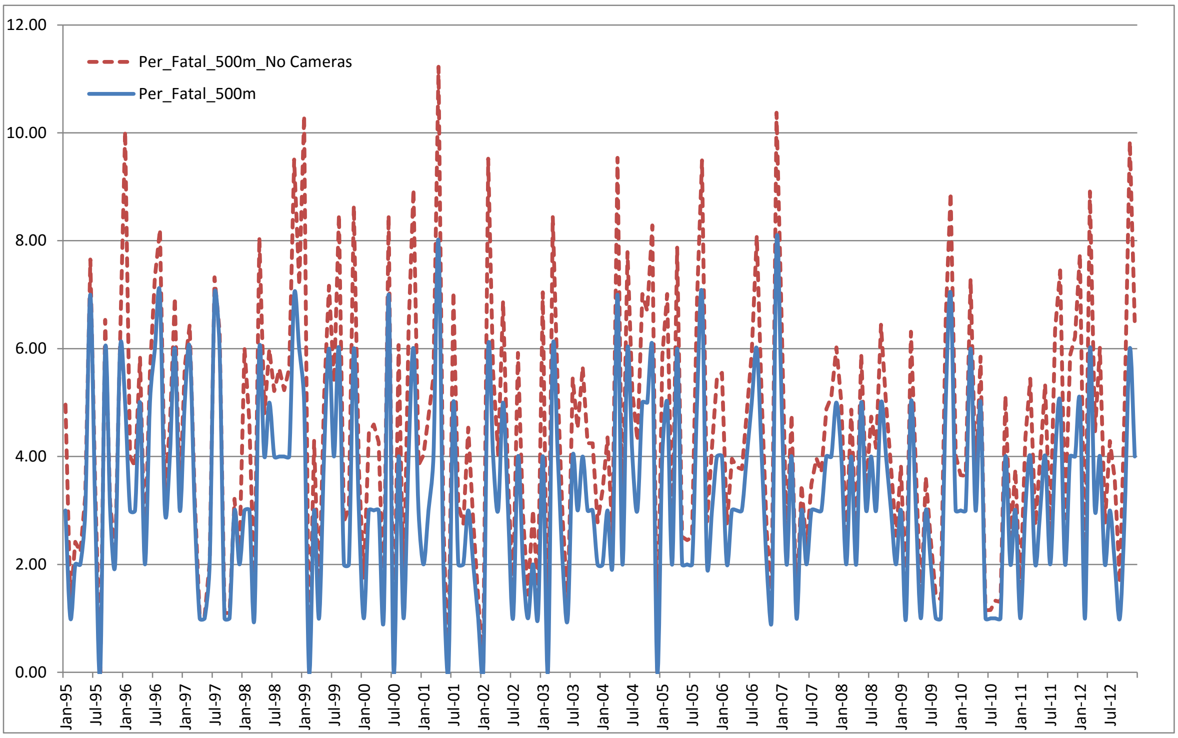
Average number of mobile speed camera session in the rest of W.A. over the program were much lower at 116 per month ranging from zero to 435. Despite this, the range of percentage crash savings associated with the mobile camera program was greater than in Perth, reflecting the stronger relationship between camera sessions and crash reductions in the rest of W.A and the greater monthly variation in operation. At the average level of operations, both across the program as a whole and in 2012, the percentage crash savings associated with the program within the vicinity of camera sites was similar for Perth and the rest of W.A.

Table 2.21 *Crash reductions associated with average, maximum and minimum monthly mobile speed camera sessions over 1995-2012 and average number of sessions undertaken in 2012 in Perth and the rest of W.A.*

	Average Monthly Sessions 1995-2012	Maximum Monthly Sessions 1995-2012	Minimum Monthly Sessions 1995-2012	Average Monthly Sessions 2012
Sessions Measure: Perth	747.0	1917.0	46.0	1187.0
%Reduction Fatal Crashes Perth 500m	24.6	51.5	1.7	36.2
%Reduction Fatal Crashes Perth 1000m	24.1	50.7	1.7	35.4
%Reduction Serious Casualty Crashes Perth 500m	4.6	11.5	0.3	7.3
%Reduction Serious Casualty Crashes Perth 1000m	5.3	13.1	0.3	8.3
Sessions Measure: RoWA	116.0	435.0	0.0	223.3
%Reduction Fatal Crashes RoWA 500m	21.1	58.9	0.0	36.6
%Reduction Fatal Crashes RoWA 1000m	15.9	47.7	0.0	28.3
%Reduction Serious Casualty Crashes RoWA 500m	7.8	26.3	0.0	14.5
%Reduction Serious Casualty Crashes RoWA 1000m	5.5	19.0	0.0	10.3

Percentage crash savings estimated form the modelling were turned into absolute crash savings by replacing the actual monthly camera sessions undertaken with zero camera sessions, to estimate the predicted crashes from the model with no camera sessions. From this the difference between the actual observed road trauma and that predicted with no mobile speed camera in place could be estimated by the difference in the two model values.

Figures 2.8 and 2.9 show both the observed monthly fatal and serious casualty crashes respectively, in Perth within 500m of a mobile camera site, along with that predicted had no camera sessions been undertaken in the month. The Difference between the two lines varies proportionately reflecting the variation in mobile speed camera sessions in Perth from month to month. Figures 2.10 and 2.11 show the analogous information for the rest of W.A. Fatalities in Figure 2.8 are shown for the raw data and also the 12 month moving average to make the trends clearer.



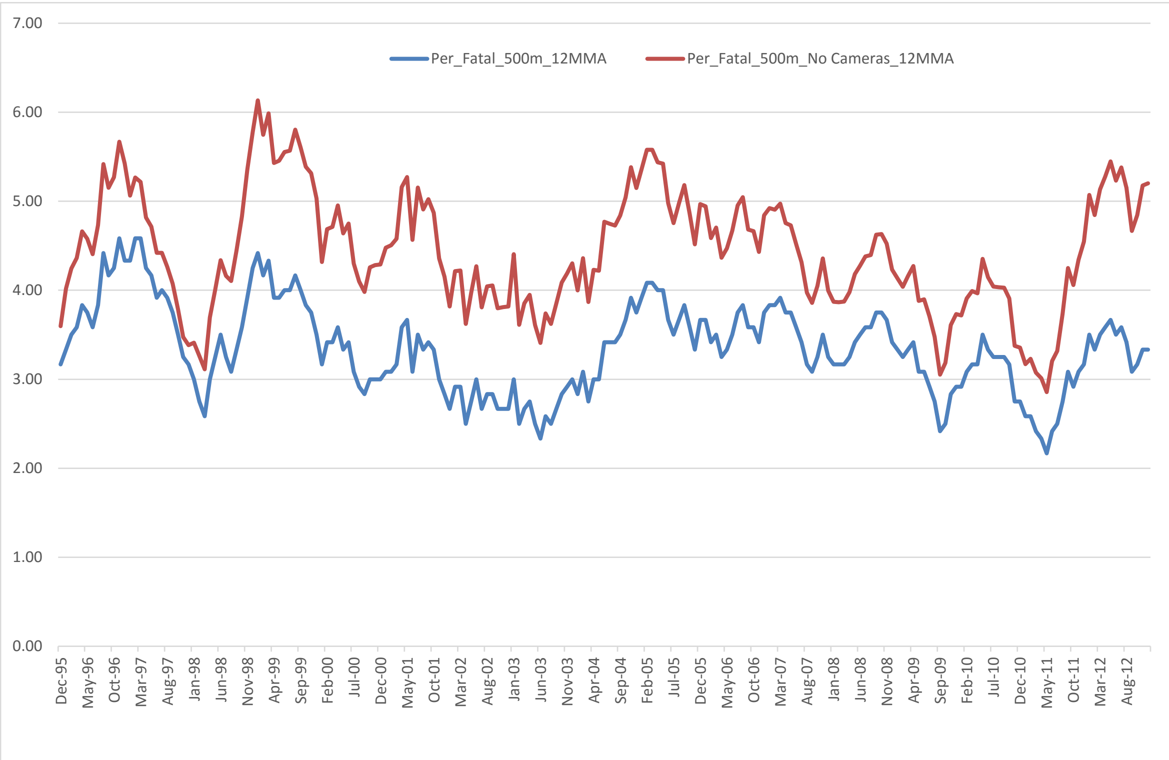


Figure 2.8 *Observed fatal crashes and fatal crashes expected within 500m of a mobile camera site had no mobile speed camera program been in operation: Perth – Raw Data and 12 Month Moving Average*

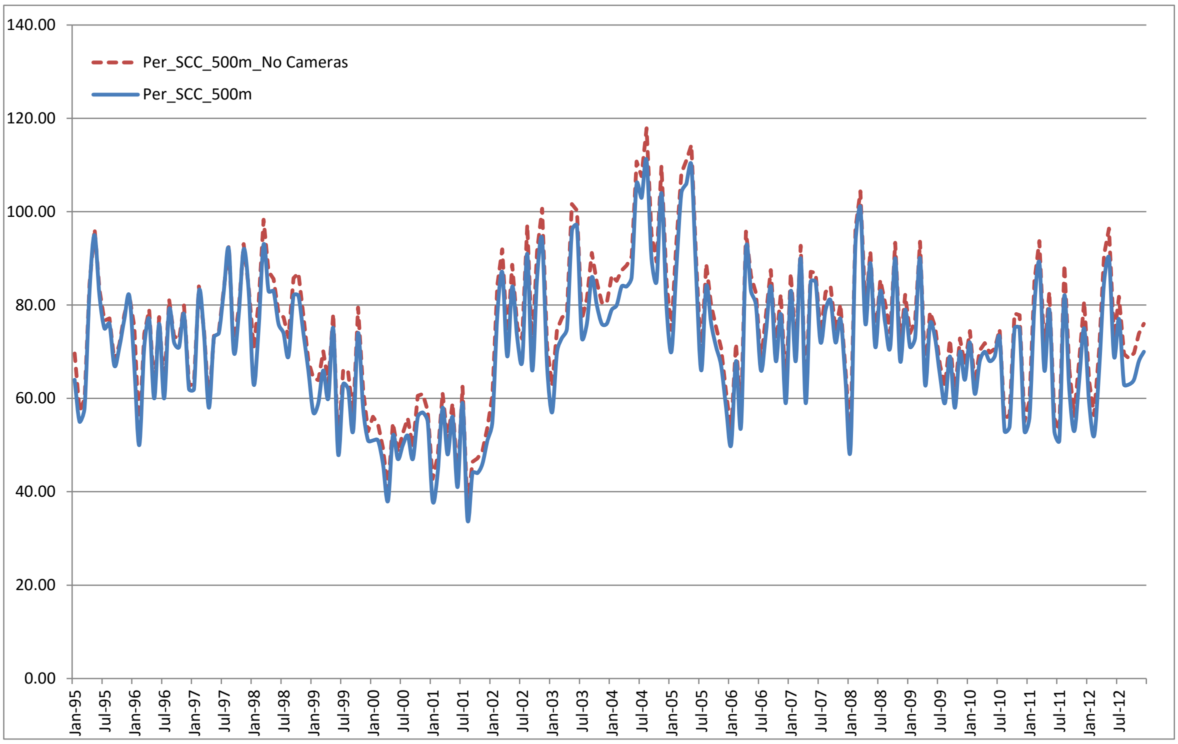


Figure 2.9 *Observed serious casualty crashes and serious casualty crashes expected within 500m of a mobile camera site had no mobile speed camera program been in operation: Perth*

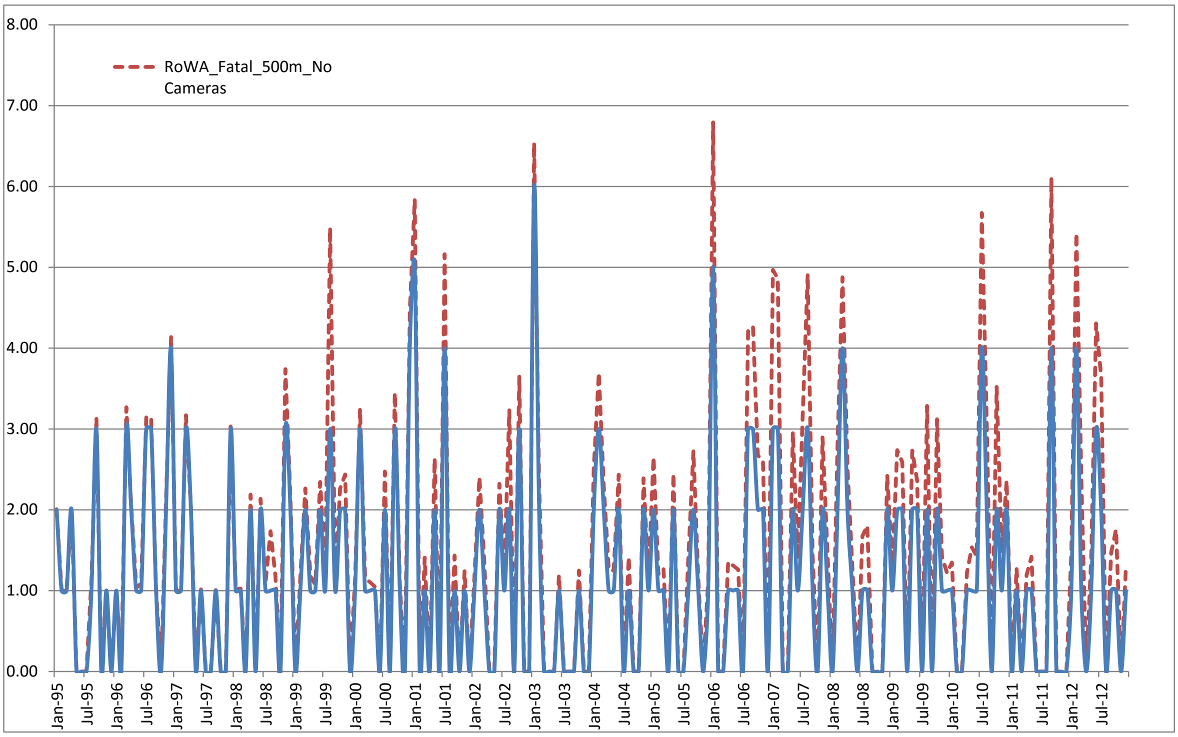


Figure 2.10 *Observed fatal crashes and fatal crashes expected within 500m of a mobile camera site had no mobile speed camera program been in operation: Rest of W.A.*

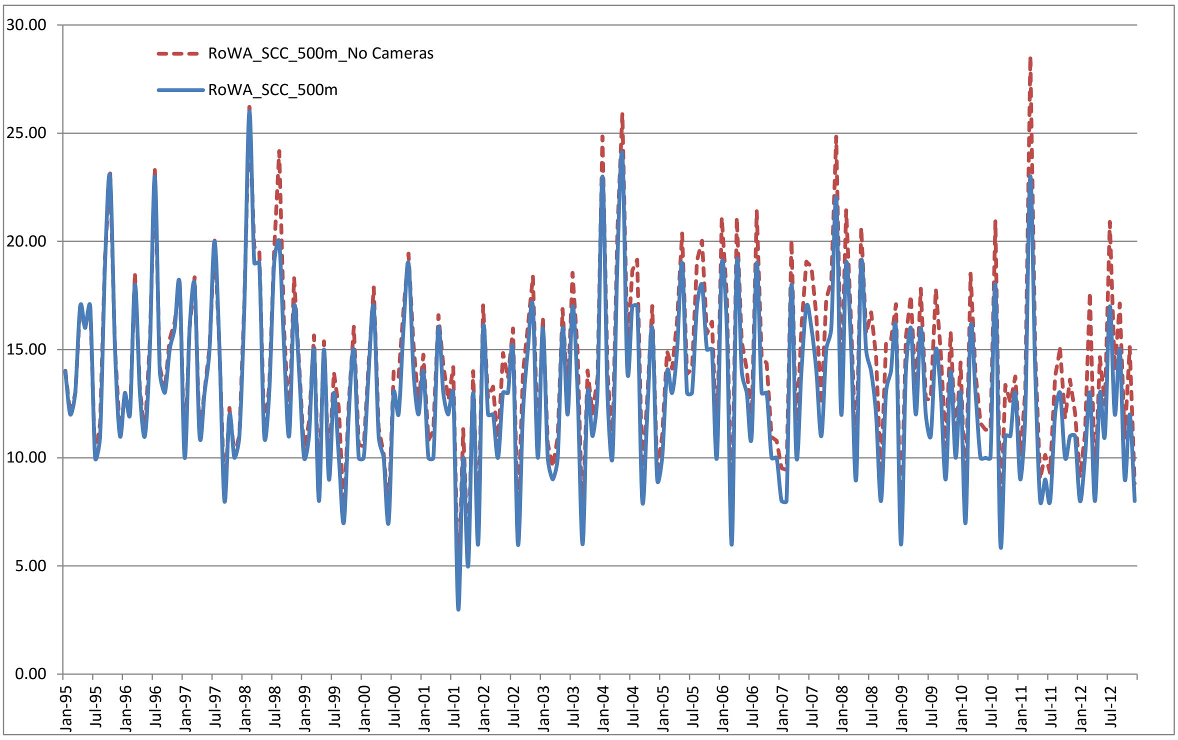


Figure 2.11 *Observed serious casualty crashes and serious casualty crashes expected within 500m of a mobile camera site had no mobile speed camera program been in operation: Rest of W.A.*

The difference between observed fatal and serious casualty crashes and that predicted with no mobile speed camera operations in each month were aggregated within each year to give annual saving in each crash severity level. As noted, most crashes in Perth are within 500m of a camera site so the annual crash savings are calculated based on the estimates of crash savings within 500m. Estimated annual crash savings in the rest of W.A. were calculated for the 500m radius and 1000m radius effects. These came out to be identical in magnitude within the bounds of statistical accuracy suggesting the vast majority of crash savings in regional W.A., associated with the mobile camera program, are also within 500m of the camera site. This is evidenced in the 1000m radius encompassing more crashes in regional areas but having a lower estimated percentage crash saving, representing a dilution of the 500m crash effect when considering the 1000m radius. Table 2.22 summarises the estimated annual savings in fatal and serious casualty crashes associated with the mobile speed camera program in Perth and the rest of W.A. Serious casualty crashes encompass both fatal and serious injury crashes. Serious injury crash savings could be inferred from Table 2.22 by subtracting the fatal savings from the serious casualty savings. In both Perth and the rest of W.A., fatal crash savings represent around one third of all serious casualty savings.

Table 2.22 *Annual Fatal and Serious Casualty crash savings in W.A. associated with the mobile speed camera program*

Year	Perth Fatal	Perth Serious Casualty	Rest of W.A. Fatal	Rest of W.A. Serious Casualty
1995	5	20	0	1
1996	13	28	1	3
1997	3	10	0	1
1998	18	50	2	10
1999	18	45	5	9
2000	15	38	2	8
2001	16	36	4	10
2002	14	59	3	13
2003	16	55	1	11
2004	17	61	3	15
2005	16	49	3	14
2006	13	38	6	17
2007	9	31	10	24
2008	10	35	4	19
2009	10	36	6	18
2010	7	27	7	18
2011	17	50	3	21
2012	22	64	8	25
Total	**239**	**732**	**68**	**237**

As evident from Table 2.22, over its years of operation from 1995 to 2012, the mobile speed camera program in W.A. has been associated with savings of 307 fatal crashes and 969 serious casualty crashes. Around 75% of the total savings have been made in metropolitan Perth.

2.5 OVERALL PROGRAM CRASH EFFECTS

To gain a perspective on the overall contribution of the automated enforcement program on total road trauma in W.A., as well as the relative contribution of each element of the program, crash savings associated with each element of the program in 2012 have been calculated and combined. These have then been compared against the total fatal and serious road trauma burden in Perth to estimate the total contribution of the automated enforcement program in W.A. to reducing road trauma in the state. Due to the variable outputs from the mobile speed camera program from year to year, the relatively recent introduction of the fixed freeway speed cameras and the phased upgrade of the intersection red light cameras to speed and red light cameras, the overall impact of the automated enforcement program was estimated in 2012. This was the most recent year of data available and the year in which all the elements of the program were operational. Since the W.A. road safety strategy is focused on fatal and serious injury crash reductions in its targets, the overall program crash effects have been estimated in terms of impacts on fatal and serious injury crashes.

To estimate the crash reductions associated with each automated enforcement element, the estimated crash reductions associated with fixed freeway and intersection cameras were taken from the results presented in Section 2.4 and combined with the average annual pre-treatment crash rates to give estimated savings. Estimates for the intersection camera were factored up by 29/25, reflecting that only 25 of the 29 listed operational intersection cameras were evaluated and assuming that the crash reductions at the remaining 4 sites were similar to the average across the evaluated 25. Even though the fixed freeway camera crash reductions were not statistically significant they were still used for the purpose of calculating the overall program impact. Mobile speed camera absolute crash reductions were taken straight from Table 2.22. Using the absolute crash reductions estimated for each camera type, the total 'expected' crash count for 2012 (had the automated enforcement program not been in place) was calculated by adding each of the crash savings to the observed crash count for 2012. From this, the percentage saving in total road trauma could be estimated using the absolute crash saving for each camera type and the total crashes expected without the camera program. The total percentage crash saving associated with the automated enforcement program as a whole could then be calculated by summing the percentages from each of the camera types.

Impacts of the automated enforcement program were estimated for Perth and the rest of W.A. separately as well as for the state as a whole. Observed crashes in each area were used as the basis. Crash savings due to the mobile camera program were available by area, whilst savings from intersection cameras and fixed freeway speed cameras were applied only to Perth where the cameras are located.

Resulting estimated total impact of the automated enforcement program on serious casualty crashes in W.A. are given in Table 2.23 and for fatal crashes in Table 2.24. Explicit estimates of the impact of each technology on serious casualty crashes were available from the analysis results in Section 2.4. Impacts of intersection cameras and fixed freeway speed cameras on fatal crashes were not available from the analysis due to limited number of fatal crashes at treated sites. Instead, impacts on fatal crashes were imputed from the mobile camera analysis by applying the proportion of serious casualty crash savings that were fatal to estimates of serious casualty crash savings for the other 2 camera types.

Table 2.23 *Overall absolute and percentage savings in serious casualty crashes associated with the W.A. automated enforcement program and its elements in 2012*

Region	Measure	Estimate
Perth	Observed Crashes	1437
	Savings Fixed Freeway	9
	Savings Intersection	33
	Savings Mobile Speed	64
	Expected Crashes with No Automated Enforcement	1542
	Total % Savings Automated Enforcement	6.84%
	% Savings Fixed Freeway	0.57%
	% Savings Intersection	2.11%
	% Savings Mobile Speed	4.15%
RoWA	Observed Crashes	725
	Savings Fixed Freeway	0
	Savings Intersection	0
	Savings Mobile Speed	25
	Expected Crashes with No Automated Enforcement	750
	Total % Savings Automated Enforcement	3.28%
	% Savings Fixed Freeway	0.00%
	% Savings Intersection	0.00%
	% Savings Mobile Speed	3.28%
All	Observed Crashes	2162
	Savings Fixed Freeway	9
	Savings Intersection	33
	Savings Mobile Speed	89
	Expected Crashes with No Automated Enforcement	2292
	Total % Savings Automated Enforcement	5.67%
	% Savings Fixed Freeway	0.38%
	% Savings Intersection	1.42%
	% Savings Mobile Speed	3.87%

Table 2.23 shows that the automated enforcement program was estimated to be associated with an overall reduction in serious casualty crashes in W.A. during 2012 of 5.6%. This comprised a 6.8% reduction in Perth and a 3.3% reduction in the rest of W.A. The mobile speed camera program was responsible for nearly 70% of this reduction, representing 100% of the reduction in regional areas and 61% in Perth. The contribution of the fixed freeway cameras was only 6.8% of the overall reduction (or a 0.4% reduction in total W.A. road trauma) or 8.3% (0.6% of total) in Perth. Intersection cameras made up the remainder of the reductions.

Table 2.24 shows a larger overall saving in fatal crashes associated with the automated enforcement program in W.A. A 19.4% reduction in overall fatal crashes in W.A. was associated with the program; 29.0% in Perth and 8.4% in the rest of W.A. The relative contribution of each camera type to this total was similar to Perth. The fatal crash estimates should be treated with some caution in Perth and for W.A. as a whole given the fatal crash estimates for intersection cameras and fixed freeway cameras were imputed.

Table 2.24 *Overall absolute and percentage savings in fatal crashes associated with the W.A. automated enforcement program and its elements in 2012*

Region	Measure	Estimate
Perth	Observed Crashes	81
	Savings Fixed Freeway	2
	Savings Intersection	8
	Savings Mobile Speed	22
	Expected Crashes with No Automated Enforcement	114
	Total % Savings Automated Enforcement	28.97%
	% Savings Fixed Freeway	1.98%
	% Savings Intersection	7.34%
	% Savings Mobile Speed	19.65%
RoWA	Observed Crashes	90
	Savings Fixed Freeway	0
	Savings Intersection	0
	Savings Mobile Speed	8
	Expected Crashes with No Automated Enforcement	98
	Total % Savings Automated Enforcement	8.37%
	% Savings Fixed Freeway	0.00%
	% Savings Intersection	0.00%
	% Savings Mobile Speed	8.37%
All	Observed Crashes	171
	Savings Fixed Freeway	2
	Savings Intersection	8
	Savings Mobile Speed	31
	Expected Crashes with No Automated Enforcement	212
	Total % Savings Automated Enforcement	19.44%
	% Savings Fixed Freeway	1.06%
	% Savings Intersection	3.95%
	% Savings Mobile Speed	14.43%

3 INTERPRETATION AND DISCUSSION

Each element of the automated enforcement program in Perth has been evaluated both in terms of how it has been operated, and how these operations compare to strategic program optimisation recommendations. Finally, the evaluation has estimated the effects on crashes in W.A. associated with each element of the program. This final section of the report considers the effectiveness of each element of program compared to other implementations in Australian and internationally. It considers the impact of the program on road trauma generally in W.A., as well as the potential for the program to be further expanded in line with recommendations from previous strategic directions documents (CamComp_Partners, 2010; M. H. Cameron, 2008; M.H. Cameron & Delaney, 2006).

3.1 FIXED FREEWAY SPEED CAMERAS

Evaluation of the fixed speed camera system in W.A. focused on four cameras located on Perth's urban freeway network. This has recently been expanded to five with the fifth also on an urban freeway. A major limitation of this evaluation of the fixed freeway speed cameras was the limited 'after activation' crash history available for analysis. After activation varied from 3 months to 13 months across the four sites evaluated averaging only about 6 months per site. This was clearly inadequate to provide the evaluation with adequate statistical power. Despite this lack of statistical significance, results of the evaluation suggested the fixed freeway speed camera system might be associated with reductions in serious casualty crashes. The point estimate of serious casualty crash reduction was around 29% within 1km of the camera site. This magnitude of serious crash reduction is not inconsistent with the effects of overt fixed or mobile cameras operated in the UK and summarised in Table 2.1 (C. Wilson, C. Willis, J.K. Hendrikz, R. Le Brocque, & R. Bellamy, 2010). Furthermore, it is almost identical in magnitude to estimated serious casualty crash reductions associated with the Victorian fixed speed camera program on the Geelong road, found in a yet unpublished study by the Monash University Accident Research Centre. The MUARC study also found crash reductions within a 1km radius local to the camera site. Concordance in these results suggests the estimated effect might ultimately be robust which could be confirmed with analysis of additional data.

Information compiled on fixed speed camera operations provides further insight into the potential effectiveness of the cameras. The number of vehicles passing the fixed camera locations is quite high. The proportion of vehicles speeding past the camera sites is also very high at between 5 and 10 percent. These figures suggest that the cameras have been placed at appropriate places on the freeway network where speeding is an identified problem. Despite the problem with speeding, only 8-13% of vehicles exceeding the speed limit are identified as offences and only 5-10% of all speeding vehicles are issued an infringement notice. This suggests that the enforcement tolerances on the fixed freeway camera network are relatively high. It is possible additional crash savings could be derived from the fixed freeway camera network by reducing the enforcement tolerance levels to encourage a higher level of speed compliance than that currently being observed even while the cameras are in place.

It is not clear why fixed speed cameras are only used on the urban freeway network in W.A. Fixed speed cameras have been successfully used in other jurisdiction at mid-block locations other than freeways, including rural highways and midblock sections in built up areas. A relevant example of this expanded approach can be seen in New South Wales where evaluation has shown the program to be successful in reducing crash rates at camera sites across all road types of installation (ARRB, 2005). Given the highly localised impacts of fixed speed cameras, site selection criteria for fixed speed cameras are similar to other blackspot type selection. Principal criteria are identified high crash frequency at the site and speed as a primary crash causation factor based on crash type or high average crash severity. W.A. could consider expansion of the fixed speed camera program to sites meeting speed related accident blackspot criteria. Cost effectiveness calculations can be included in assessing site suitability as demonstrated in previous strategic automated speed enforcement work from W.A. (M. H. Cameron, 2008; M.H. Cameron & Delaney, 2006).

Additional expansion of the program might be best considered after further evaluation of the current fixed freeway speed camera program. Given the inconclusive results for this camera type, this further evaluation is recommended. An additional 3 years of crash data would be available in the near future and should prove adequate to provide more robust estimates of effectiveness. A further issue that needs to be investigated through evaluation is the recent move from rotating a small number of cameras through a larger number of sties (meaning not all sites have a camera at all times) to having a permanent camera at each site. Despite strategic work identifying that the former methodology was an efficient way to enforce freeway speeds via the fixed camera network resulting in less fines to process (CamComp_Partners, 2010), this permanent camera change was made regardless. Further evaluation could identify whether this change has had any additional impact on crash savings.

3.2 INTERSECTION SPEED AND RED LIGHT CAMERAS

Although there is some contention, it is assumed that the majority of the intersection speed and red light cameras currently in operation in W.A. were new installations of the technology at previously unenforced sites. Consequently the evaluation undertaken is of new installation of speed and red light intersection cameras at previously un-enforced intersections.

Analysis of crash effects of the intersection camera installations estimated a statistically significant 36% reduction in serious casualty crashes associated with the camera installations. Lesser but still significant reductions were estimated for all casualty crashes, although there was some question about whether these results were a result of regression to the mean effects. Regression to the mean did not appear to impact the serious casualty estimates.

The W.A. intersection speed and red light camera program has been previously evaluated by C-MARC in an unpublished study (H.Y. Chen, 2012). The previous evaluation focused on the same set of intersections as this evaluation and the same broad evaluation design but used a slightly different methodology for comparison site matching and time period of data. Despite this the results should be comparable. The overall crash reduction associated with the intersection camera upgrade in the previous study was 19% which is almost identical to the estimate of this study without correction for regression to the mean. The previous study made no attempt to assess regression to the mean effects. The previous study estimated a 73% reduction in serious injury crashes associated with the camera upgrades which is around double that estimated in this evaluation and also inconsistent with the results from the fixed freeway speed cameras. Lack of concordance between the results suggests the previous study might be impacted by regression to the mean artefacts or poor choice of comparison group.

One aim of the previous study was to investigate the impact of intersection speed and red light cameras on specific crash types relevant to the cameras such as right angle, right through and rear end crashes. The intention of this study was to provide an estimate of the overall impact of automated enforcement on crashes, rather than a comprehensive evaluation of each camera type. Consequently the impact of intersection cameras on specific crash types was not investigated. In light of the differences between this study and the previous one for intersection camera results, in future research it might be worth revisiting the more comprehensive evaluation of intersection cameras research using the methodology of this current evaluation.

There are relatively few other studies into the effects of combined speed and red light cameras with which to compare the W.A. results. The most comprehensive is probably the Victorian study of the crash effects of predominantly new speed red light camera installations (Budd et al., 2011). This study found an overall statistically significant reduction in all casualty crashes across the camera enforced intersection of 26%. No differential effects by crash severity were identified. The overall casualty crash effects in W.A. were slightly smaller than those estimated in Victoria. Effects on serious casualty crashes in W.A. were higher than in Victoria. Of note is that the serious casualty crash effects estimated for the intersection cameras are similar in magnitude to those estimated for the fixed freeway speed cameras in W.A. Similarity of the results point to the speed enforcement component at intersections being a major factor leading to the reductions in serious casualty crashes measured. The intersection camera results also provide some indication of the validity of the freeway speed camera analysis results which did not achieve statistical significance.

Data in Table 1.21 shows there is a significant speeding problem at intersections in Perth enforced by cameras. Nearly 40% of infringements issued at these sites for speeding were for speeding more than 10km/h over the speed limit. The analysis results indicate that speed enforcement in addition to the red light camera capacity was both warranted in W.A. and is proving to be effective in addressing high crash severity related to speeding at Perth intersections.

Strategic advice on intersection speed and red light camera placement in W.A. (CamComp_Partners, 2010) identified 17 priority intersections for camera placement of which 10 have currently been treated. Results of this evaluation indicate that consideration of installing speed and red light intersection cameras at the remaining seven high priority sites is warranted. This is re-enforced by noting the role intersection camera enforcement has played to date in the overall benefits of the W.A. automated enforcement program. The contribution of intersection cameras to the overall benefits of the program in Perth were half that of the mobile camera program, despite the much more limited coverage of the road network by the intersection cameras. This shows the importance of enforcing high crash rate intersection sites.

3.3 MOBILE SPEED CAMERAS

Like a number of other jurisdictions in Australia, the mobile speed camera program is the centre piece of automated enforcement in W.A., a reflection of the high proportion of the crash population that can be covered by a mobile camera program. Assessment of the overall impact of the W.A. automated enforcement program on serious crashes confirm this. It shows three quarters of the benefit of the program comes from the mobile speed camera program with the entire benefit in regional W.A. coming from mobile speed cameras.

Evaluation of the crash effects of the W.A. mobile speed camera program used a relatively weak design due to the lack of crash history prior to commencement of the program available for analysis. Despite this, the evaluation was able to find a clear association between the number of speed camera sessions undertaken in each month and the levels of serious road crashes observed each month, which indicates the program is having the desired effect of reducing serious road trauma. From the relationships established it was possible to infer the level of road trauma expected had the program not been in place and to estimate the crash reduction effects of the program at various intensities of operation. As expected due to the highly overt nature of the W.A. mobile camera program, effects were highly localised to the site of operation, with the majority of benefits in both Perth and the rest of W.A. confined to within 500m of a speed camera operation site. Benefits were also confined largely to daytime hours given the times at which cameras are typically operated.

Over the life of the program, at the average level of operation, the program was associated with serious casualty crash reductions in the area and time of influence. These reductions were approximately 5% in Perth based around 750 session per month or around 1875 hours of enforcement and 8% in regional W.A. based on an average of 116 sessions per month (290 hours). Monthly hours of operation do not appear fixed with up to 1900 sessions per month (3800 hours) delivered in Perth and 435 (870 hours) in regional W.A. At these levels of operation associated serious casualty crash reductions in the areas and times of influence were estimated to be round 12% in Perth and 26% in regional W.A. Crash effects in later years of the evaluation were slightly higher than average due to increases in the average number of monthly sessions over time since 2008. Effects of the program associated with fatal crashes were estimated to be much higher with average reductions between 20 and 25% and maximum reductions in excess of 50%.

Despite the strong association between mobile speed camera operations and both serious casualty and particularly fatal crashes, the overall impact of the mobile camera program on crashes in W.A. has been relatively modest. In 2012 the program delivered a 4% reduction in serious casualty crashes in Perth and 3% in regional W.A. In Perth the models reductions do not reflect the coverage of the total daytime crash population which is high. Instead it reflects limited enforcement at night during the study period when speed related crashes are more prevalent due to lower traffic volumes. As noted, W.A. Police have now moved to undertaking some camera enforcement at night. The latter points will be discussed further later. In regional W.A. the same issues are also relevant but combined with a lower crash coverage due to the more spatially dispersed nature of crashes in regional areas. It is worth noting that the association between camera use and serious crash reductions was stronger in regional W.A. suggesting greater potential for this area of the state providing the issue of coverage can be efficiently addressed. This might prove difficult in remote areas of the state where crash densities are very low.

It is difficult to compare the effectiveness of the W.A. mobile camera program relative to other similar programs given it is administered in a way unlike any other Australian jurisdiction. Its operation is highly overt with cameras being marked during operations and sites publicised in advance on the W.A. Police web site and routinely in the media. Although comparable in visibility with Queensland where cameras are generally signed during operation, other aspects of W.A. mobile camera operation remain dissimilar. Although signed Queensland camera site operations are not widely advertised. They operate mobile cameras at around 2,500 carefully chosen sites based on crash history and schedule operations using a rigorous random scheduling process aimed to maximise public uncertainty about camera placement (S. Newstead & Cameron, 2003). Site selection in Queensland ensures good coverage of the crash population whilst overt operation in combination with random scheduling aims for crash effects generalised over time at these sites. Victoria also uses around 2500 sites chosen on crash history or public recommendation to place mobile cameras. Whilst not scheduling operations on any particular basis, in contrast

Victoria aims for generalised deterrence in time and space through covert operation of the cameras.

The way in which W.A. cameras are operated is a hybrid of the Queensland and Victorian approaches. Whilst sites are selected on the basis of crash history, at least in Perth there must be a number of sites with low crash counts given the large number of sites operated. Although working to a set schedule for camera placement and operation, the specific criteria by which scheduling takes place is unclear and seems to have an element of randomness based on the operations data. The deterrence model in Perth seems to be more along the lines of the Random Road Watch Program operated in Queensland which has been shown to be effective in reducing crashes (S. V. Newstead, Cameron, & Leggett, 1999). Random Road Watch is aimed at producing deterrence generalised in time and space by using high visibility enforcement at random times and places across a jurisdiction to maximise is unpredictability. Whilst this may not have been the intention, the large number of mobile camera sites used in W.A. and the lack of any identified systematic scheduling process aligns well with the Random Road Watch principle.

The effectiveness of the W.A. approach to mobile camera operation can be gauged by comparing the crash effects achieved to those of the Victorian and Queensland programs. Current W.A. mobile camera operations are similar to those used in Victoria in the early 1990s with respect to the number of hours enforced and being confined largely to daylight hours. Evaluation of the early Victorian program estimated a casualty crash reduction of around 20%, with higher reductions associated with serious casualty crashes (30% severity reduction) in Melbourne during daylight hours. These reductions are considerably higher than those currently estimated for the W.A. program. Crash effects of the mobile camera program in regional W.A. are more comparable with those in regional Victoria, with a 14% reduction in 2012 being similar to the 20% reduction in regional Victoria at similar levels of enforcement. Notably, the crash severity reduction estimated in regional W.A. for the mobile camera program were not replicated in regional Victoria although, the Victorian program was largely implemented on lower speed roads during the early years of the program.

Evaluation of the Queensland mobile speed camera program (S. Newstead & Cameron, 2003), based on overt operation with effects confined to 2km from a camera site, estimated a serious casualty crash reduction of around 30%. This again is greater than the W.A. mobile camera program but partly reflects the Queensland program delivering more than twice the number of enforcement hours compared to the W.A. program (S. Newstead, Cameron M, 2013).

On the whole, the W.A. mobile speed camera program appears to have delivered lower overall crash reduction effects than other similar large programs operated in Victoria and Queensland. With program effects in regional areas being of a similar magnitude, this difference seems to have stemmed from lower efficiency of the program in metropolitan areas. The cause of this is partly the low number of hours enforced under the W.A mobile camera program. Although the effectiveness of the program measures seem to stem from the principles of the Random Road Watch type approach, it is possible effectiveness is being compromised by too low site visitation frequency. A large proportion of the sites used have only been visited once in a five year period which may not be often enough to generate deterrence effects beyond the time at which the camera is present at the site. Conversely, a small proportion of the sites (up to 15%) have been used far more frequently. These findings suggest the need for more efficient and systematic scheduling of operations to maximise the spatial coverage and associated deterrence of the program. Study of the time based effects of the program associated with specific sites was beyond the scope of the evaluation although, may be valuable as part of future research to establish the optimum site visitation frequency to maximise crash effects.

Overall results show that the mobile speed camera program in W.A. is proving effective in reducing crashes under its current mode of operation. However, comparison with other programs suggests there is potential for improving the efficiency of the program through aligning it more with the operations of the other major overt mobile speed camera program in Queensland. Changes warranting consideration include:

- Review of the site selection process to ensure the program covers the crash population as effectively as possible. This may involve rationalising the total number of sites used under the program, particularly in Perth.
- Review of the mechanism for scheduling operations to ensure appropriate enforcement across all sites. A random scheduling process, similar to that used in Queensland, might be appropriate with potentially higher weighting to high risk sites.
- Increasing the number of enforcement hours delivered per month.
- Continue and potentially increase operations in night time hours (8pm-6am) which until recent years were largely unenforced

The above recommendations are based on the continued operation of the program in overt mode. Consideration could also be given to operation of the program in covert mode to maximise the spatial and temporal deterrence from the program. Any move to covert operations would increase back office processing requirements which W.A. Police report can be increased as required to meet demand. A first step might be to undertake a trial of covert mobile camera operations in certain regions of the state to assess crash effects through appropriate evaluation.

3.4 OVERALL PROGRAM EFFECTS AND FUTURE PROGRAM POTENTIAL

As noted in the previous discussion, the overall impact of the automated enforcement program on road trauma in W.A. has been estimated to have a smaller impact on overall serious trauma compared to similar programs operated in other states. The primary reason for this difference is the smaller size of the program in W.A., particularly the relatively low number of hours enforced under the mobile speed camera program, the automated enforcement type with the potential to produce the greatest crash savings. At 2012 levels of operation, the program was estimated to be associated with an overall reduction in serious casualty crashes of 5.7%.

As described in Section 1.4.3, W.A. has identified a desired enforcement level for the automated enforcement program of 3,800 hours for the mobile camera program per month (2,500 metro, 1300 country), and expansion of the fixed freeway network and intersection speed and red light camera network to 30 and 90 camera sites respectively. Based on the results of the evaluation and using 2012 road trauma levels, the expected overall crash savings are shown in Table 3.1, including the additional benefits over those estimated for 2012 under current operational levels. As evident from the table, this strategy roughly doubles the serious casualty crash savings associated with the program noting that the target increase for metropolitan mobile speed camera operations is similar to what was already achieved in 2012. Hence the additional benefits have stemmed from an increase in regional mobile camera operations and a large expansion of the fixed camera network which has been assumed to be installed in Perth.

Table 3.1 *Estimated absolute and percentage serious casualty crash savings for the automated enforcement program under the desired W.A. Government targets*

Region	Measure	Estimate	Additional Savings
Perth	Observed Crashes	1437	
	Savings Fixed Freeway	53	44
	Savings Intersection	101	69
	Savings Mobile Speed	64	0
	Expected Crashes with No Automated Enforcement	1655	
	Total % Savings Automated Enforcement	13.17%	6.33%
	% Savings Fixed Freeway	3.18%	
	% Savings Intersection	6.12%	
	% Savings Mobile Speed	3.87%	
RoWA	Observed Crashes	725	
	Savings Fixed Freeway	0	
	Savings Intersection	0	
	Savings Mobile Speed	50	26
	Expected Crashes with No Automated Enforcement	775	
	Total % Savings Automated Enforcement	6.47%	3.19%
	% Savings Fixed Freeway	0.00%	
	% Savings Intersection	0.00%	
	% Savings Mobile Speed	6.47%	
All	Observed Crashes	2162	
	Savings Fixed Freeway	53	44
	Savings Intersection	101	69
	Savings Mobile Speed	114	25
	Expected Crashes with No Automated Enforcement	2430	
	Total % Savings Automated Enforcement	11.03%	5.36%
	% Savings Fixed Freeway	2.17%	
	% Savings Intersection	4.16%	
	% Savings Mobile Speed	4.70%	

Strategic advice given by Cameron (2008) suggested different targets including 24 fixed freeway cameras and an increase in the number of mobile camera hours to 9000 per month in Perth and 3000 hours per month in regional W.A. No specific increase in intersection cameras was recommended. The resulting serious casualty crash reductions are shown in Table 3.2 including the additional benefit over 2012. Additional benefits estimated in this scenario are larger than for the W.A. Government targets and achieved largely through mobile camera operations increases.

Table 3.2 *Estimated absolute and percentage serious casualty crash savings for the automated enforcement program under the targets recommended by Cameron (2008)*

Region	Measure	Estimate	Additional Savings
Perth	Observed Crashes	1437	
	Savings Fixed Freeway	42	33
	Savings Intersection	33	
	Savings Mobile Speed	180	116
	Expected Crashes with No Automated Enforcement	1692	
	Total % Savings Automated Enforcement	15.07%	8.24%
	% Savings Fixed Freeway	2.49%	
	% Savings Intersection	1.93%	
	% Savings Mobile Speed	10.65%	
RoWA	Observed Crashes	725	
	Savings Fixed Freeway	0	
	Savings Intersection	0	
	Savings Mobile Speed	96	72
	Expected Crashes with No Automated Enforcement	821	
	Total % Savings Automated Enforcement	11.74%	8.46%
	% Savings Fixed Freeway	0.00%	
	% Savings Intersection	0.00%	
	% Savings Mobile Speed	11.74%	
All	Observed Crashes	2162	
	Savings Fixed Freeway	42	33
	Savings Intersection	33	
	Savings Mobile Speed	277	188
	Expected Crashes with No Automated Enforcement	2513	
	Total % Savings Automated Enforcement	13.98%	8.31%
	% Savings Fixed Freeway	1.68%	
	% Savings Intersection	1.30%	
	% Savings Mobile Speed	11.01%	

A final scenario considered brings together the increases in fixed cameras targeted by the W.A. Government with the mobile increases recommended by Cameron (2008). As expected this returns the largest benefits of all with a total serious casualty crash saving of 16.3%, or an additional 10.6% over 2012 levels. This analysis demonstrates that there is significant additional potential from crash savings to be gained by further expansion of all elements of the automated enforcement program. Which combination of elemental increases brings the most cost effective outcome remains to be established through revisiting the analysis of Cameron (2008) but also including the estimates of W.A. camera effectiveness derived from this study.

Table 3.3 *Estimated absolute and percentage serious casualty crash savings for the automated enforcement program under the targets recommended in a combination of both Cameron (2008) and the W.A. Government targets.*

Region	Measure	Estimate	Additional Savings
Perth	Observed Crashes	1437	
	Savings Fixed Freeway	42	33
	Savings Intersection	101	69
	Savings Mobile Speed	180	116
	Expected Crashes with No Automated Enforcement	1761	
	Total % Savings Automated Enforcement	18.38%	11.54%
	% Savings Fixed Freeway	2.39%	
	% Savings Intersection	5.75%	
	% Savings Mobile Speed	10.24%	
RoWA	Observed Crashes	725	
	Savings Fixed Freeway	0	
	Savings Intersection	0	
	Savings Mobile Speed	96	72
	Expected Crashes with No Automated Enforcement	821	
	Total % Savings Automated Enforcement	11.74%	8.46%
	% Savings Fixed Freeway	0.00%	
	% Savings Intersection	0.00%	
	% Savings Mobile Speed	11.74%	
All	Observed Crashes	2162	
	Savings Fixed Freeway	42	33
	Savings Intersection	101	69
	Savings Mobile Speed	277	188
	Expected Crashes with No Automated Enforcement	2582	
	Total % Savings Automated Enforcement	16.27%	10.59%
	% Savings Fixed Freeway	1.63%	
	% Savings Intersection	3.92%	
	% Savings Mobile Speed	10.72%	

Future potential of the automated enforcement program quantified in this section have only considered camera types currently in operation. The potential use of point to point camera systems has been covered in strategic directions of the program but not in calculations of potential benefits. This is partly because there is yet to be a reliable evaluation of the benefits of point to point systems in Australia on which to base potential benefits. There have also been a number of operation difficulties with current point to point systems in Australia related to camera synchronisation, roadworks and speed limit changes. These need to be resolved before wide spread application of point to point speed cameras becomes feasible. Future technologies such as use of the mobile speed cameras in point to point mode by pairing cameras might also be a useful advance for enforcing sparsely trafficked regional areas such as found in large areas of W.A.

3.5 DATA REQUIREMENTS

Issues that hampered the evaluation of the W.A. automated enforcement program were the quality and availability of the speed camera operations data for the analysis. These issues with data quality and availability made the evaluation far more complicated and costly than anticipated, as well as limiting the analysis that could be undertaken. W.A. Police were extremely helpful in providing access to the data for the evaluation and background information on the program within the limited resources they have available. However, they did not have the capacity to extract the data on behalf of C-MARC requiring a research assistant to be placed in the W.A. Police offices to first learn the data systems and then undertake the data extraction. If W.A. Police had the resources to extract and provide the data directly it would have made the process of data provision more efficient, timely and cost effective.

Existing data quality issues within the extracted data were a major problem requiring significant time and resources to both identify and correct. Primary amongst these was missing location data for the mobile speed camera sessions, with over two thirds of the data missing accurate GPS operation co-ordinates. Many of these were in the early years of the program however the problem persisted throughout the program to some degree. All mobile speed camera operations require accurate GPS location coordinates recorded in the data, with the coordinates routinely verified against the site descriptors to identify any errors. Mobile speed camera sessions also need accurate start and end times recorded for each session. Having this data would have allowed the number of enforced hours to be used in the evaluation rather than simply the number of sessions, which may have varied in length. Other data such as site speed limit, number of vehicles checked, number of vehicles detected over the speed limit by speed bin, and the number of infringement notices issues by speed bin is also critical data for monitoring the implementation and impact of the mobile speed camera program and should all be complete and accurate. Data collection and entry in-service courses for associated staff may assist in addressing some of these short-falls

Data on intersection and fixed freeway cameras could also be enhanced. Information on the original installation dates of the intersection red light cameras rather than just the upgrade to combined speed and red light cameras was missing. The date of installation of 21 of the 46 camera upgrades was also unavailable, meaning these locations could not be included in the analysis. Information on both installation and activation for both testing and full enforcement should be routinely documented for all fixed camera installations, to ensure evaluations can be based on accurate dates identifying when deterrence from each camera installation is likely to commence. Currently installation date for fixed cameras does not appear to be collected.

4 CONCLUSIONS

Evaluation of the automated enforcement program in Western Australia has shown the program to be associated with statistically significant crash reductions with estimated effects highest for fatal and serious injury crashes, the target of the Western Australian Road Safety Strategy. Contributions to crash reductions from each camera type of the automated enforcement program have been estimated. Evaluation design was informed by the international literature on traffic camera enforcement evaluation as well as the specific operational practices in place in Western Australia. Operational practices have also been interrogated to guide interpretation of the estimated camera effects, as well as to provide comment on how the automated enforcement program might be enhanced in the future to provide even greater crash savings.

Evaluation of the impact of the 25 combined speed and red light camera installations, at signalised intersections, estimated a statistically significant 37% reduction in serious casualty crashes at enforced intersections associated with the installation of the cameras. Operations data showed a significant prevalence of speeding at these intersections suggesting the speed enforcement component to the cameras has been an effective component in addressing this problem. Evaluation of the fixed freeway speed camera system was somewhat inconclusive due to the limited time period of crash data available post-installation of the cameras. Although not statistically significant, estimated reductions in serious casualty crashes were consistent in magnitude to those estimated for the intersection cameras. Ongoing monitoring of the effectiveness of this camera type is recommended.

The mobile speed camera program in W.A. appears to have been operated on the principles of Random Road Watch using highly overt enforcement, at a large number of sites, with low site visitation frequency over most sites. Sites operated cover the majority of the crash population in metropolitan Perth. In regional areas the cameras are used predominantly in south-west areas of the state where crash densities are the highest. Until recent years operations have been confined largely to the daytime hours of 6am to 8pm although this has now changed. The number of hours enforced using mobile speed cameras is relatively small compared to other Australian jurisdictions operating a mobile camera program. Evaluation of the crash effects associated with the W.A. mobile camera program showed a strong relationship between the number of sessions undertaken in a month and reductions in fatal and serious casualty crashes within 500m of the site where a speed camera had been used. The association was stronger for fatal crashes and in regional W.A. compared to Perth. At the level of enforcement effort delivered in 2014, the program was associated with a 36% reduction in fatal crashes and a 7% reduction in all serious casualty crashes within 500m of a camera site in Perth. In regional W.A. the corresponding reductions were 36% for fatal crashes and 14% for serious casualty crashes.

Given the coverage and level of camera operations in 2012, the automated enforcement program was estimated to be associated with an overall reduction in serious casualty crashes in W.A. during 2012 of 5.6%. This comprised a 6.8% reduction in Perth and a 3.3% reduction in the rest of W.A. The mobile speed camera program was responsible for nearly 70% of this reduction, representing 100% of the reduction in regional areas and 61% in Perth. The contribution of the fixed freeway cameras was only 6.8% of the overall reduction (or a 0.4% reduction in total W.A. road trauma) or 8.3% (0.6% of total) in Perth. Intersection cameras made up the remainder of the reductions.

Further analysis showed significant potential for additional fatal and serious crash savings through expansion of the automated enforcement program. Under the long term expansion targets for the program set by the W.A. Government, including major expansion of the fixed camera network and modest increases in mobile camera use in regional W.A., total serious casualty crash reductions under the program could be increased to 11%, double the current level. Major expansion of the mobile speed camera program and increases in the fixed speed camera network, as recommended in independent strategic advice, would increase overall serious casualty crash reductions to 14%. Combining both strategies would increase these savings to over 16%. Evaluation shows that implementation of any of these strategies is justified on the basis of expected crash savings although the optimum program based on economic benefits is yet to be determined.

Ongoing monitoring and evaluation of the program is recommended. To support this, improvements to data collection on program operations is critical and should be implemented as soon as practicable.

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APPENDICES

Appendix A *Number of sites per month of year by year of OPERATION (N=203,852)*

Year	Month of year												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1995	1333	638	501	290	217	236	342	318	247	153	196	46	4517
1996	1842	758	672	425	325	337	551	444	303	401	412	180	6650
1997	334	189	196	130	101	59	128	142	249	291	198	135	2152
1998	1847	1172	928	825	516	509	742	1171	791	970	917	505	10893
1999	1953	1343	1009	921	678	548	882	1213	965	1184	1064	674	12434
2000	1563	1074	1199	982	818	574	890	1293	886	1267	1185	711	12442
2001	1925	1327	998	948	945	528	1035	1421	1025	1161	1023	881	13217
2002	1650	1312	1018	863	1035	565	1151	1272	1191	1059	1190	1027	13333
2003	1539	1114	997	818	976	610	944	1276	1104	1029	1046	946	12399
2004	1503	1087	707	931	901	787	823	1118	1092	852	941	990	11732
2005	1150	985	750	838	704	629	710	1042	957	955	991	876	10587
2006	1018	967	883	777	733	609	527	960	813	827	982	795	9891
2007	955	866	621	540	582	515	630	980	743	736	826	666	8660
2008	740	737	617	652	555	413	702	1154	865	803	768	721	8727
2009	783	937	744	733	670	577	711	1179	992	938	806	867	9937
2010	668	666	724	506	625	544	551	966	920	932	778	679	8559
2011	1129	1100	1123	907	918	936	836	1415	1260	1177	1322	1298	13421
2012	1346	1430	1482	1157	1250	1035	1239	1766	1531	1627	1640	1425	16928
2013	1518	1495	1333	1202	1383	1078	1100	1668	1649	1858	1629	1460	17373
Total	**24796**	**19197**	**16502**	**14445**	**13932**	**11089**	**14494**	**20798**	**17583**	**18220**	**17914**	**14882**	**203852**

Appendix B *District location of sites by year (N=203,852)*

Year of site	District														Total
	CENTRAL METROPOLITAN	EAST METROPOLITAN	GOLDFIELDS-ESPERANCE	GREAT SOUTHERN	KIMBERLEY	MIDWEST-GASCOYNE	NORTH WEST METROPOLITAN	PEEL	PILBARA	SOUTH EAST METROPOLITAN	SOUTH METROPOLITAN	SOUTH WEST	WEST METROPOLITAN	WHEATBELT	
1995	527	314	0	0	0	2	412	114	0	1192	609	100	1229	18	**4517**
	11.7	7.0	0.0	0.0	0.0	0.0	9.1	2.5	0.0	26.4	13.5	2.2	27.2	0.4	**100.0**
1996	923	419	20	56	0	66	738	156	0	1585	958	30	1613	86	**6650**
	13.9	6.3	0.3	0.8	0.0	1.0	11.1	2.3	0.0	23.8	14.4	0.5	24.3	1.3	**100.0**
1997	305	270	0	31	0	32	215	118	0	431	238	33	449	30	**2152**
	14.2	12.5	0.0	1.4	0.0	1.5	10.0	5.5	0.0	20.0	11.1	1.5	20.9	1.4	**100.0**
1998	1699	1072	0	16	0	47	1044	504	5	2058	1249	384	2493	322	**10893**
	15.6	9.8	0.0	0.1	0.0	0.4	9.6	4.6	0.0	18.9	11.5	3.5	22.9	3.0	**100.0**
1999	1718	998	6	6	0	0	1568	774	13	1915	1696	595	2665	480	**12434**
	13.8	8.0	0.0	0.0	0.0	0.0	12.6	6.2	0.1	15.4	13.6	4.8	21.4	3.9	**100.0**
2000	1733	1542	0	1	0	7	1510	1193	0	1800	1250	422	2512	472	**12442**
	13.9	12.4	0.0	0.0	0.0	0.1	12.1	9.6	0.0	14.5	10.0	3.4	20.2	3.8	**100.0**
2001	2465	1352	17	7	0	0	1354	1081	0	1717	1457	939	2368	460	**13217**
	18.7	10.2	0.1	0.1	0.0	0.0	10.2	8.2	0.0	13.0	11.0	7.1	17.9	3.5	**100.0**
2002	2713	1437	8	6	0	0	1533	1070	0	1666	1322	1031	2120	427	**13333**
	20.3	10.8	0.1	0.0	0.0	0.0	11.5	8.0	0.0	12.5	9.9	7.7	15.9	3.2	**100.0**
2003	2339	1232	28	11	0	0	1157	1414	0	1779	1140	875	2013	411	**12399**
	18.9	9.9	0.2	0.1	0.0	0.0	9.3	11.4	0.0	14.3	9.2	7.1	16.2	3.3	**100.0**
2004	1853	1318	16	24	0	0	1209	1876	0	1420	923	877	1797	419	**11732**
	15.8	11.2	0.1	0.2	0.0	0.0	10.3	16.0	0.0	12.1	7.9	7.5	15.3	3.6	**100.0**
2005	1452	1375	0	89	33	0	1023	1464	9	1368	967	770	1596	441	**10587**
	13.7	13.0	0.0	0.8	0.3	0.0	9.7	13.8	0.1	12.9	9.1	7.3	15.1	4.2	**100.0**
2006	1039	1257	17	261	10	70	1078	1503	0	1209	856	853	1326	412	**9891**
	10.5	12.7	0.2	2.6	0.1	0.7	10.9	15.2	0.0	12.2	8.7	8.6	13.4	4.2	**100.0**
2007	788	1016	25	594	0	72	666	1426	0	913	542	1044	977	597	**8660**
	9.1	11.7	0.3	6.9	0.0	0.8	7.7	16.5	0.0	10.5	6.3	12.1	11.3	6.9	**100.0**
2008	1055	1169	8	474	58	42	967	898	24	1061	613	920	1062	376	**8727**

	12.1	13.4	0.1	5.4	0.7	0.5	11.1	10.3	0.3	12.2	7.0	10.5	12.2	4.3	**100.0**
2009	1159	1359	37	386	7	191	1100	1120	14	1461	768	886	1076	373	**9937**
	11.7	13.7	0.4	3.9	0.1	1.9	11.1	11.3	0.1	14.7	7.7	8.9	10.8	3.8	**100.0**
2010	794	954	0	375	0	598	1077	762	14	1192	906	759	733	395	**8559**
	9.3	11.1	0.0	4.4	0.0	7.0	12.6	8.9	0.2	13.9	10.6	8.9	8.6	4.6	**100.0**
2011	1896	1457	8	342	24	707	1939	832	27	1896	1491	746	1607	449	**13421**
	14.1	10.9	0.1	2.5	0.2	5.3	14.4	6.2	0.2	14.1	11.1	5.6	12.0	3.3	**100.0**
2012	2187	1719	0	396	0	778	2597	1173	167	2531	1977	838	2065	500	**16928**
	12.9	10.2	0.0	2.3	0.0	4.6	15.3	6.9	1.0	15.0	11.7	5.0	12.2	3.0	**100.0**
2013	2258	1761	24	390	0	837	2264	1235	33	2847	1901	1019	2316	488	**17373**
	13.0	10.1	0.1	2.2	0.0	4.8	13.0	7.1	0.2	16.4	10.9	5.9	13.3	2.8	**100.0**
Total	**28903**	**22021**	**214**	**3465**	**132**	**3449**	**23451**	**18713**	**306**	**30041**	**20863**	**13121**	**32017**	**7156**	**203852**
	14.2	**10.8**	**0.1**	**1.7**	**0.1**	**1.7**	**11.5**	**9.2**	**0.2**	**14.7**	**10.2**	**6.4**	**15.7**	**3.5**	**100.0**

Appendix C *Speed limit of site where mobile speed camera was located by year (N=195,978)*

Year		Speed limit of site								Total
		40	50	60	70	80	90	100	110	
1995	n	0	0	2955	1023	271	52	154	54	4509
	%	0.0	0.0	65.5	22.7	6.0	1.2	3.4	1.2	100.0
1996	n	3	1	4573	1297	372	56	269	48	6619
	%	0.0	0.0	69.1	19.6	5.6	0.8	4.1	0.7	100.0
1997	n	3	1	1399	423	206	20	88	8	2148
	%	0.1	0.0	65.1	19.7	9.6	0.9	4.1	0.4	100.0
1998	n	3	0	6815	1981	1120	284	540	149	10892
	%	0.0	0.0	62.6	18.2	10.3	2.6	5.0	1.4	100.0
1999	n	0	0	6989	2288	1562	508	737	323	12407
	%	0.0	0.0	56.3	18.4	12.6	4.1	5.9	2.6	100.0
2000	n	0	2	6692	2558	1848	404	645	276	12425
	%	0.0	0.0	53.9	20.6	14.9	3.3	5.2	2.2	100.0
2001	n	1	0	7685	2715	1677	405	416	314	13213
	%	0.0	0.0	58.2	20.5	12.7	3.1	3.1	2.4	100.0
2002	n	1	1	7307	2691	1766	650	514	400	13330
	%	0.0	0.0	54.8	20.2	13.2	4.9	3.9	3.0	100.0
2003	n	68	26	6102	2302	1918	660	922	394	12392
	%	0.5	0.2	49.2	18.6	15.5	5.3	7.4	3.2	100.0
2004	n	18	44	5316	2367	2053	552	961	418	11729
	%	0.2	0.4	45.3	20.2	17.5	4.7	8.2	3.6	100.0
2005	n	344	33	4407	2474	1575	463	885	396	10577
	%	3.3	0.3	41.7	23.4	14.9	4.4	8.4	3.7	100.0
2006	n	287	283	3494	2499	1613	551	596	564	9887
	%	2.9	2.9	35.3	25.3	16.3	5.6	6.0	5.7	100.0
2007	n	958	400	2557	1695	1192	670	478	700	8650
	%	11.1	4.6	29.6	19.6	13.8	7.7	5.5	8.1	100.0
2008	n	746	329	2786	1970	1153	641	616	486	8727
	%	8.5	3.8	31.9	22.6	13.2	7.3	7.1	5.6	100.0
2009	n	1129	409	3198	2076	1271	603	840	411	9937
	%	11.4	4.1	32.2	20.9	12.8	6.1	8.5	4.1	100.0
2010	n	680	449	1694	1301	922	464	554	401	6465
	%	10.5	6.9	26.2	20.1	14.3	7.2	8.6	6.2	100.0
2011	n	626	528	2326	2038	1196	363	840	296	8213
	%	7.6	6.4	28.3	24.8	14.6	4.4	10.2	3.6	100.0
2012	n	1642	886	4530	4208	2331	904	1737	478	16716
	%	9.8	5.3	27.1	25.2	13.9	5.4	10.4	2.9	100.0
2013	n	1515	1676	4885	3781	2233	1004	1380	668	17142
	%	8.8	9.8	28.5	22.1	13.0	5.9	8.1	3.9	100.0
Total	n	8024	5068	85710	41687	26279	9254	13172	6784	195978
	%	4.1	2.6	43.7	21.3	13.4	4.7	6.7	3.5	100.0

Appendix D *Grouped number of speeding infringements detected per session by year (N=185,507)*

Year		Number of infringements													Total
		0	**1-9**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100-149**	**150+**	
1995	**n**	414	1018	819	596	468	362	205	161	134	115	64	140	21	4517
		9.2	22.5	18.1	13.2	10.4	8.0	4.5	3.6	3.0	2.5	1.4	3.1	0.5	100.0
1996	**n**	1009	1249	1234	937	689	487	331	250	196	137	68	56	7	6650
		15.2	18.8	18.6	14.1	10.4	7.3	5.0	3.8	2.9	2.1	1.0	0.8	0.1	100.0
1997	**n**	281	376	387	275	215	171	113	86	96	75	38	35	4	2152
		13.1	17.5	18.0	12.8	10.0	7.9	5.3	4.0	4.5	3.5	1.8	1.6	0.2	100.0
1998	**n**	1135	2110	2080	1578	1108	853	538	410	373	285	168	203	52	10893
		10.4	19.4	19.1	14.5	10.2	7.8	4.9	3.8	3.4	2.6	1.5	1.9	0.5	100.0
1999	**n**	871	2535	2365	1838	1428	1001	660	474	408	310	197	301	40	12428
		7.0	20.4	19.0	14.8	11.5	8.1	5.3	3.8	3.3	2.5	1.6	2.4	0.3	100.0
2000	**n**	1044	3071	2467	1629	1110	870	541	413	347	291	186	314	33	12316
		8.5	24.9	20.0	13.2	9.0	7.1	4.4	3.4	2.8	2.4	1.5	2.5	0.3	100.0
2001	**n**	597	2327	2105	1782	1485	1217	867	674	500	373	282	667	288	13164
		4.5	17.7	16.0	13.5	11.3	9.2	6.6	5.1	3.8	2.8	2.1	5.1	2.2	100.0
2002	**n**	755	3212	2485	1918	1388	936	695	457	387	253	190	459	176	13311
		5.7	24.1	18.7	14.4	10.4	7.0	5.2	3.4	2.9	1.9	1.4	3.4	1.3	100.0
2003	**n**	701	2604	2520	1842	1347	1000	630	444	331	239	177	327	183	12345
		5.7	21.1	20.4	14.9	10.9	8.1	5.1	3.6	2.7	1.9	1.4	2.6	1.5	100.0
2004	**n**	494	2197	2130	1705	1352	971	705	513	410	260	221	550	222	11730
		4.2	18.7	18.2	14.5	11.5	8.3	6.0	4.4	3.5	2.2	1.9	4.7	1.9	100.0
2005	**n**	481	2038	1867	1450	1090	839	580	510	350	267	225	575	294	10566
		4.6	19.3	17.7	13.7	10.3	7.9	5.5	4.8	3.3	2.5	2.1	5.4	2.8	100.0
2006	**n**	301	1071	793	583	357	338	180	150	135	114	73	271	196	4562
		6.6	23.5	17.4	12.8	7.8	7.4	3.9	3.3	3.0	2.5	1.6	5.9	4.3	100.0
2007	**n**	1	1114	713	418	318	195	155	110	73	70	61	174	138	3540
		0.0	31.5	20.1	11.8	9.0	5.5	4.4	3.1	2.1	2.0	1.7	4.9	3.9	100.0
2008	**n**	0	2198	1502	1014	653	488	305	242	191	167	113	327	227	7427
		0.0	29.6	20.2	13.7	8.8	6.6	4.1	3.3	2.6	2.2	1.5	4.4	3.1	100.0
2009	**n**	0	2509	1807	1168	810	576	382	299	224	181	146	369	237	8708
		0.0	28.8	20.8	13.4	9.3	6.6	4.4	3.4	2.6	2.1	1.7	4.2	2.7	100.0
2010	**n**	0	2119	1695	1021	728	497	350	272	217	160	142	310	297	7808
		0.0	27.1	21.7	13.1	9.3	6.4	4.5	3.5	2.8	2.0	1.8	4.0	3.8	100.0
2011	**n**	0	3171	2389	1563	1063	769	585	489	399	341	278	680	751	12478
		0.0	25.4	19.1	12.5	8.5	6.2	4.7	3.9	3.2	2.7	2.2	5.4	6.0	100.0
2012	**n**	0	4757	3061	1893	1304	911	593	458	390	285	250	631	579	15112
		0.0	31.5	20.3	12.5	8.6	6.0	3.9	3.0	2.6	1.9	1.7	4.2	3.8	100.0
2013	**n**	0	4866	3150	1958	1369	930	708	558	447	330	278	750	456	15800
		0.0	30.8	19.9	12.4	8.7	5.9	4.5	3.5	2.8	2.1	1.8	4.7	2.9	100.0
Total	**n**	**8084**	**44542**	**35569**	**25168**	**18282**	**13411**	**9123**	**6970**	**5608**	**4253**	**3157**	**7139**	**4201**	**185507**
		4.4	**24.0**	**19.2**	**13.6**	**9.9**	**7.2**	**4.9**	**3.8**	**3.0**	**2.3**	**1.7**	**3.8**	**2.3**	**100.0**

Appendix E *Speed Red Light Speed Camera percentage of speeding offences by range and camera site*

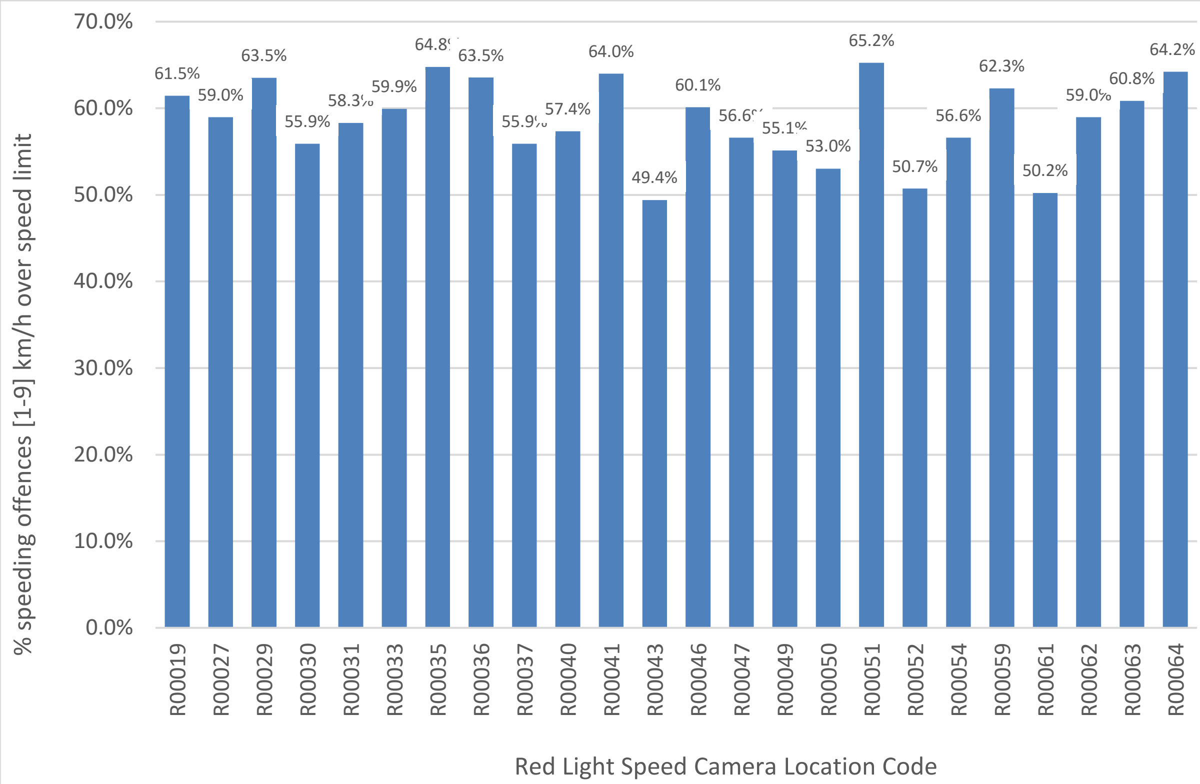

Figure E1 *Percentage of speeding offences [1-9]km/h over the speed limit at combined Red Light Speed Camera sites in Western Australia; July 2010 to February 2014*

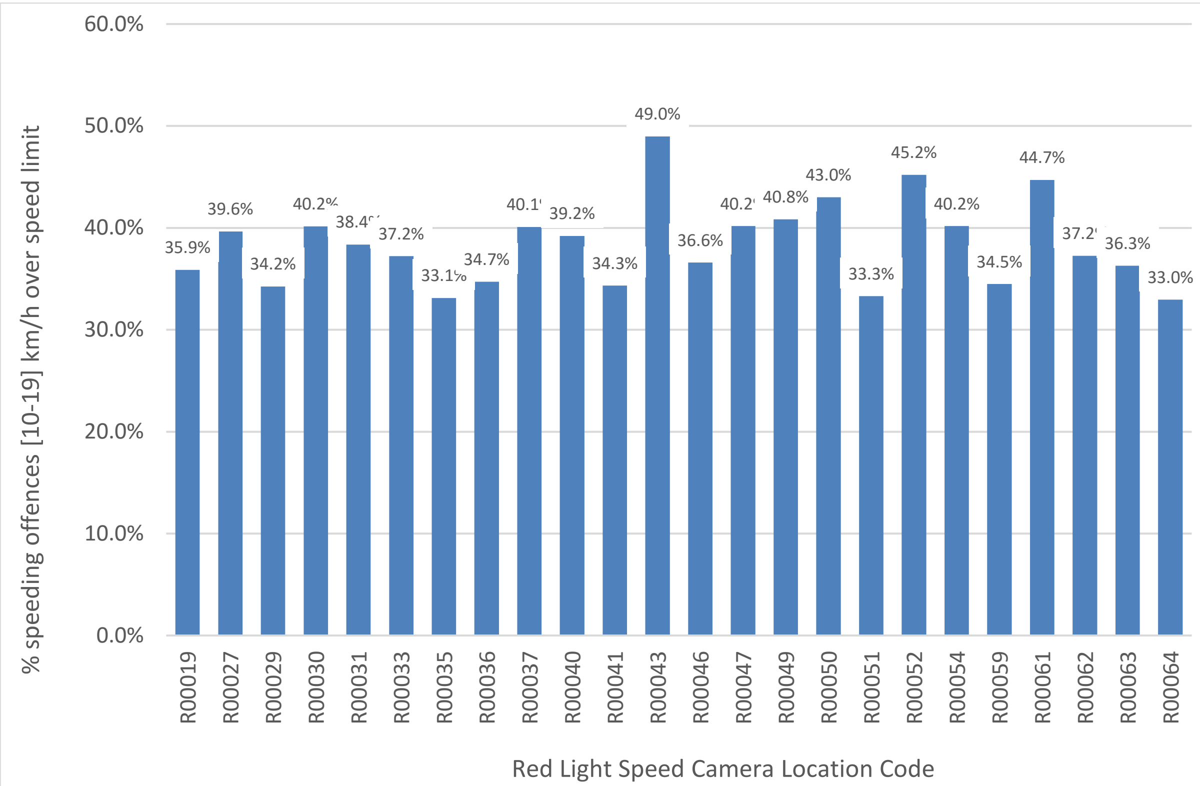

Figure E2 *Percentage of speeding offences [10-19]km/h over the speed limit at combined Red Light Speed Camera sites in Western Australia; July 2010 to February 2014*

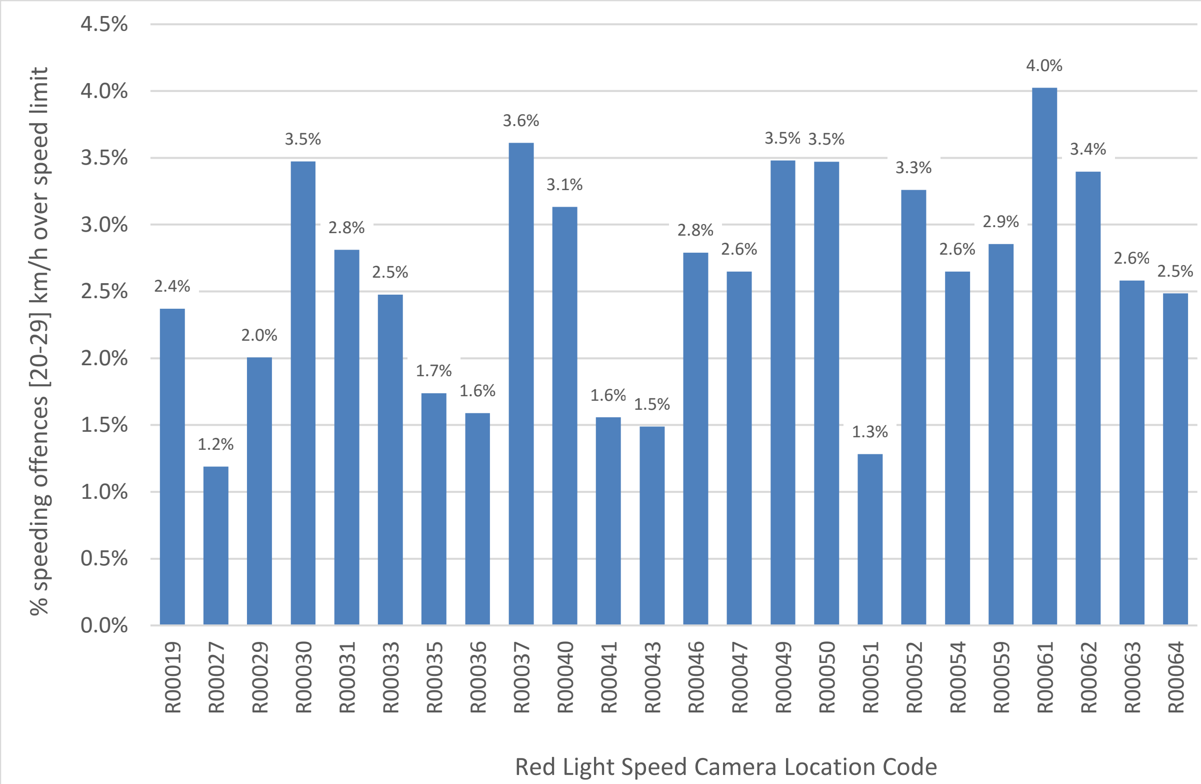

Figure E3 *Percentage of speeding offences [20-29]km/h over the speed limit at combined Red Light Speed Camera sites in Western Australia; July 2010 to February 2014*

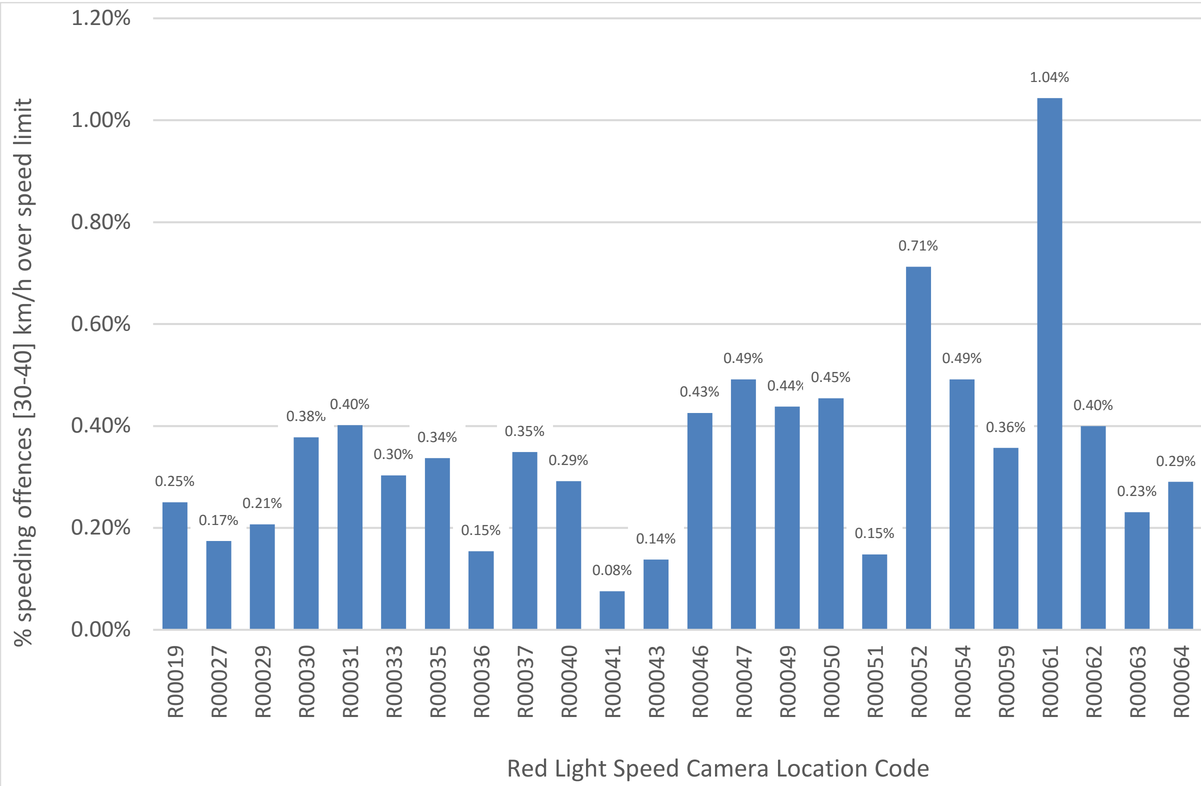

Figure E4 *Percentage of speeding offences [30-40]km/h over the speed limit at combined Red Light Speed Camera sites in Western Australia; July 2010 to February 2014*

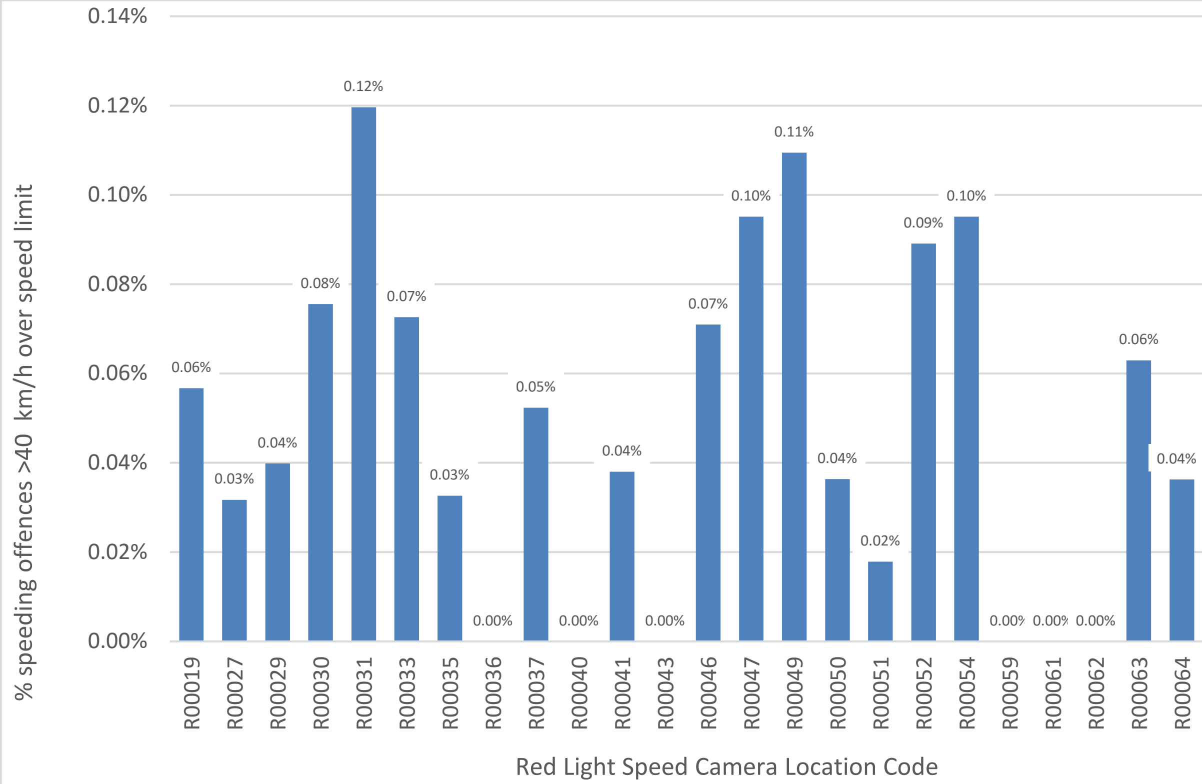

Figure E5 *Percentage of speeding offences > 40 km/h over the speed limit at combined Red Light Speed Camera sites in Western Australia; July 2010 to February 2014*