EVALUATION OF THE ROAD SAFETY BENEFITS OF THE QUEENSLAND CAMERA DETECTED OFFENCE PROGRAM (CDOP) IN 2017

by

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Abstract:
The Queensland Camera Detected Offence Program (CDOP) covers management and operation of all modes of camera-based traffic enforcement in Queensland. Currently this includes the mobile speed camera program, the red-light camera program and fixed speed cameras, and has been expanded over recent years to include point-to-point cameras and combined speed and red-light cameras at intersections. The broad objective of this study was to measure impacts on crash frequency, severity and social costs to the community in Queensland associated with the ongoing operation of the CDOP over the year 2017. An updated evaluation framework for the mobile speed camera component of the CDOP was developed which has provided more robust estimates of associated crash effects and directly links levels of operation of the mobile speed camera program by specific camera type to observed crash outcomes.

Evaluation results show that the Queensland CDOP was associated with sustained crash reductions across Queensland in the year 2017 with correspondingly large economic benefits to the community accruing from its operation. Both fixed and mobile elements of the program produced significant crash reductions. Crash effects associated with red-light cameras, upgrades of red-light cameras to combined speed and red-light cameras and tunnel cameras estimated in the evaluation were robust. In contrast, the evidence of effectiveness for some of the more recently implemented fixed camera types, including point-to-point speed cameras, fixed mid-block spot speed cameras and new intersection speed and red-light cameras, remains weaker due to insufficient post-implementation history and small number of camera installations. Despite the expansion of the number of fixed cameras in use under the CDOP, the mobile camera program continues to produce around 95% of the measured benefits associated with CDOP reflecting the high proportion of the crash population it covers.

Overall crash reductions in Queensland associated with CDOP in 2017 were 12.2% of serious casualty crashes and 11.2% of all casualty crashes. It was estimated that CDOP was associated with absolute casualty crash savings of 1,594 in 2017 of which 767 were fatal or serious injury crash savings. Conversion of the estimated crash savings into (2017 $) cost savings estimated annual savings of around $703M in 2017 associated with the program valued using Willingness to Pay estimates, or $320M using Human Capital crash costs. About 88% of the total savings stem from savings in fatal and serious injury crashes which are the focus of the Queensland road safety strategy.

For the first time, the study also provided valuable evidence on the mechanisms of crash reduction effects associated with the mobile speed camera program.

Key Words:
CDOP, mobile speed, fixed speed, red light speed, Queensland, red-light cameras, Quasi-experimental, time series

Disclaimer
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Preface

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Stuart Newstead:	Study design, mobile camera analysis, evaluation framework design, and report editing/writing
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Ethics Statement

Ethics approval was not required for this project.

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Contents

GLOSSARY OF ABBREVIATIONS AND TERMS

Term / Abbreviation	Meaning
CDOP	Camera Detected Offence Program.
GIS	Geographical Information System – a computer program which maps and relates information spatially.
Human Capital crash cost (HC)	A method of determining the cost of a road crash to the community based on the actual cost of all the associated events (property damage, medical costs, lost productivity etc.).
Negative Binomial regression	A form of statistical regression analysis used to model count data and contingency tables. It assumes the response variable has a Negative Binomial distribution and assumes the natural logarithm of the response variable can be modelled by a linear combination of a set of independent variables.
Poisson regression	A form of statistical regression analysis used to model count data and contingency tables. It assumes the response variable has a Poisson distribution and assumes the natural logarithm of the response variable can be modelled by a linear combination of a set of independent variables.
PtP	Point-to-Point Speed Camera System – an automated enforcement system designed to measure average speed over a length of road.
Quasi experiment	A scientific study design similar to the randomised controlled trial except selection of participants to receive the intervention is not random.
Relative Risk	The risk of an outcome in one situation or group relative to another (e.g. in males relative to females).
Simpson's Paradox	A situation in statistical analysis where the outcome effects of an action are estimated incorrectly (and more typically in the wrong direction) due to the failure of the analysis to account for the effect of another factor effecting the outcome but associated with the factor of interest.
SLA	Statistical Local Area – local geographical areas defined by the Australian Bureau of Statistics.
Speed bins	Ranges of speed into which individual speed observations are classified for analysis (e.g. 0-5kph, 5-10kph etc.).
Speed enforcement tolerance	The amount over the speed limit a motorist can travel before a traffic offence notice will be issued.
Test of homogeneity	A statistical test to establish whether a countermeasure has achieved the same outcome effect over multiple sites.
TMR	Transport and Main Roads – a Queensland Government department.
Traffic/crash migration	When implementation of a countermeasure causes traffic, and resulting crashes, to move to another site.
Willingness to Pay crash cost (WTP)	A method of determining the cost of a road crash to the community based on a survey of the population's opinion of what it would be willing to pay to prevent a crash and associated injury outcome.

EXECUTIVE SUMMARY

The Queensland Camera Detected Offence Program (CDOP) covers management and operation of all modes of camera-based traffic enforcement in Queensland. Currently this includes the mobile speed camera program, the red-light camera (RLC) program and fixed speed cameras. It has been expanded over recent years to include point-to-point (PtP) cameras and combined speed and red-light cameras (RLSCs). Use of mobile speed cameras since April 2010 has also involved some use of cameras covertly which has been confined to up to 30% of deployment hours.

The broad objective of this study was to measure impacts on crash frequency, severity and social costs to the community in Queensland associated with the ongoing operation of the CDOP over the year 2017. An updated evaluation framework for the mobile speed camera component of the CDOP was developed which has provided more robust estimates of associated crash effects and directly links levels of operation of the mobile speed camera program by specific camera type to observed crash outcomes. From this, the effects of the CDOP on crash frequency and costs were able to be estimated both by police region and for Queensland as a whole.

Police-reported data for minor, serious and fatal injury crashes were available up to the end of 2017 for the analysis. Non-injury crash data has not been collected in Queensland past the end of 2010 therefore this analysis was confined to casualty crashes only. Camera installation and operations data were provided by Queensland Police Service (QPS).

Evaluation results show that the Queensland CDOP was associated with sustained crash reductions across Queensland in the year 2017 with correspondingly large economic benefits to the community accruing from its operation. Both fixed and mobile elements of the program produced significant crash reductions. Crash effects associated with RLCs, tunnel cameras, and upgrades from RLCs to combined RLSCs estimated in the evaluation were robust. In contrast, the evidence of effectiveness for some of the more recently implemented fixed camera types, including PtP cameras, fixed mid-block spot speed cameras and new intersection RLSCs, remains weaker due to insufficient post-implementation history and small number of camera installations. Further evaluation of these camera types in the future when additional cameras have been installed and a longer post-installation crash history has accumulated is likely to yield more statistically robust estimates of associated crash effects. Despite the expansion of the number of fixed cameras in use under the CDOP, the mobile camera program continues to produce around 95% of the measured benefits associated with CDOP reflecting the high proportion of the crash population it covers.

Overall crash reductions in Queensland associated with CDOP in 2017 were 12.2% for serious casualty crashes and 11.2% for all casualty crashes. It was estimated that CDOP was associated with absolute casualty crash savings of 1,594 in 2017 of which 767 were fatal or serious injury savings. Conversion of the estimated crash savings into (2017 $) cost savings estimated annual savings of around $703M in 2017 associated with the program valued using Willingness to Pay (WTP) estimates or $320M using Human Capital (HC) crash costs. About 88% of the total savings stem from savings in fatal and serious injury crashes which are the focus of the Queensland road safety strategy. By far the greatest effects for the program were estimated in the Brisbane area where many of the fixed speed camera elements are located, and the covert and portable mobile speed camera operations have the highest effectiveness. It is also where the crash density is highest consequently achieving highest coverage of the crash population.

For the first time, the study also provided valuable evidence on the mechanisms of crash reduction effects associated with the mobile speed camera program. Hours of operation of both overt and covert car-based mobile speed cameras were statistically significantly associated with all casualty crashes with no difference in association between high and low severity crashes. Relationships were estimated to differ between urban and rural areas with generally higher percentage crash reductions per hour of enforcement in rural areas compared to urban areas. Furthermore, covert car-based mobile operations were found to produce around double the crash savings per hour of

enforcement compared to overt operations although the difference between overt and covert effectiveness varied between urban and rural settings, being much more pronounced in urban areas. Associations between portable / LTI cameras and crash outcomes were only found in urban areas and only for serious casualty crashes where the level of effectiveness per hour enforced was similar to that of overt car-based operations.

Overall, evaluation of the Queensland CDOP shows it aligns closely with the goals and objectives of the Queensland road safety strategy. It aligns specifically on the key safe system pillars of safe speeds and safe people, and has proven to be an effective program with the actions achieved under the program producing measurable reductions in road trauma hence reducing the burden of road trauma on Queensland communities. Estimated overall serious casualty crash reductions associated with the program in 2017 of 12.2% of the total represent a significant proportion of the total strategy target reductions of 30-33% reduction in serious casualties by 2021 reinforcing the high value of the program in the context of the broader strategy.

Recommendations for continued evaluation of the Queensland CDOP have been made.

1. BACKGROUND AND AIMS

1.1. BACKGROUND

The Queensland Camera Detected Offence Program (CDOP) is jointly managed by Transport and Main Roads (TMR) and the Queensland Police Service (QPS). It covers management and operation of all modes of camera-based traffic enforcement in Queensland. Currently this includes mobile speed cameras, red-light cameras (RLCs), fixed spot speed cameras (FSSCs), combined red-light / speed cameras (RLSCs) and a point-to-point (PtP) speed camera system. Covert operation of the mobile speed cameras commenced in April 2010 with cameras deployed in both urban and rural areas. Road safety trailer cameras have also been added to the CDOP in recent years. These are deployed to high-risk areas including highways and motorways, roadworks sites and school zones. Unlike other mobile cameras, which are sited only for short time periods and manned during operation, the road safety trailer cameras are left on site for longer periods with operation managed and monitored remotely with daily checks.

To inform the ongoing management and development of the program, evaluations of the program have been conducted previously at regular intervals. The Monash University Accident Research Centre (MUARC) developed an initial evaluation framework for the CDOP when its only component was the mobile speed camera program (Newstead and Cameron, 2003). The framework was applied to estimate the crash and economic impacts of the mobile speed camera program from its introduction in 1997 to June 2001. A further component of the initial study was to relate mobile speed camera operational measures to estimated crash outcomes to ascertain the most important operation parameters of the program that determined effectiveness.

With the progressive introduction of other camera types under CDOP, including PtP camera systems, combined RLSCs and fixed digital cameras, TMR commissioned MUARC to develop a new evaluation framework to measure the crash and economic impacts of each of these camera types in addition to the mobile speed camera program. An evaluation framework was developed and successfully applied to evaluate the CDOP to the end of 2008 including the impact of each individual camera type as well as the combined impact of the CDOP on reducing crashes across Queensland (Newstead and Cameron, 2012). The evaluation framework also incorporated the assessment of changes in measured travel speeds in Queensland using data collected from periodic state-wide travel speed surveys as an intermediate measure of CDOP effectiveness. This evaluation framework has been reapplied periodically to provide an ongoing basis for assessment of the road safety performance of the Queensland CDOP in the years 2009-2012 (Newstead and Cameron, 2014), 2013-2015 (Newstead, Budd and Cameron, 2017) and most recently for 2016 (Newstead, Budd and Cameron, 2018).

In the most recent application of the evaluation framework to estimate CDOP road safety benefits (Newstead, Budd and Cameron, 2018) a number of difficulties in applying the framework were identified. In particular, it was noted that the existing framework was deficient in being able to assess the specific impacts of operational changes to the CDOP, particularly around site selection and scheduling of mobile speed camera operations. Operational changes to the mobile camera program included the introduction of a new scheduler in 2016, increases in deployment hours and changes in the number of sites enforced, all of which occurred around the same time. Expansion of the number of sites enforced by mobile cameras as well as changes to the way in which new sites were identified for enforcement also created challenges for the application of the existing evaluation framework. A further problem with the existing evaluation framework for the mobile camera program was that the framework considers all mobile camera sites which have been operational at any time during the program without regard to what sites are operational at what time. This has contributed to the inability to evaluate specific changes to operations at current sites. Modifications to the mobile speed camera evaluation framework for future updates of the CDOP evaluation were recommended to allow more specific consideration of the impact of changes to the mobile camera component of the CDOP. Whilst the framework has become problematic for evaluation of the mobile camera program, the existing framework has proved effective for evaluation of the other CDOP camera types. Consequently, it was recommended apparent that the required revision of the CDOP evaluation framework should focus primarily on evaluation methods for the mobile camera component of CDOP.

1.2. AIMS

The primary objective of the project was to develop a statistically reliable and valid method for the measurement of the performance of the Queensland CDOP in terms of its impact on crash frequency and severity. The framework was required to reflect the impact of broad changes to the CDOP including expansion of the number of cameras, introduction of new camera types and technologies, development of a new mobile speed camera scheduling system, increases in mobile speed camera operating hours and covert operation of the mobile cameras. Like the previous evaluation framework, the new evaluation methodology needs to evaluate FSSCs, PtP camera systems, upgrades of RLCs to combined RLSCs and installation of new combined RLSCs, as well as the introduction of road safety trailer cameras.

In particular, the framework needed to be capable of explicitly measuring the impact of operational changes to the mobile speed camera program introduced over time, including changes to the methodology for selecting sites for enforcement, increased number of cameras and sites enforced, changes in the mix of overt and covert enforcements and the introduction of a new scheduling program which has increased the level of randomisation achieved in mobile camera operations scheduling. To achieve this, the framework needed to incorporate a design for the mobile speed camera program that measured crash effects at operational sites at each time point in the program against sites not operational. A key requirement of the new evaluation framework was to allow more specific understanding of the crash impacts of the mobile speed camera program to be determined.

Once developed, a subsequent aim of the project was to apply the new framework to estimate the road safety benefits of the CDOP in 2017. Results of applying the evaluation framework will be used by TMR to report publicly on the crash effects and associated economic savings of the CDOP and to guide future policy development and analysis. Whilst the aim of the analysis was to report CDOP effects in 2017, impacts of the mobile speed camera program were to be estimated over a number of recent years in order to compare the new and old methodologies.

As per application of the previous evaluation framework, the new evaluation framework aimed to estimate crash outcomes associated with the CDOP both in aggregate and by crash severity level. Percentage crash savings were converted to absolute crash savings and subsequently into social cost savings per annum using both Willingness to Pay (WTP) and Human Capital (HC) crash costs provided by Queensland TMR. Furthermore, estimates of the effectiveness of individual program elements were brought together to arrive at aggregate effectiveness estimates both within specific police regions as well as across the whole of Queensland. This involved consideration of the crash population covered by each mode of enforcement. Further analysis of speed survey data was not an objective of this evaluation update.

2. DATA

2.1. CRASH DATA

The Data Analysis Unit within TMR supplied MUARC with crash data covering the period from January 1992 to December 2017 inclusive. Property damage only crashes were not reported beyond the end of 2010. The data covered all crashes reported to police in Queensland with each unit record in the data representing a unique crash. A total of 490,113 crash records were contained in the data; 324,019 pertained to casualty crashes. The data included the following fields pertaining to the crash:

- Unique crash identification number
- Date of occurrence
- Severity (fatal, hospitalisation, medically treated injury, other injury, no injury)
- Police region
- Statistical Local Area
- Speed limit
- Street on
- Intersecting street
- Traffic control
- DCA code (Definition for Classifying Accidents)
- Roadway feature (intersection geometry, bridge, etc.)
- Divided/undivided carriageway
- Number of lanes
- Speed related crash indicator
- Number of traffic units involved in crash
- Sector ID, activation date, urban/rural status and urban centre name for crash
- Distance from five closest mobile speed camera sites and the unique site identifiers for the five closest mobile speed camera areas of possible influence including: sites, sectors, weighting areas and zones, all of which are further defined in the next section.
- Distance from the three closest FSSC sites and the unique site identifiers for the three closest FSSC sites
- Distance from the closest combined RLSC site and the unique site identifier for the closest combined RLSC site
- Distance from the closest average speed camera site and the unique site identifier for the closest average (PtP) speed camera site
- GDA latitude and longitude for the crash
- WTP 2017 Crash cost
- HC 2017 Crash cost

In addition, for certain road segments where available, average annual daily traffic volume was provided and for some intersections where available, an intersection ID was provided.

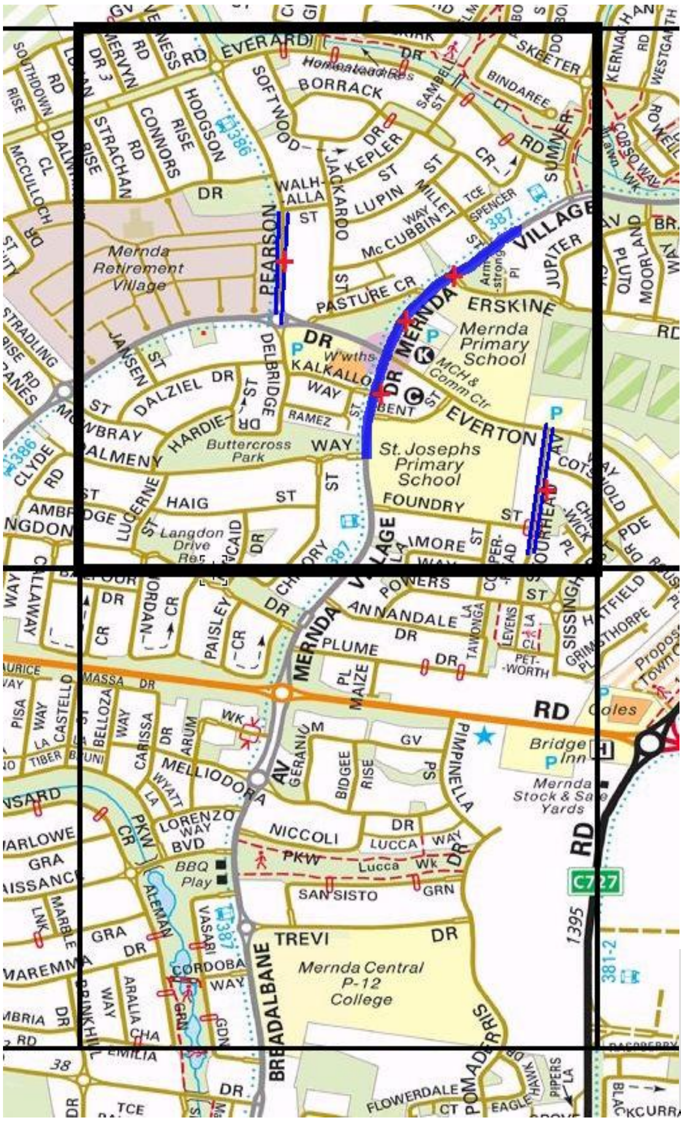
2.1.1. Mobile speed camera site selection and definition

From the commencement of the Queensland mobile speed camera program in 1997, zones for mobile camera operation were defined as a 1-kilometre (urban) or 5-kilometre (rural) diameter circle which was approved enforcement based on prior crash or speeding history or public reporting of a road safety problem. Once a zone was identified for potential mobile speed camera enforcement, Queensland Police Service would undertake an operational assessment to identify locations within the zone for mobile speed camera sites based on safe operation of the camera. They were able to pick multiple sites within the zone if necessary or reject the zone as not suitable. Previous evaluation of the mobile speed camera program in Queensland has defined the area of influence of the mobile speed camera program relative to the centre of the zone of operation.

During 2016, Queensland TMR changed to a new methodology for partitioning Queensland into areas for consideration of mobile speed camera enforcement. Previously areas for enforcement were based on circular zones which left gaps in areas of the road network considered. Transition to square sectors allowed all of Queensland to be considered for mobile camera enforcement. All areas of Queensland were divided up into nominally square sectors of 1km side length in urbanised (built up) areas and 5km side length in rural areas. The concepts of sectors, segments and sites are illustrated in Figure 1.

Each sector was assessed for enforcement and each sector included sites chosen for enforcement based on operational and safety criteria which included consideration of the frequency and severity of crashes.

As evident from Figure 1, the spatial disaggregation of Queensland for the purpose of speed camera operations siting allows multiple potential references for relating crash occurrence to speed camera operations. These include the specific camera site, the weighting area or the whole of the sector. Each of these was considered in designing the mobile speed camera evaluation framework in this study.



A sector is a rectangular (or polygon) block which may contain sites where mobile speed camera operations are carried out. To the left is a bolded block with examples of primary and secondary speed camera sites and speed camera criteria crashes (illustrative only and not from the Queensland program).

A speed camera site may be defined as a point, or a segment of road (blue line), which is called a "weighting area" in the crash data. The actual site of the scheduled operation may occur anywhere along this segment. Such a block would be defined as a treatment block in the evaluation. Under this block is another sector which has no mobile camera sites which would be used as a comparison or control site in the previous evaluation framework.

A zone is defined as a circle with a 1km radius in urban areas and a 5km radius in rural areas. The centre of the zone is the site/area centroid.

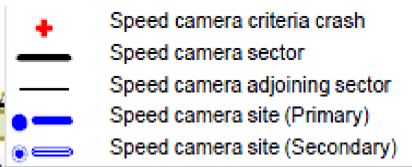


Figure 1 *The new format for the identification of mobile speed camera operations*

2.2. CAMERA DATA

2.2.1. Red-light cameras (RLCs)

The provided crash data allowed the identification of crashes within 100m of 139 RLCs. Additionally, the crashes associated with site **115** (Gold Coast Highway & Government Road, Labrador) were manually identified, using street names, as were those of camera **2** (Stafford Road, Kedron (at intersection with Gympie Road) and **255** (George Street, Rockhampton City at the intersection with Albert Street). The crash data provided placed site 115 at an incorrect location and additionally did not identify cameras 2 or 255. It was considered that due to the proximity of camera 2 to sites 67 and 68, this decommissioned camera should be included in the analysis. Camera 255 was not listed as decommissioned, and was stated to have gone live during the study period.

The 142 cameras at sites where crashes had been observed over the study period, were located at 128 unique intersections. Nine intersections had two camera sites (40/60, 43/52, 67/68[1], 153/483153, 157/158, 206/209 460/462, 110/119 & 69/500). Three cameras were sited in different points within the intersection of Kessels and Mains Roads (5, 76 &77). Four cameras were positioned at different locations at the junction of the Gateway Arterial and Old Cleveland Road in Belmont (62-65).

Ten of the cameras (each of which were at unique intersections) were upgraded to RLSCs and were analysed as both. The crash and economic effects of the RLC (prior to upgrade) and the speed camera upgrade were estimated.

In addition to the 142 RLC locations described, information was provided for a further eleven RLCs (33, 51, 81, 107, 111, 120, 127, 201, 251, 303 and 352), each at unique and different intersections. Cameras at these sites were indicated as being decommissioned during the period 1992 to 2014. Furthermore, the crash data provided did not indicate that any of these thirteen camera sites had crashes located within 100 metres of them so they were not considered further in the analysis.

All RLCs were made active prior to July 2014, so all have at least 18 months of '*after go-live*' crash data.

During the study period (1992-2017), all intersections with RLCs and associated crash data had at least one camera site at the intersection upgraded to, or installed as, a digital red-light or digital RLSC with the following exception:

- over the period September 2014 to May 2015, RLC sites (203, 301, 351, and 355) at four unique intersections were parked awaiting digital upgrade.

For all RLCs considered in the study, it was assumed that all posts and camera housing remained in place so that effective deterrence remained plausible from the '*go live*' date to the end of 2017. Cameras with less than three years of crash data prior to the '*go live*' date for the intersection, were excluded from the analysis due to issues of statistical analysis power in the evaluation. There were 63 intersections (with associated crash data) that went live prior to 1995; five of these became RLSC sites (153/483153, 154, 252, 304 and 353); three were one camera of multi-camera intersections (62-65, 153/483153 and 5/76/77). Although the crash effects at these RLC sites were not able to be estimated, provided that the site was identified in the crash data, the overall contribution of these

[1] Decommissioned RLC #2 is very near this intersection so this site was combined with the 67/68 intersection rather than used as a control intersection.

sites to road trauma outcomes in Queensland were considered by assuming the average crash effects estimates for the sites evaluated applied equally to the sites not evaluated.

2.2.2. Intersection fixed speed and red-light cameras (RLCs) and mid-block fixed speed cameras

As of December 2017, there were fifteen digital RLSCs operating in Queensland: one at each of the location numbers 2001 to 2007, 2010 to 2012 and 2015 to 2017; and two at location 2014. Nineteen additional RLSCs, at 19 intersections, went live in 2018 and 2019; ten of these intersections previously housed RLCs.

Four RLSC locations were analysed using a no-camera before period, as these locations were not upgraded from RLC sites (2002, 2015, 2016 and 2017). Three of these have less than one year of operating period as at the end of December 2017.

The RLSCs at the other ten locations were installed at sites previously enforced by RLCs, so were analysed as upgrades with the 'before' period being where the RLC was operational. The RLCs for these locations were evaluated with the before implementation period being where there was no camera operational at the sites and the post-implementation period being where the RLC was operational but before installation of the RLSC periods. As previously stated, five of these ten: 2005, 2006, 2007, 2010 and 2011; had no period prior to RLCs, so for these five, no red-light only camera evaluations were made.

As with RLCs, the overall contribution of all RLSC sites to road trauma outcomes in Queensland were considered by assuming the average crash effects estimates for the sites evaluated applied equally to the sites not evaluated. Although, where analysis allowed, all RLSC sites active during the crash data period were analysed.

There were nine analogue FSSC (one per site) made active prior to 2012. Two of these were decommissioned during the observation period. However, on the assumption that the housing structure and signage have remained in place, they were assumed to continue to remain an effective deterrent and as such the post-activation observation periods for these two cameras were considered to continue to the end of 2017.

There were more than 40 fixed spot digital speed cameras at a minimum 16 locations that were activated prior to December 2017:

- Five, on the PtP section of the Bruce Hwy, (three at one end, two at the other end - these still operate as FSSC when the PtP system is down)
- Unknown number and locations on the PtP section of the Mt Lindesay Highway, South Maclean (this system was decommissioned in 2019 due to the installation of a set of traffic lights within the system and other upgrades to the highway)
- Ten in the Airport-Link Tunnel (at four locations)
- Six in the Legacy Way Tunnel (at two locations)
- Eight in the Clem 7 tunnel (at four locations)
- Four at location number 1002 (with one in each of four lanes)
- Five at location 1012 (with one in each of five lanes)
- One at location 1011 (Nambour) and
- One at location number 1001 (Nudgee)

The active average speed PtP camera system, operating on a segment of the Bruce Highway between Landsborough and the Glass House Mountains, began operation five months after the FSSCs operating at each end of the average speed camera system on this road section went live.

The currently decommissioned average PtP camera system on the Mount Lindesay Highway at Maclean was operational between 21 July 2017 and 6 March 2019. The five months of operations in the crash data period permitted inclusion in this analysis.

A summary of fixed speed camera sites available for evaluation is presented in Section 8.2 of the Appendix. From this it may be seen that there was insufficient post-period crash data to analyse the Legacy Way Tunnel cameras, so these cameras were excluded from the analysis. The next shortest post-activation observation periods are for RLSCs.

The pre-activation period for all fixed spot, average and RLSCs exceeded the suggested three year minimum period for minimisation of regression to the mean effects by providing an accurate base estimate of the underlying crash rates at each camera site. It is not known whether this period is coincident with the time period used to identify each site as a candidate for enforcement. However, using a long pre-installation evaluation time period maximises the chance that this time period is not fully coincident with the selection period hence further minimising regression to the mean prospects.

The post-activation period of crash data has made it possible to consider analysis of digital fixed spot speed and RLC effects disaggregated by police region. Disaggregated by severity and region, low crash counts and the relatively few cameras, each with very specific halos of influence, meant that statistical power was insufficient to draw conclusions with statistical significance from this analysis. However, over all regions for all combined fixed cameras (and also individually for some specific camera types), strongly significant injury crash reductions were estimated. Hence overall estimates of average camera effectiveness were the focus of the analysis.

2.2.3. Mobile cameras

Data on the hours and locations of mobile camera operations were provided by QPS with the locations subsequently matched to crash data to determine the spatial distribution of crashes in relation to camera locations.

Data were also aggregated into tables summarising the hours of deployment per month (or quarter), deployment type, sector, camera type (vehicle mounted, tripod mounted or hand held) and covert/overt status.

Vehicle mounted cameras consisted of digital, analogue or wet film deployment types and operations could be covert or overt. A small percentage of digital mobile speed camera operations were classed as other or ‘N/A’, these were considered ‘overt’ for the purposes of this analysis.

Portable mobile speed cameras were either tripod mounted or hand held. Tripod mounted portable operations were listed in the data as unknown, and were considered overt for the purposes of this analysis. Hand held mobile speed cameras were classified as covert, overt and unknown. Hand held operations were tabled in two categories: those specifically identified as covert, and the remainder.

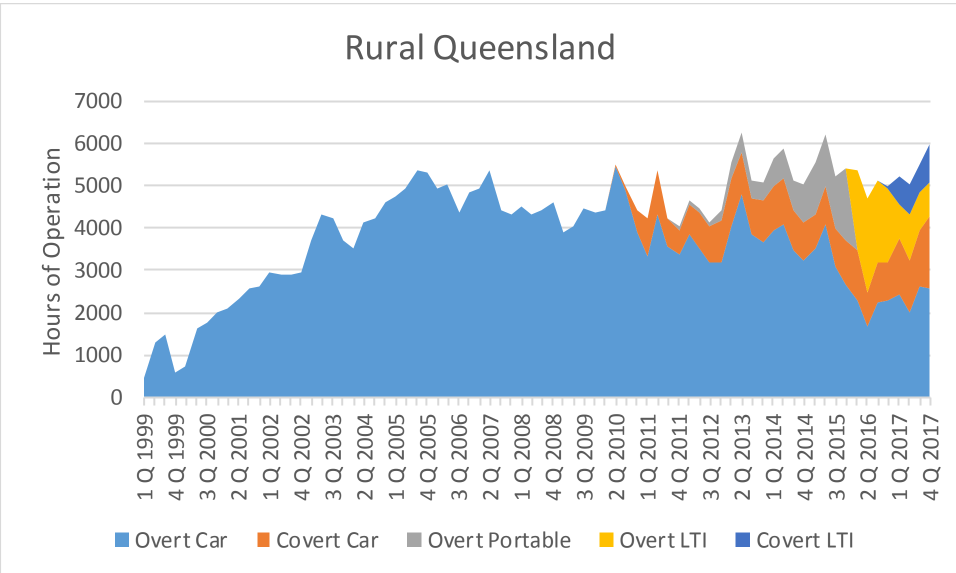
In specific circumstances, such as during school holidays and during road works, mobile speed cameras mounted to trailers are employed. The data for these operations was provided separately (with the fixed camera data) and were identified using site (not sector) and commencement of operation. Sectors were found to be associated with these site identification numbers (using crash and operation data). Where a site passed through more than one sector, the trailer operation was considered to be within all of the associated sectors. Trailer operation commencements were similarly tabled by month. It was assumed that the operation did not carry through to the month following the commencement date.

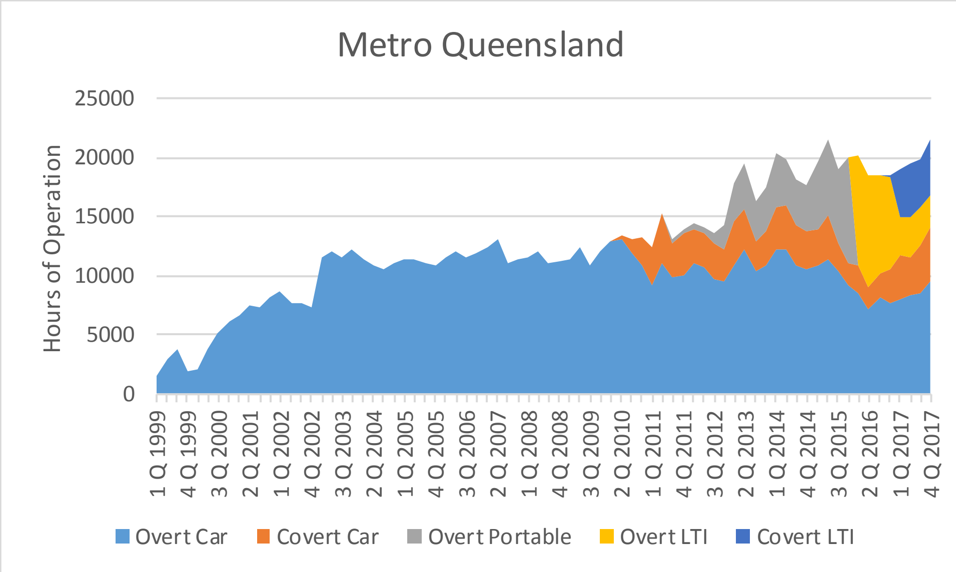
The crash data modal police region and modal urbanisation (urban or rural) for a sector were added to each operations table.

Notable features of mobile camera deployment included:

- Deployment hours increases in January and July 2013 and July 2014 (see Figure 2)
- A reduction in the enforcement thresholds staggered by speed zone over the period July 2013 to June 2014
- A steady increase in the use of portable speed cameras with a trial of the Poliscan system in the second half of 2014 (see Figure 2)
- Removal of the requirement for signage of mobile speed cameras in July 2015
- New Scheduler in May 2016.

Figure 2 shows the number of hours of mobile speed camera operations per quarter year by mobile camera type and overt/covert nature for the whole of Queensland as well as broken down by urban and rural areas. Prior to April 2010, operations were only car mounted of the overt type. It shows the increase in camera hours over 2013-2014, rising from around 18,000 to 24,000 total hours of operation per quarter, as well as the introduction of both covert camera operations and the commencement and growth of use of the portable speed cameras. Operation patterns are similar between urban and rural areas. Portables cameras were relabelled LTI in 2016. Although a proportion of the LTI operations were labelled as being covert, the nature of LTI and portable camera operations suggests they are all likely to be relatively overt in nature, being hand operated at the roadside. As such, all portable and LTI operations have been combined for consideration in the analysis and assumed to be overt. Car-based operations have been considered separately based on overt and covert operation.





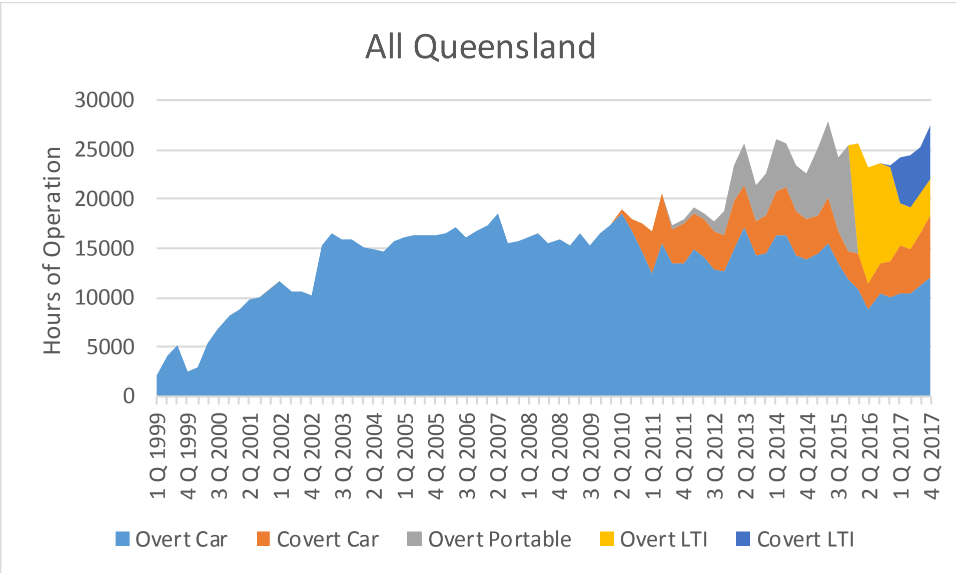


Figure 2 *Quarterly mobile speed camera hours by mobile camera type and operation nature: urban and rural areas and all of Queensland*

2.3. CRASH COSTS

Human Capital and Willingness to Pay crash costs for use in the economic evaluation were provided by TMR with the crash data (Table 1). The post-activation camera crash distribution by severity and police region (and speed category) was used to weight fatal, hospital, medically treated, other injury and no injury costs to produce serious injury (fatal + hospital) and minor injury (minor injury + medical treatment) unit costs (Table 2 and Table 3).

Table 1 2017 Willingness to Pay (WTP) and Human Crash (HC) Unit Costs by severity

	WTP	HC
Property Damage Only	$9,960	$12,833
Minor Injury	$41,708	$18,959
Medical Treatment	$127,778	$18,959
Hospitalisation	$645,276	$343,074
Fatal	$9,249,738	$3,443,635

Table 2 2017 WTP Crash costs by severity and police region according to the distribution of Fixed camera crashes

		Serious Casualty Crashes	Minor Injury	All Casualty Crashes
Brisbane		$803,884	$108,024	$342,499
Central	Urban	$894,681	$106,418	$370,447
	Rural	$973,065	$109,144	$558,212
Northern	Urban	$836,790	$111,297	$396,640
South Eastern	Urban	$809,171	$109,521	$308,608
	Rural	$845,380	$111,260	$333,564
Southern	Urban	$836,790	$111,765	$404,137
	Rural	$941,982	$118,556	$537,492

Table 3 2017 HC Crash costs by severity and police region according to the distribution of Fixed camera crashes

		Serious Casualty Crashes	Minor Injury	Casualty Crashes
Brisbane		$400,227	$18,959	$147,430
Central	Urban	$432,945	$18,959	$157,624
	Rural	$461,191	$18,959	$248,832
Northern	Urban	$412,085	$18,959	$174,996
South Eastern	Urban	$402,132	$18,959	$127,992
	Rural	$415,180	$18,959	$138,941
Southern	Urban	$412,085	$18,959	$179,379
	Rural	$449,990	$18,959	$238,255

Average fatal and hospitalisation (serious casualty) crash costs in Table 3 and 4 vary a relatively large amount between police regions due to the different mix of fatal and hospitalisation crashes in each region; the rural Central region had a higher rate of fatal crashes per hospitalisation crash. As there were no fatal crashes in a three-year post-camera period at the camera sites in Southern and Northern urban regions, the average ratio of fatal to serious crashes was used in weighting the costs of serious injury crashes in these regions.

3. LITERATURE REVIEW AND NEW EVALUATION FRAMEWORK DEVELOPMENT

A literature review had previously been conducted to inform the development of the previous evaluation design used for the Queensland speed camera program (Newstead and Cameron, 2012). Covered in the previous review were both evaluation designs suitable for evaluation of the CDOP as well as statistical methods and data requirements to support the various designs. A primary objective of the current study was to conduct further review of the literature to establish whether more recent evidence for road safety program evaluations, or evaluations from the broader public health domain, have developed any new methodologies that might be applied to the evaluation of the CDOP. A key objective of the review was to identify potential alternative evaluation designs that would overcome the deficiencies identified in applying the previous CDOP evaluation design. Specifically, the design is required to be able to estimate the differential trauma impacts of different mobile camera type use at different levels, in particular the covert use of mobile speed cameras in Queensland.

In developing the previous evaluation framework for the Camera Detected Offence Program (CDOP), a comprehensive literature review was undertaken covering the period to the end of 2008. This literature review was updated to include published works over the last ten years both specific to evaluation of automated traffic enforcement as well as relating to the evaluation of road safety or public health programs more generally. Specific focus was given to the literature which describes the evaluation of programs with localised effects in both space and time given this is the established influence of the Queensland mobile camera program.

The following international road safety research, transport and road links websites and research databases were searched:

- Google search engine – www.google.com
- Transportation Research Board (TRB or TRIS)
- Australian Transport Index (ATRI)
- Transport
- ScienceDirect
- PsychInfo
- MUARC reports and research papers – www.monash.edu/muarc
- Australian Transport Safety Bureau (ATSB) – www.atsb.gov.au
- Australian Transport Commission (ATC) – www.ntc.gov.au
- Bureau of Infrastructure – www.bitre.gov.au
- Main Roads Western Australia – www.mainroads.wa.gov.au
- Austroads – www.austroads.com.au
- Transport and Main Roads – www.transport.qld.gov.au
- Roads and Traffic Authority NSW – www.rta.nsw.gov.au
- Ministry of Transport NSW – www.transport.nsw.gov.au
- Office of the Auditor General NZ – www.oag.govt.nz/reports/by-sector/transport/
- NZ Transport Agency – www.nzta.govt.nz/index.html
- Insurance Institute for Highway Safety (IIHS) US – www.iihs.org
- Federal Highway Administration (FHWA) US – www.fhwa.dot.gov
- National Highway Traffic Safety Administration (NHTSA) US – www.nhtsa.gov
- Transport Canada – www.tc.gc.ca/en/menu.htm
- Transportation Research Laboratory (TRL Crowthorne) England – www.trl.co.uk

- Royal Society for the Prevention of Accidents (RoSPA) UK – www.rospa.com/index.htm
- Swedish Road Administration (SRA) Sweden – www.vv.se
- Institute for Road Safety Research (SWOV) Netherlands – www.swov.nl/index_uk.htm
- European Road Safety Observatory – www.erso.eu
- The French National Institute for Transport and Safety Research – www.inrets.fr

The literature review focused on the following areas:

- Evaluation designs for road safety or other injury prevention / public health programs with localised effects in time and/or space.
- Evaluation designs for road safety or other injury prevention / public health programs with general (or dispersed) effects in time and/or space.
- Statistical analysis methods that could be applied to the key evaluation designs identified.

Key search terms and combinations were applied to identify applicable research designs in three relevant areas: road safety program evaluations; general public health program evaluations; and general research methods.

Road safety program evaluations including RLSC, RLC and black spot treatments

The following search term combinations were used:

Speed camera AND evaluat*
Speed camera AND evaluat* AND framework
Black spot AND (program OR treat*) AND evaluat*
Red light AND camera AND evaluat*
Red light AND camera AND evaluat* AND framework
Case cross-over AND road safety AND (evaluat* OR design or framework)
Case cross-over AND speed camera AND (evaluat* OR design or framework)

General public health program evaluations

Public health AND program AND evaluat*
Public health AND program AND evaluat* AND (method* OR framework)

General research methods

Program AND evaluat* AND research AND (method* OR framework)
Multi-site AND program AND evaluat* AND (method* OR framework)
Case cross-over AND (evaluat* OR design or framework)

3.1. EVALUATION DESIGNS FOR ROAD SAFETY OR OTHER INJURY PREVENTION / PUBLIC HEALTH PROGRAMS WITH LOCALISED EFFECTS IN TIME AND/OR SPACE

3.1.1. Randomised control trials

The randomised control trial allocates groups – typically crash sites or persons – randomly to treatment or control entities. This design is considered the gold standard approach because it eliminates any potential problems with selection bias, in particular regression-to-the-mean, and generally results in comparisons between treatment and control entities that are well balanced on all factors aside from the countermeasure being studied. Despite its inherent strengths, the randomised control design is typically not achievable for road safety countermeasure implementation. The main reason for this is because crash sites are typically treated on the basis of their crash history and so allocating a site with a defined crash problem to the control arm is generally not feasible from either a financial or political standpoint.

For these reasons, fully randomised designs are rarely observed in the implementation of road safety programs and, not surprisingly, no such designs were identified in the literature for road safety countermeasure implementation. It is clear that the Queensland speed camera program has not been implemented according to the requirements of a randomised control trial and hence this evaluation framework is not applicable for the evaluation framework being developed.

Alternative designs compromising at least some of the benefits of the fully randomised trial have been developed. Two alternative study designs are often used. Both evaluate programs with localised effects where the local areas have been chosen not randomly but on some other basis, such as a history of a high crash frequency or rate.

3.1.2. The simple before – after comparison

The first of these alternatives simply compares crash rates before implementation of a countermeasure to those after and evaluates effectiveness by the difference in these. A number of published studies on speed camera effectiveness have used simple before–after comparisons to estimate crash and/or speed changes attributable to the cameras. A number of examples of studies using this design have been published in the road safety arena (Datta 1988, BTCE 1993, Frith 2013, Lahrmann 2016). One implicit assumption made when using this design is that the treatment being evaluated is the only factor affecting the number of crashes during the evaluation period at the treated site. This assumption could be questioned if factors other than the treatment being studied also affect crash numbers in the same local area and are changing concurrently with the treatment. Other such factors may include other road safety programs or socio-economic factors affecting travel or risk-taking behaviours.

A variation on the simple before-after comparison is to adjust the comparison explicitly for the effects of known confounders. Adjustment of the before–after comparison for the effect of confounding factors is generally only possible when analysing data as a time series where a time series measure of the confounding factor is then included as a covariate in the time series model. A more general formulation of the adjusted simple model includes long term trend and seasonality measures in the model to generally represent the confounding factors. The latter approach is useful when measures of the confounding factors may not be available, but has the difficulty that the representation of the trend and seasonal components must be sufficiently complex to accurately represent the underlying trends in the data driven by the influence of the confounding factors.

A more complex adjusted before–after comparison approach has also been utilised for speed camera evaluation. An evaluation of camera effectiveness in British Columbia, Canada (Chen, Wilson et al. 2000) used an uncontrolled interrupted time series model controlling for long term trends and seasonality but no other specific covariates. Allsop (Allsop 2010) examined the effectiveness of fixed and mobile speed cameras on crashes across Great Britain using an uncontrolled before-after study. The total numbers of injury crashes on all urban and all rural roads in Great Britain were used in a preliminary analysis to estimate trends and variation in these numbers as a basis for allowing for sources of variation in the main analysis of data from the camera sites. Such sources include, for example, the effect of trends in the amount of traffic and in the levels of reporting of collisions. Log-linear models were used to estimate for each camera site the numbers of injury crashes that would have been expected if collisions and casualties had continued to occur at the rates per year prevailing in the baseline period, subject only to the trends and seasonal variations (i.e., traffic volume, levels of reporting of collisions) estimated in the preliminary analysis. Application of this methodology required access to relevant traffic volume data and made the critical assumption that expected trends were only driven by traffic volume. This key assumption would be invalidated if other major road safety programs or socio-economic factors were influencing trauma levels at the treated sites.

Other examples of the time-series design similar to that used by Allsop include a study by Vanlaar, Robertson and Marcoux (Vanlaar 2014) to examine crashes relating to speeding and red-light running at intersections in Winnipeg, Canada and a study by Shin, Washington and van Schalkwyk (Shin 2009) to examine crashes associated with the introduction of a fixed speed camera in Arizona, US.

3.1.3. The quasi–experiment

The second non-randomised design used is commonly referred to as a quasi-experimental design. It is similar to the simple before-after comparison but differs in that it incorporates a control group or area (sometimes referred to as a comparison group or area). The quasi-experiment compares the crash rates before and after program implementation (the 'treatment') in the 'treated group or area' to the before and after crash rates in the control area. The measure of treatment effectiveness is the relative change between treatment and control area from before to after treatment implementation. As the name suggests, it has many similarities to the fully randomised experimental design, albeit without the randomisation of the localised areas to treatment or control groups. Richardson et al (1987) is an example of a typical study using the classic quasi-experimental design for the evaluation of treatment crash effects.

As in the fully randomised controlled trial, the purpose of the control group in the quasi-experiment is to represent the effects of factors other than the treatment being evaluated on observed crash history in the treatment area. It assumes that the effects of all other factors besides the treatment being evaluated act equally on both treatment and control areas and affect crash outcomes at both in the same way. The control area is assumed to be unaffected by the treatment being evaluated. Comparing relative change in crash outcome between the treatment and control groups from before to after treatment implementation allows an unbiased net crash effect of the treatment being evaluated to be estimated.

Using a control group in the quasi-experiment to provide an implicit measure of the effects of other non-treatment factors at the treatment site has a number of advantages. It is the only viable alternative if there is no measure of the non-treatment factors available, either because the other factors are difficult to measure or data on the factor are not readily available. It also negates the need to know or assume a relationship between the measures of the other factor and crash outcome. It is a particularly useful approach when the measure of the other factor is a simple intervention term that is coincident or close to coincident with the introduction of the program being evaluated. In this case, the high degree of co-linearity between the intervention of the other factor and the program being evaluated prevents techniques such as covariate analysis in a simple before to after study design from being utilised.

Many of the published speed camera evaluations have been based on quasi-experimental study designs. Along with the previous evaluations of the Queensland speed camera program (Newstead and Cameron 2003), other evaluations that have employed quasi-experimental designs include the fixed camera program in New South Wales (ARRB 2005), evaluations of mobile speed cameras in the UK (Christie, Lyons et al. 2003), the Netherlands (Goldenbeld and Shagen 2005) and New Zealand (Tay 2000).

More recent examples of published studies using the quasi-experimental design include evaluations of fixed speed cameras in Israel (Bar-Gera 2017), Belgium (De Pauw 2014), Columbia (Martinez-Ruiz 2019), the United States (Shin 2009, Hu 2016), and evaluations of PtP speed cameras in the UK (Owen 2016) and mobile speed cameras in the US (Moon 2010). The quasi-experimental design has also been employed for black spot treatment evaluations in Victoria (Cairney 2015) and Western Australia (Chow 2017) and for evaluations of red-light running cameras in the US (McCartt 2014).

Quasi-experiments have been employed outside of the road safety domain, for example in the study of the effectiveness of hygiene compliance strategies (Creedon 2005) as a stronger alternative to the observational studies typically used in this area where randomised controlled trials were not possible.

3.1.4. The adjusted quasi–experiment

The evaluation of the initial stages of the introduction during 1990 and 1991 of the covert mobile speed camera program in Victoria used a quasi-experimental design in which corresponding areas of NSW (Sydney and rural NSW) were used as controls (Cameron, Cavallo and Gilbert 1992). Unemployment rates in each area and State were used as covariates in time series models of monthly casualty crashes during “low alcohol hours” to take into account the confounding influence of changes in economic conditions during 1984-1991. The apparent impact in each introduction stage in Victoria, after adjusting for trends in unemployment rates, was netted for the “impact” in corresponding months in NSW following calculation in the same way using NSW unemployment rates for the corresponding area type. Thus, the method was a quasi-experiment in which a measured influential factor supplemented the use of a control area in taking into account the effect of factors other than the treatment.

Another study design which has been recently demonstrated is the evaluation of the Western Australian mobile speed camera program (Newstead, Diamantopoulou et al. 2015). This study uses what is fundamentally a quasi-experimental design based on time series data analysis, but adds individual adjustment of the treatment and control area time series crash data for confounding factors that may not be necessarily similar between the two areas. Motivation for using this design in the WA study was dictated by the implementation of the mobile speed camera program in that jurisdiction. Deployment of speed cameras in WA achieved such a high geographical coverage that there were no unenforced areas available to utilise as controls in the design. Analysis of camera deployment data showed enforcement to be confined to daytime hours leaving the night hours as a potential control. Since exposure and socio-demographic and economic effects were suspected to impact night time crashes differently to those in the day time, a number of measures were included as covariates in the analysis models, including population, unemployment, vehicle travel and alcohol sales. The models were specified to allow differential relationships of these factors with crash trends between treatment and control times, hence standardising the treatment and control series to be compatible in the quasi-experiment.

Another interesting feature of the WA mobile speed camera study was that, rather than including dummy variables to represent the differing impact of the introduction of the mobile speed camera program overt time, measures of program delivery were include as covariates in the models to ascertain the relationship between level of program operation (in this case hours enforced per month) and monthly crash effects attributable to the program. Once this relationship was established. It could be used to derive program effects within a period based on the level of program delivery. The approach was also strategically valuable in facilitating strategic analysis estimating potential benefits of further expanding the program. Models were separately estimated for crashes in urban and rural areas with significantly different relationship between program delivery and trauma outcomes established between the two areas.

3.1.5. The Empirical Bayes approach

A further study design different to those previously described sitting somewhere between the quasi-experimental and simple before-after comparisons is that stemming from the use of the Empirical-Bayes method of statistical analysis (Hauer 1990). This class of technique was originally proposed by Abbess et al(1981) and was further developed by Jarrett et al (1988) and Wright et al (1988). Mountain also expands on this method (Mountain and Fawaz 1991, Mountain and Fawaz 1992, Mountain, Fawaz et al. 1992, Mountain, Fawaz et al. 1992) as does Pendleton (the 'EBEST' method) (Morris, Christiansen et al. 1991, Pendleton 1991, Pendleton 1992) and Brude and Larsson (Brude and Larsson 1988). Use of Empirical Bayes methods for adjusting for RTM are incorporated as part of a complete analysis strategy for evaluating road safety countermeasure crash effects based on this technique. A summary of the Empirical Bayes methods for crash black spot evaluation is given in Hauer (1997).

Extensive development and discussion of the Empirical-Bayes analysis method has also been made by Hauer and colleagues including extension of the technique to handle over-dispersion in the crash counts (Hauer 1980, Hauer, Byer et al. 1983, Hauer and Persaud 1984, Hauer and Lovell 1986, Hauer 1990, Hauer 1997, Hauer 2001). This method of analysis requires the use of all possible sites from which the set of treated sites were drawn standardised in some appropriate way, for example by traffic volumes. The non-treated sites in the full set of available sites, however, are not strictly used as controls but rather to define the full crash frequency distribution against which to assess the treated sites; firstly, to compute the post-treatment expected values, and secondly to assess likely RTM effects.

One of the key assumptions in using the Empirical Bayes method is that the underlying crash rate at each site in the before and after period is either constant over time or can be estimated using available traffic volume and other suitable exposure data. The assumption of constant crash rates is often not likely to be true, particularly in jurisdictions with a history of population growth and hence exposure change or of sustained road safety effort. If an underlying trend is present in the mean crash frequency, this is likely to be confounded in RTM effect estimates when based on only a single data point before and after treatment. Apparently, no work has been carried out in testing the sensitivity of this method to this key assumption.

A key difficulty in applying the Empirical-Bayes method is standardising the population of sites used in the study. This typically requires some form of suitable exposure data such as traffic volumes or total travel which are quite often not available, particularly on a site by site basis as required by the methodology. This problem has been noted by the Australian Bureau of Transport Economics in rejecting the Empirical-Bayes analysis method for use in evaluating the Australian national black spot program (BTE 2001). Generally, the lack of available suitable traffic volume data or other relevant exposure methods on a wide enough basis to adequately define the reference group for use in the Empirical Bayes method precludes its use in a number of studies. Where exposure data is available for standardising the crash site population, the Empirical Bayes methods have been applied successfully.

A further problem with this method making it problematic for general treatment effect estimation is its inability to specifically incorporate control group information aside from its use in the reference population. Furthermore, specification of the reference population is often not clear. These problems are highlighted in the various applications of these methods (Hauer 1980, Hauer, Byer et al. 1983, Hauer and Persaud 1984, Hauer and Lovell 1986, Danielsson 1988). A final problem with the Empirical Bayes method is its relative inflexibility to testing specific evaluation hypotheses, such as the equivalence of treatment effect across a range of sites with the same treatment. These difficulties apparently have not been successfully overcome. Related to this is the inability to correlate different program operation levels with trauma outcomes as demonstrated in the adjusted quasi-experiment used for the Western Australian speed camera evaluation.

A number of the reported evaluations of speed camera effectiveness have used the Empirical Bayes analysis methodology (Elvik 1997, Chen, Wilson et al. 2002, Mountain, Hirst et al. 2004). Two of these studies have described evaluation of fixed conspicuous camera programs which are closest in design to the traditional black spot studies to which the Empirical Bayes methodology is typically applied, whilst the third evaluated a mobile covert camera program on a single length of road.

More recent examples of studies employing the Empirical Bayes analysis methodology include black spot evaluations in Belgium (De Pauw 2014), fixed speed camera evaluations in Belgium (De Pauw 2014) and the US (Shin 2009), PtP speed camera evaluations in Italy (Montella 2012) and red-light running camera evaluations in the US (Ko 2017). Whilst it is evident that a number of studies have successfully employed the Empirical Bayes methodology, it is certainly less commonly used than other methods perhaps highlighting the difficulty of applying the approach in these more complex evaluation settings or the lack of required data to adequately support analysis.

3.1.6. The case cross-over approach

The case cross-over design is a relatively new analytical technique in which each case serves as its own control. The simplest case cross-over design is similar to the case control design (and to the quasi-experimental design) in which each case has a matched control. The key difference between the two is that in a traditional matched case-control study, the control is a different site at a similar time whereas in the case cross-over study, the control is the same site at a different time.

The case cross-over design was originally developed in 1988 to study risk factors associated with the onset of myocardial infarction (Mittleman 1993). Since then it has also been used within the road safety context to study crash risk associated with mobile phone use and driving (Redelmeier 1997) and more recently to study crash risk associated with drug use and driving (Asbridge 2014) and fatigue and driving (Valent 2010).

The main advantage of the case cross-over design over the case control design is that it eliminates confounding associated with differences in stable features (both measured and unmeasured) that differ between entities or persons (Maclure 2000). Another advantage of the case cross-over design over the case control design is that it eliminates time and costs associated with identifying and measuring data from separately matched control groups (Lombardi 2016).

The advantages of the case cross-over design make it particularly suitable for examining the effect of speed cameras on crashes and/or speeding. First, it can be difficult to find control sites that adequately match the treatment sites in terms of key factors including traffic volumes, crash numbers etc. Second, in some areas where speed cameras are commonly employed, there are no or very few suitable control sites available because most sites have already been treated. For example, in a quasi-experimental study of 176 motorcycle black spot treatments in Victoria (Cairney 2015) there was difficulty identifying suitably matched control sites because the majority of the popular motorcycling routes in the area had already been included as treatment sites. Therefore, a limitation of this study was the inclusion of control sites that had a disproportionately higher number of crashes than the treatment sites.

The case cross-over design has rarely been applied to examine the effect of speed cameras on crashes and/or speeding. A notable exception is a study in the UK (Tang 2017) that used future to-be-treated sites as controls for sites that were treated now. This design is similar to the case cross-over design in that the same site is at one time used as control site and at a later time used as a treatment site. The benefit of using a site as a control that will later be used as a treatment site is that it reduces any differences in the two sites contributing to crashes that may be attributable to factors other than the camera. This is important in quasi-experimental designs because sites that are treated are typically more prone to collisions than control sites and this is likely to accentuate the difference in sites with and without cameras. As such, the case cross-over design reduces any differences between control and treatment sites that may otherwise incorrectly have been attributed to the effect of the speed camera rather than to factors associated with the site itself.

The case cross-over design has also been used applied to quasi-experimental designs outside of the road safety domain. An example is in the evaluation of the effectiveness of gun control legislation in Victoria in reducing gun related deaths (Ozanne-Smith, Ashby et al. 2004). Here the rest of Australia was used as a control for comparing the effectiveness of the legislation in Victoria. The design was then reversed when legislation was introduced in the rest of Australia at a later time, leaving Victoria as the control area.

It is important when planning a case cross-over study to select control periods that are sufficiently distant in time from the treatment period to minimise their correlation. Otherwise concordance is likely to lead to reduced statistical power and an increased potential of a Type 2 error (Lombardi 2016). In the Tang study (Tang 2017), the installation of speed cameras at control sites that were treated later occurred less than six years apart from the sites that were treated now. This was based on a concern that sites treated further apart in time could be more dissimilar than sites treated more closely together in time.

A further issue identified with the case-crossover study design is that factors that change over time, such as changes in enforcement patterns are not controlled for (Redelmeier 2003, Walter 2015). The case-case-time-control study design is an extension of the case-crossover study design, which enables changes in trends over time to be controlled for. This is achieved by the inclusion of a comparison group, like that used in the quasi-experiment, where time-based differences in exposure-based risk are accommodated in the case-crossover design through the inclusion of a comparison group which measures the difference in risk between the two times used in the case crossover analysis set. Instead of representing the impact of all other factors as in the quasi-experiment, the comparison group in the case-case crossover is limited to representing time-based changes in risk at the treated sites.

3.2. STATISTICAL METHODS APPLIED TO EVALUATION FRAMEWORKS

Statistical methods relevant to the evaluation designs reviewed fall into three broad classes. In general, the statistical methodology suitable for analysis of crash data is more closely linked to the distribution in the random variation in the crash data. Various studies have attempted to quantify the most suitable distribution to describe road crash data. Large bodies of research have identified crash or injury count distributions as generally falling onto one of the two common count distributions, namely the Poisson or negative binomial distributions (Nicholson 1985, Nicholson 1986, Nicholson 1986, Senn and Collie 1988). These distributions are most commonly applied to the before-after and quasi experimental studies identified in the previous section.

For some before-after studies utilising more traditional ARIMA type time intervention series analysis (Henstridge, Homel et al. 1997), normal distribution of crash counts has been assumed but this is more likely as a result of the limitations in available distributions in the analysis methodology rather than reflecting the true distribution of the outcome data. More modern state space time series models allow a greater choice of outcome distributions although normal distributions are still often chosen (Harvey and Durbin 1986 , Harvey 1989).

The most common statistical methodology applied to before-after or quasi-experimental evaluation design is the Generalised Linear Model (GLM). This allows the analysis of data classified into categorical contingency table format and includes the ability to reflect the most likely distributions in the crash count data (Poisson or Negative Binomial). In some instances where the data are represented as time series, a Generalised Estimating Equation (GEE) approach, which is a further extension of the GLM, has been used to accommodate the likely intercorrelation between multiple measurements of crash counts at the same site in the time series data. A parsimonious approach to deciding on the most appropriate model to employ amongst the available GLM / GEE alternative is to start with most general form and then test for the efficacy of using different intercorrelation structure, or Poisson versus Negative Binomial error structures through comparing model likelihoods or information measures such as QIC and QICC.

In some instances, intervention time series analysis is applied to the before-after study design and the quasi-experiment. As described, this is sometimes implemented using the GEE approach. However, traditional ARIMA time series methods have been employed in the past (Drummond, Sullivan et al. 1992), whilst more recently, state space time series models have been used (Harvey and Durbin 1986). State space methods have an advantage over the more traditional ARIMA approach of being easier to formulate to meet key assumptions as well as better accommodating the use of covariates in the analysis where the evaluation framework requires. A further example of an extension to the GLM/GEE approach for time series analysis is the quasi-Poisson regression method (Novoa, Pérez et al. 2010). Of the established methods for time series data analysis, the GEE method seems to be the most versatile in reflecting intercorrelation between repeated measures as well as accommodating a range of error distributions. State space time series modelling seems to represent the next most viable method albeit for evaluation designs which are not too complex (e.g. highly stratified).

The Empirical Bayes methods also generally assume crash data follows Poisson or Negative Binomial crash distributions although many studies of program effects across multiple sites also require an additional assumption about the inter site variability distribution. Gamma distributions are often utilised for this component (Mountain and Fawaz 1991, Mountain, Fawaz et al. 1992). Specific statistical methodology has been developed for application of the Empirical Bayes methodology which requires either specialist software or high-level programming in more general statistical software. This, combined with the more rigorous data requirements to apply the method, often limit its accessibility in application.

3.3. ASSESSMENT OF CANDIDATE METHODS FOR THE CDOP EVALUATION FRAMEWORK

The previous evaluation framework for the Queensland CDOP utilised a quasi-experiment. Treatment areas were defined as those within a 1km (urban) or 5km (rural) from the centroid of zones where a speed camera site had existed. Comparison sites were chosen as areas outside the treatment areas. In order to match more closely treatment and control areas, the analysis was stratified by police region and urbanisation as location (urban / rural). Data were prepared as a monthly time series count of crashes by severity level within each stratum and treatment and control pair. Analysis focused on assessing differences in the post-implementation time trends between treatment and control areas within each stratum as a measure of the effectiveness of the program.

As noted, the previous evaluation framework had a number of operational limitations that were unable to answer key questions about the effectiveness if the program. These included;

- Geographical confusion about the area of influence of the mobile cameras resulting from the extensive overlap of the halos from each camera leading to potential multiple sources of influence on each crash
- Relating crashes to approved camera sites across Queensland from the commencement of the program regardless of when those camera sites were actually enforced
- No adequate means to relate operation inputs to the program, including hours of enforcement by specific camera types and modes of operation, to trauma outcomes. Some analyses had attempted to make these associations post-hoc with limited success and resolution.

Furthermore, there were some questions about how well the comparison group of crashes in the previous design represented the general trends in road trauma due to factors other than the mobile camera program. However, the apparent deficiencies in the comparison group may be more a reflection of the other inadequacies in the design such as how the control was compared to the treatment data series in the analysis framework. For example, representation of trends in the control crash series in the previous evaluation was relatively crude, necessary due to the simple intervention style representation of the mobile camera program treatment effects.

In designing the new evaluation framework, a number of specific features were required of the framework reflecting the current way in which the mobile speed camera program in Queensland is operated and the available data on those operations. Key features of the program and available data that dictated the evaluation framework were:

- For enforcement, Queensland has been partitioned into sectors for consideration of speed camera enforcement as illustrated in Figure 1. Each sector is a discrete area that can be considered for analysis. Within each sector there are a number of sites and road lengths chosen for enforcement.
- Queensland Police Service have made available, through TMR, data on each mobile speed camera deployment from January 1999 to December 2017 including the site of enforcement, hours of enforcement and type of enforcement (overt, covert, car-based, portable / LTI). These can be related to specific enforcement sites to ascertain the exact time and type of enforcement at each site or within each sector of Queensland down to the specific day.
- Interpretation of the mobile camera enforcement data allows the commencement date of enforcement at each specific site and within each sector to be ascertained.

In addition, it is evident from population and other socio-economic data as well as through reviewing the current Queensland road safety strategy that other factors have likely influenced road trauma levels over time in addition to the mobile speed camera program. Such factors include the introduction of other road safety programs, growth in population and travel exposure and changes in economic circumstances. Consequently, simple before-after study designs or case-crossover studies are likely to be inadequate in producing unbiased estimates of the mobile speed camera program on trauma outcomes. Clearly, some form of time-based control was needed to be incorporated in the evaluation design since it was not possible to explicitly measure the impact of all factors other than the mobile camera program on road trauma trends in Queensland.

3.3.1. Initial study design

Based on the results of the literature review, the case-crossover type design incorporating comparison group (case-case-crossover) appeared to offer the evaluation design that best suited the operation and data structure of the Queensland mobile speed camera program. Use of the controlled case-crossover design offered the best opportunity to control for site-based effects, acknowledging the likely location and time-based influence of the Queensland mobile speed camera program dictated by how operations are scheduled. Use of the comparison group also offered the ability to control for time-based effects other than the program across the evaluation period. Finally, the design offered the opportunity to compare enforcement exposure to crash occurrence to draw the link between camera operations and crash outcomes.

In a strict sense, the study design employed is not a strict case-crossover design as typically employed which looks for difference in exposure (in this case enforcement) between times when a crash occurred and times when no crash occurred. Instead the design estimated the risk of outcome in periods of enforcement compared to periods of no enforcement at the same site. In this sense it is more a time-based cross-sectional study incorporating a control to measure time-based effects, so sits somewhere between the traditional quasi-experiment and the case-crossover study.

To operationalise the design, the analysis grid for the framework was defined as the sector partitioned by time periods, reflecting how areas and sites within those areas are now chosen for enforcement. Analysis looked at the crash and enforcement overlay on each sector over time defining an analysis grid of sectors by time period, the time period starting a suitable length before program implementation (in this case 1992) and extending to the latest available data (December 2017 in this case). The nominal study design matrix is shown in Table 4 which gives an example with three sectors and eight time periods. The E in Table 4 represents times at which the sector was enforced by the mobile speed cameras. This variable could be represented as a categorical yes/no variable in the analysis or as a continuous measure, for example, the number of hours of enforcement. Multiple enforcement indicator variables could be formulated and overlayed on the analysis grid, for example indicators of different enforcement type (car / LTI) and level of overtness. The C in Table 4 represents the crash overlay. Again, this could be represented as an indicator of at least one crash occurring or could be the actual crash count if supported by the data.

Table 4 Example analysis grid for initial study design

Time Sector	T1	T2	T3	T4	T5	T6	T7	T8
1	E C	C	C	E			C	E
2		C	E	C	E	E C		
3	E	E C			E		E	C

The objective of the analysis was to estimate the association between enforcement and crash occurrence in the analysis grid of Table 4. For the example of using indicators of crash type and enforcement in the analysis, a logistic regression model was formulated using the structure of Equation 1 to achieve this objective.

$$Logit(C_{st}) = \alpha + \beta_s + \gamma_t + \delta_{st} \ldots \text{(Equation 1)}$$

In Equation 1, C_{st} is the indicator of a crash occurring in sector *s* and time period *t* (0=no crash, 1 = crash, s = 1, 2, 3, t= 1, 2, …, 8). Logit is the logistic transform with a logistic model being the most appropriate for a binary crash outcome. Parameter β_s represents the inherent risk in Sector *s*, whilst γ_t represents the average relative risk at time t across all sectors. The final parameter, δ_{st} is the measure of program effect, being represented in the model as an indicator variable (= 0 if sector *s* unenforced at time *t* or, = 1 if sector *s* enforced at time *t*). The natural log of δ_{st} ($\ln(\delta_{st})$) is the relative odds of a crash when enforcement is present compared to when it is not present.

Reformulation of the model to handle crash counts as the outcome is straight forward with a Poisson or Negative Binomial model being used, reflecting the different distribution of the outcome variable. Similarly, using the number of hours of enforcement in each sector and time period instead of an indicator requires modification of the final term in the model to δE_{st}, where E_{st} is the number of hours enforced in sector *s* at time *t*. The natural log of δ then becomes the change in relative crash risk per unit increase in enforcement.

The form of the model of in Equation 1 inherently accommodates the difference in risk between sectors and time-based changes in overall risk across all sectors related to factors other than the program. It relies on each sector having observed crash data in some time period and each time period having at least one sector that is not enforced at that time to be able to derive estimates of the relationship between enforcement effort and crash risk. The use of unenforced sectors in the analysis ensures this requirement is met whilst allowing contrast between risk in enforced and unenforced time periods of each sector to measure program crash effects adjusted for these broader underlying factors. It also investigates the specific relationship between enforcement actually being present in a sector and the corresponding change in crash risk, hence meeting all the requirement set of the new evaluation framework.

The example of the framework given makes a correction for time-based influence of other factors which is the same for each sector. In practice, this correction may need to differ between regions and levels of urbanisation to reflect differential impacts of non-program safety effects on trauma across these strata. Extension of the model to accommodate multiple strata is straight forward and given in Equation 2 where the index *r* indicates the strata (region by urban / rural).

$$Logit(C_{rst}) = \alpha + \beta_{rs} + \gamma_{rt} + \delta_{st} \ldots \text{(Equation 2)}$$

In theory, the initial analysis framework met all the requirements of the new evaluation framework. When applying the framework to the Queensland mobile speed camera data, a number of difficulties were encountered. Within the five police regions and urban / rural strata, Queensland has been broken down geographically into 13,790 sectors in which at least one crash has been recorded since 1992. There are additional sectors with no crashes recorded. In practice these will make no contribution to the analysis even if enforced by a mobile speed camera at some stage since there will be no crashes in either the before or after camera implementation period and they will have no impact on the treatment area time series. Of the sectors where a crash has been recorded, 2,708 or 19.6% have had a speed camera operation scheduled at a nominated speed camera site since the commencement of the program in April 1997. Each police region has enforced and unenforced sectors in both urban and rural areas. This provides adequate coverage and contrast to estimate both sector-based average risk as well as time-based trends in the ten defined strata.

However, the analysis grid defined is large due to the large number of sectors and extensive time period covered by the program and corresponding evaluation data, being 228 months in total for which enforcement data was available. Together, they defined an analysis grid of over 3.1M data cells. Although not exceeding the theoretical limits of the analysis software, when the model of Equation 2 was applied to the data, the model estimates would not converge, even after collapsing the data to quarter year time periods (786,000 data points). Various software packages and options were explored to estimate the model but without successful outcome.

Consequently, it was concluded that the original model formulation was too complex for the available analysis software meaning the original study design was abandoned. It may be possible to further explore this design in the future with greater computing resource.

3.3.2. Final study design

The second most rigorous study design identified in the review appropriate for evaluation of the Queensland CDOP was the adjusted quasi-experiment used for evaluation of the Western Australia mobile speed camera program and described in Section 3.1.4. This evaluation design sits somewhere between the traditional quasi-experiment and the case-crossover study as described in the previous section. Given the over-complication of the model resulting from attempting to consider each of the 13,790 sectors as an analysis unit, the alternative design proposed collapsed the data within region and urban rural strata into a pair of crash time series: one for sectors that have speed mobile speed camera sites which have been enforced at some time since implementation of the mobile camera program ('treatment') and one for those sectors which have never been enforced ('comparison').

This is somewhat similar to the previous evaluation framework except sectors were used to define the treatment and control areas. Advantages of a sector-based analysis compared to the previous evaluation framework is that the sectors are geographically discrete. Furthermore, camera operations within the sectors can be accurately allocated based on the camera sites within each sector, in comparison to the previous definition, to give a geographically precise analysis grid. The halo-based analysis was unable to define operations geographically with precision given there is significant geographical overlap between site halos, particularly in metropolitan Brisbane; this means the one crash is potentially influenced by multiple sites at different times making its state of influence difficult to categorise.

The resulting analysis grid for the evaluation framework is similar to the initial grid except each time series is an aggregation across treatment or control sectors in the stratum. Crash counts within each cell are calculated by summing crashes over the relevant sectors and are denoted C_{sgt} in the table where *s* is the stratum index, *g* is the treatment or control group index and *t* is the time interval. Overlaid on the grid are the mobile camera program delivery measures relevant to the time period being:

- Hours of overt car-based speed camera operation O
- Hours of covert car-based speed camera operation V
- Hours of LTI / portable speed camera operation L

Table 5 Example analysis grid for initial study design

Time Stratum	Treatment / Control	T1	T2						TN
1	Treatment	C_{1T1}	C_{1T2}						C_{1TN}
	Control	C_{1C1}	C_{1C2}						C_{1CN}
2	Treatment	C_{2T1}	C_{2T2}						C_{2TN}
	Control	C_{2C1}	C_{2C2}						C_{2CN}
…									

The following statistical model was applied to the analysis data grid to estimate the net effects of the mobile speed camera program on crash outcomes.

$$Ln(C_{sgt}) = \alpha + \beta_{sg} + \gamma_{st} + A.O_{sgt} + B.V_{sgt} + C.L_{sgt} \ldots \text{(Equation 3)}$$

Like previously, in Equation 3, C_{sgt} is the crash count occurring in stratum *s* and treatment or control group *g* in time period *t*. There were ten analysis strata defined by Queensland police region and urban or rural geographical location as used in the sector definitions. *Ln* is the natural log transform reflecting the Poisson or Negative Binomial model structure appropriate for application to road crash count data as identified in the review. GEE forms of the Poisson or Negative Binomial model were also considered to accommodate serial correlation in the time series data within each stratum and treatment and control group. Choice between using a Poisson or Negative binominal models was made using model information criterial. Parameter β_{sg} represents the inherent risk in region *s* and treatment and control group *g*, whilst γ_{st} represents the average relative risk at time *t* across stratum *s*. Measures O_{sgt}, V_{sgt} and L_{sgt} are the hours of each speed camera operation type enforcement in each stratum and treatment control group in time period. Values for each of these variables will be zero in the control time series. Parameters A, B and C represent the association between the hours of mobile speed camera enforcement of each type respectively and crash counts in each time period.

Like the initial analysis framework, the alternative framework explicitly controls for confounding effects of time changing non-program factors in the analysis model as well as accommodating difference in the underlying risk between treatment and control areas in each analysis stratum. The previous evaluation framework which estimated the net impact of the mobile speed camera program on crash risk using dummy intervention variables in the statistical model was unable to measure the impact of different modes of camera operation. The new evaluation framework incorporated direct measures of speed camera program operations as predictors in the analysis model. This has the advantage of measuring directly the relationship between variations in the level of use of each camera type and corresponding road trauma outcomes. The natural log of parameters represents *A, B* and *C* in Equation 3 directly measure the change in relative risk per hour if increased enforcement. This is a measure of program effectiveness specific to each camera type as required for the framework. These parameters are used to measure the differential year on year impact of the mobile speed camera program through working out the specific level of trauma reduction related to the actual level and modal mix of mobile speed camera operations occurring in each year.

Small variations in the structure of the model in Equation 3 were used to test for differential relationships between each mobile speed camera program input measure and road trauma outcomes in urban and rural areas. Models were fitted to the data from January 1999 to December 2017 in this application for the framework, the period for which detailed mobile speed camera operations by site were available. This does not include data prior to the introduction of the mobile speed camera program in Queensland. This is not problematic for application of the framework since estimation of program effects relies only on regional-cross sectional and time-based variation in the deployment of mobile speed cameras in Queensland by mode of operation to establish the relationship between program inputs and trauma outcomes. This variation was observed for the Queensland program as is illustrated in Figure 2.

4. NEW CDOP EVALUATION FRAMEWORK AND ANALYSIS METHODS

The evaluation framework used for the fixed CDOP elements was that developed and applied to recent evaluation of the program developed specifically for the Queensland CDOP (Newstead 2012). Unlike for the mobile camera program in Queensland, previous application of the framework to the fixed elements of the CDOP found no particular inadequacies with the framework developed for the fixed elements. Since the framework had been developed from a literature identifying best practice, there was considered to be no need to further update the framework. For the mobile speed camera component of the evaluation, the new evaluation framework described in Section 3.3.2 was used which overcame difficulties identified in applying the previous evaluation framework to the mobile camera program. The following sections outline the relevant specific details in applying the framework to estimate the crash and economic benefits of the CDOP in 2017. For the mobile speed camera program, the road safety benefits of the program have been re-estimated from 1999 to demonstrate the new methodology across the available data period and to allow comparison with estimates from the previous evaluation framework.

Analysis has considered crashes by severity: serious casualty, minor injury and all casualty crashes in aggregate. Non-injury crashes are not reported beyond 2010 in Queensland and hence cannot be considered in estimating effects of the program in 2017. Analysis has focused on the crash and economic effects of CDOP at the state-wide level and within each of the five police regions in Queensland. State-wide savings estimates have been derived by summation of regional savings estimates.

4.1. EVALUATION OF FIXED CDOP ELEMENTS

4.1.1. Treatment and control selection

A table summarising the treatment and control selection for fixed CDOP elements (FSSCs, RLSCs, PtP cameras) is presented in Section 9.3 of the Appendix. Included in the table is the matching criteria for selecting the control sites. Choice of the matching criteria reflected the availability and quality of information available in the crash data.

For example, matching of the control sites for RLSCs, PtP and FSSC sites by number of lanes, crash history or traffic volume was not attempted due to traffic volume not being reliably available across all road segments and intersections and tight restrictions on number of lanes and crash history being too restrictive in identifying sufficient control areas to maintain adequate statistical power. An intersection identifier was provided, it was not sufficiently complete to allow broad control matching. Additional analysis using street names and GPS location was undertaken to uniquely identify control intersections for RLC/RLSC sites. Once identified, a pre-period crash history was defined and used to eliminate control intersections with a very different history[2]. Generally, there were insufficient control intersections available to do very specific crash history matching. Traffic volume data, again could not practically be identified for many RLSC and RLC intersections which precluded this factor being used to match control sites. Traffic volume data, although provided for a number of major arterial roads, were not available for all control sections of road. By matching on other road geometry characteristics, speed limits (Table 6), intersection control type (signalisation), road dividedness and by the locality (SLA and similar surrounding SLAs), it was deemed that a sufficiently similar and sizeable set of control crash sites were identified that were likely to broadly represent traffic volume and crash history. To extend the numbers of control sites

[2] If the pre-period history of the control was less than 0.025 or more than 1.975 times the pre-period crash history of the matched treatment site, the control intersection was excluded.

to enhance statistical power, control crashes for RLSCs were matched by SLA or the distance from the camera.

Control sites for FSSCs were chosen from the same road, limited to 2km outside the hypothesised zone of camera influence (defined as 1km either side of the camera) and from the same locality (SLA) so it was also deemed unnecessary to further distinguish by lane number, crash history and crash volume. In addition, road dividedness was not used as a control matching variable due to the complications caused by the varying nature of reporting this variable along the road where the camera was placed. However, speed limit was used in the selection of these controls, but was broadened for five fixed speed camera control sections so that sufficient controls could be found hence providing adequate analysis power. The following gives the camera site number and the speed limit range used for matching controls:

- Site 1001: 80-100km/h
- Site 1011: 60-80km/h
- Site 3003: 90-100km/h
- Site 3004: 60-70km/h
- Site 3006: 80-90km/h

Both treatment and control crashes for fixed spot cameras were excluded from analysis if their location was listed as being on an entry or exit ramp to a motorway.

Table 6 Speed limits (km/h) associated with Fixed Speed Cameras

Red-Light Speed ID	Speed limit	**Fixed Spot ID**	Speed Limit	**Tunnel ID**	Speed Limit
2001	60	1001	90	1003-1006	80
2002	80	1002	100	1007-1010	80
2003	60	1011	70	1013-1016	80
2004	60	1012	110		
2005	60	3001	100		
2006	60	3002	60		
2007	80	3003	100		
2010	60	3004	60	**Point-to-Point**	
2011	60	3005	60	4001	110
2012	60	3006	90	403	unknown
2014	60	3007	100		
2015	70	3008	70		
2016	70	3009	100		
2017	60				

Direction of travel was not available as a variable in the data (since vehicles in a crash can have multiple directions of travel) so control crashes for the PtP average speed cameras had to be allocated on both outbound and inbound sections of divided road. The controls for this segment of road were chosen not by speed or road geometry but by using the lengths of road north and south of the outermost halo region for the cameras defined as 5km up and downstream of the system end points). The control section was equally split between the northern and the southern ends. Distances were measured along the Bruce Highway using the Google Earth "path" function and GIS mapped camera locations. Crashes were counted north or south of the latitude position (measured to seconds) of the outer control and halo points on the Bruce Highway section. Table 7 gives the map coordinates of the treatment and control sections.

Table 7 Segment Distances and Location of Point-to-Point camera and control segments

Position on Bruce Hwy	Latitude	Longitude	Distance (km)
Northern end of Control segment	26°42' S	153°00' E	7.2
Northern End of camera Halo	26°45' S	153°03' E	5.0
Northern Camera	26°47' S	153°03' E	14.8
Southern Camera	26°55' S	152°60' E	14.8
Southern End of camera Halo	26°58' S	152°59' E	5.0
Southern end of Control segment	27°01' S	152°59' E	7.2
Position on Lindsay Hwy	**Latitude**	**Longitude**	**Distance (km)**
Northern end of Control segment	27°38' S	153°02' E	5
Northern End of camera Halo	27°41' S	153°01' E	5.0
Northern Camera	27°43' S	153°01' E	8.83
Southern Camera	27°48' S	153°01' E	8.83
Southern End of camera Halo	27°50' S	153°01' E	5.0
Southern end of Control segment	27°53' S	152°59' E	5.0

The *Airport-Link, Legacy Way* and *Clem 7* tunnels had no period without cameras since the cameras were installed before the roads were opened. There were also no suitable feeder roads to use as controls, so the *Southern Cross Way* and *Port of Brisbane Motorway* were chosen as control segments. The crash counts were then analysed with a volume and distance offset (an offset being a constant term included in the model) to give a comparison of relative crash rates per distance travelled across the treatment and control sections. Using volume times distance as the offset represented the total travel exposure on the road segment meaning the analysis measured change in risk associated with the cameras per unit travel. The *Inner-City Bypass* (ICB) was not chosen as traffic volume data were not available for all years and were recorded in a different manner to the state AADT surveys. Also, the ICB was complicated by having sections with varying speed limits and multiple exit/entry points. Crash counts, volume data, volume location and distances measured using Google Maps are shown in Table 8.

Table 8 Tunnel cameras, treatment and control road lengths and traffic volume

Road	Position of Volume Data	AADT 2013	AADT 2014	AADT 2015	AADT 2016	AADT 2017	Distance (km)
Clem 7	U12A North of Ipswich Rd O'pass	124,435	125,445	126,115	127,310	127,310	6.84
Airport-Link	400m East of Sandgate Rd	43,272	45,946	63,881	69,580	69,580	6.7
Legacy Way	Western Arterial road S of Mt Cootha Roundabout			68,526	76,545	76,545	4.6
Southern Cross Way	913 Gateway Mwy Sth of Toombul Rd O'pass	41,351	41,588	43,516	43,516	43,516	7.15
Port of Brisbane Mwy	WiM site Lytton	12,164	12,834	13,161	13,161	13,161	7.07

The volume data for the *Clem7* was collected just prior to the exit for the southern start of the *Clem7* tunnel on the South Eastern Arterial (M3). The *Airport-Link* volume data was collected just east of the tunnel, on the same road. Crash counts in each tunnel are summarised in Table 9. There were no crashes observed in the two years of observation for the *Legacy Way* tunnel.

Table 9 Crash counts for treatment and control segments in the cross-sectional analysis of the Clem 7 and Airport-Link tunnels

Road	Serious Casualty	Minor Injury	Casualty
Treatment			
Clem 7	4	7	11
Airport-Link	3	8	11
Control			
Southern Cross Way	25	23	48
Port of Brisbane Mwy	5	9	14

4.1.2. Analysis period

The analysis periods were defined by the 'go live' dates for each camera. For consistency, dates for the installation of signage were not used in the analysis because they were only available for the PtP cameras, four digital fixed speed cameras and the RLSCs. However, due to the RLSCs being previously RLCs, sign installation dates were not relevant for RLSCs. In addition, the fixed speed camera crash data were too few to attempt a two point after period effect (i.e. measuring the crash effects after camera placement but before activation but with signage, and then after activation). Analysis before periods were from the start of available data to the point of camera or signage installation, whichever was first whilst analysis after periods were from the period after installation to the end of available data.

4.1.3. Analysis by crash type

There was sufficient statistical power to analyse red-light (RL) and red-light speed (RLS) cameras both on crashes overall and by broad crash type (targeted – right turn against or cross traffic crashes - or rear-end). For the crash types analysis, it was necessary to exclude sites from analysis where the treatment or control sites had no before or after crash history of the specific crash type.

4.1.4. Matching treatment and control crash history

Every attempt was made to balance control site proximity to the camera site and the size of the control crash group. However, in order to preserve the integrity of the crash location, so that the traffic volume and local events were controlled, the control crash population did not always meet the preferred size. Newstead & Cameron (2012) suggested that the pre-activation control crash history should be within the two standard error range of treatment crashes indicating statistical compatibility. From Section 9.5 of the Appendix, which presents the crash history at RLC treatment and control sites, it can be seen that although this condition has not been universally met, control site crash counts are generally of a similar magnitude to those of the treatment sites.

4.1.5. Crash savings and community cost savings for the fixed camera program

Analysis of camera effectiveness resulted in an estimated net percentage crash saving at camera sites relative to the control site. Percentage crash savings were converted to absolute crash savings and subsequently into community cost savings using the following methods. The average annual crash counts at fixed camera treatment sites, after the camera went live, were first calculated by camera type, police region (and rural/urban status) and severity for the years 2013 to 2017. Absolute annual crash savings for each crash severity, police region (and speed category) and fixed speed camera type were determined from the application of crash reduction percentages (for each crash severity), determined from regression analysis, to the average annual crash counts.

Regression estimates of camera effectiveness were produced for all cameras combined on average. The exception was for the tunnel cameras, which, in having no pre-camera period, could not be analysed within the treatment-control, before-after quasi-experimental design.

Average annual absolute crash reductions were converted into community cost savings according to the process illustrated in the CDOP evaluation framework (Newstead & Cameron, 2012) by multiplying the estimated absolute crash savings at the crash severity level being considered by the per unit cost of each crash (Table 2 and Table 3) to derive the community cost savings related to the crash reductions.

4.1.6. Trailer operated speed cameras

One camera type not considered in the new evaluation framework was trailer based speed cameras. These cameras are used to enforce roadworks sites and school zones and are typically placed in a location and left for some time. As such, these cameras are more like temporary fixed cameras and are likely to have localised effects at camera sites for the duration of the presence of the camera. Because of this, it was not considered appropriate to include them as an element in the mobile camera evaluation framework. Furthermore, they have not been considered in the fixed camera analysis here due to problems with the operations data available for these cameras. Available data provided by TMR showed the location of deployment and start time of enforcement however no information was provided on the duration the camera was left at the site. Trailer cameras have only been used since 2016 and only 35 deployments have been recorded during 2016 and 2017. Given the likely highly localised effects of the cameras and limited deployments, it is unlikely the cameras would have had a major impact on the overall crash effects of the CDOP to date.

Should data on the total deployment time for each trailer camera placement become available, the same evaluation methods used for other fixed camera elements could be used to evaluate trailer camera crash effects in future application of the evaluation framework.

4.2. EVALUATION OF THE MOBILE SPEED CAMERA PROGRAM

The new evaluation design detailed in Section 3.3.2 above was applied to estimate the crash effects of the mobile speed camera program. Application of the framework required the specification of a number of details of the framework including the final definition of treatment and control areas, definition of the analysis strata, selection of the periodicity for the analysis time series data and decisions about the measure of speed camera program delivery measures that would be used as predictors in the analysis models. Each of these aspects is described in the following sections along with details about the interpretation of the analysis model outputs and the conversion of these to estimate absolute crash savings and crash cost savings both by region and for Queensland overall.

4.2.1. Treatment and control area definition and analysis strata

As illustrated in Figure 1, Queensland is geographically defined into segments for the identification of areas to enforce with mobile speed cameras. Within each sector chosen for enforcement, individual sites for camera placement have been identified. Through matching with the mobile speed camera operations data, sites and hence sectors in which a mobile speed camera session had taken place at some time since January 1999 were identified. The number of mobile speed camera operations by type of operation in each month in each sector were identified through linking via the sites within each sector.

Police-reported crashes in Queensland were also geographically linked to sectors. Every reported crash was linked to a sector unless locational details were missing which was the case for only a small number of crashes (less than 20 crashes). Furthermore, 3.4% of casualty crashes in the data were excluded for being within the zone of influence of a fixed camera. A total of 241,837 crashes were included in the analysis from January 1, 1999 to December 2017, the period for which mobile speed camera operations data were available. A total of 13,709 sectors had at least one crash recorded over the period of the analysis. An average of 2.8 sites were enforced within each sector.

Treatment areas were defined as those sectors in which at least one mobile speed camera operation (of any duration) had taken place during the study period. Control areas were defined as those sectors in which no mobile speed camera operations had taken place over the study period. Treatment and control sectors were then aggregated for analysis by police region (Brisbane, Central, Northern, South-Eastern and Southern) and urban and rural status according to the sector in which the crash fell (defined by TMR). Aggregation in this way allowed estimation of program effects within each region whist broadly controlling for confounding factors which differ by region and level of urbanisation. The resulting analysis stratification defined ten treatment and control pairs of crash time series data. Separate sets of treatment and control data pairs were formed for each crash severity level considered, being all casualty crashes and fatal or serious injury crashes combined. There was insufficient data to consider fatal crashes alone and non-injury crashes have not been reported in Queensland after 2010.

4.2.2. Time series periodicity

For each regression analysis by crash severity, data were aggregated into a time series structure within each police region, urban /rural split, sector and treatment and control pair having its own time series of data for analysis. To ensure a viable analysis, a periodicity for the data analysis needed to be chosen that had two properties. First, it had to display significant time to time variation in the mobile speed camera operations within each treatment time series to give analytical power in establishing a relationship between variation in crashes and variation in camera operations. Second, it needed to have sufficient number of crashes within each time period, stratum and treatment and control pair to also ensure sufficient analysis power. After some investigation it was decided that quarter of a year was the most appropriate periodicity on which to form the analysis time series to ensure both criteria were met.

4.2.3. Measures of mobile speed camera operations considered

As described in Section 2.2.3, mobile speed camera operations were classified in the operations data provided into five specific types: overt car-based, covert car-based, overt portable, overt LTI and covert LTI. Also as noted in Section 2.2.3, LTI camera operations replaced portable operations, essentially presenting the same hand held mode of roadside operation. Furthermore, although a small proportion of LTI operations were designated as covert, it is unlikely that these operations are truly covert. In consultation with TMR project staff, it was decided to treat all portable and LTI camera operations in aggregate in the analysis resulting in three different types of camera operation being included in the analysis model: overt car-based, covert car-based and total portable/LTI.

Significant quarterly variation in the number of hours of deployment of each camera type was observed over the study period, as illustrated in Figure 2. Furthermore, the pattern of quarterly variation differed significantly between analysis strata as did the balance between type of camera use. Time series of quarterly hours of deployment of each of the three camera types in each of the analysis strata were calculated from the operations data provided for each quarter over the study period. These were included as predictors in each analysis model as described by Equation 3 in section 3.3.2.

4.2.4. Analysis output and conversion to crash and crash cost savings

Key output from the analysis model are the parameter estimates of *A, B* and *C* from Equation 3. These parameters give the relationship between the number of hours of enforcement by each speed camera type in each stratum and the observed crash count in each stratum. The exponent of each of these parameters (*exp(A), exp(B) and exp(C)*) gives the proportionate change in expected crash outcome per hour change in enforcement in each stratum and quarter.

To estimate the absolute crash saving attributable to the mobile speed camera program in each stratum and quarter, the predicted crash count in each stratum at the level of enforcement observed in that stratum *s* and time period *t* was compared to that predicted if no camera enforcement of any type had occurred in that time period (i.e. O_{sgt}, V_{sgt} and $L_{sgt} = 0$). The crash saving (δ_{st}) in stratum *s* and time period *t* is then given by Equation 4.

$$\delta_{st} = \exp\left(\alpha + \beta_{sg} + \gamma_{st} + A.O_{sgt} + B.V_{sgt} + C.L_{sgt}\right) - \exp(\alpha + \beta_{sg} + \gamma_{st}) \ldots\text{(Equation 4)}$$

Total crash savings per year, within each stratum and across Queensland as a whole were then calculated by aggregating individual savings across the appropriate time periods (e.g. quarters in the year) and strata.

Absolute crash reductions were converted into community cost savings by multiplying the estimated absolute crash savings at the crash severity level being considered by the unit cost of each crash (Table 44) to derive the cost savings related to the crash reductions. Savings were calculated by police region, crash severity and crash year.

4.3. COMBINED ESTIMATE OF STATE-WIDE CDOP CRASH EFFECTS

The final step of the evaluation framework development for measuring crash effects of the CDOP was to combine estimates of the effectiveness of individual program elements to arrive at aggregate effectiveness estimates both within specific police regions as well as across the whole of Queensland. This process involved consideration of the crash population covered by each mode of enforcement along with the estimated effectiveness of each camera type. The methodology used to combine state-wide CDOP effects is the same as that described in Section 4.3 of the previous evaluation framework (Newstead & Cameron, 2012). The only significant difference in this process for the new evaluation framework was that the absolute crash savings for the mobile speed camera program were available directly and hence did not need to be derived proportionately from the overall stratum crash population.

In this report average annual crash savings were calculated by crash severity, police region and camera type groupings: RLCs, RLSCs, mobile speed cameras, tunnel fixed cameras, all other fixed speed cameras (including average speed cameras). The state–wide CDOP annual absolute crash reductions and average annual crash cost savings were determined through regional summation over tunnel, other fixed (combined) and mobile camera type. The state-wide CDOP average crash reduction was weighted using the average annual *post-activation* base period crash counts.

5. RESULTS

5.1. RED-LIGHT CAMERAS (RLCS)

Table 10 presents a summary of the estimated crash effects associated with CDOP RLCs by region and crash severity grouping. The table presents the estimated relative risk, 95% statistical confidence limit on the estimate and statistical significance probability for each crash severity and region. Results of homogeneity tests indicated that there was no statistical evidence that the crash effects associated with the RLC operation differed between police regions at any level of crash severity, thus whole state crash reductions associated with the different severities are the most informative with differences in estimates between police regions an artefact of random variation. Consequently, the state-wide average estimates have been used in the estimation of savings by region.

Table 10 Estimated crash risks associated with the red-light camera sites relative to sites without red-light cameras (all urban sites)

Estimate (95% CI) Significance	Serious Casualty	Minor Injury	All Casualty†
All	**0.81** (0.68,0.96) **0.01**	**0.85** (0.76,0.95) **0.004**	**0.84** (0.76,0.92) **0.0001**
Brisbane	0.79 (0.61,1.03) 0.08	0.90 (0.77,1.06) 0.20	**0.87** (0.76,1) **0.04**
Central	0.93 (0.59,1.47) 0.76	0.84 (0.63,1.12) 0.23	0.87 (0.68,1.11) 0.26
Northern	1.11 (0.54,2.27) 0.78	0.90 (0.56,1.46) 0.67	1.00 (0.68,1.48) 1.00
South Eastern	0.88 (0.64,1.2) 0.41	**0.80** (0.65,0.99) **0.04**	**0.81** (0.69,0.97) **0.02**
Southern	**0.41** (0.23,0.73) **0.002**	0.72 (0.48,1.09) 0.12	**0.58** (0.42,0.81) **0.001**

† Estimated from an all casualty crash model

Annual crashes, in the post-camera period, identified within the defined halo of influence of a RLC (<100m from camera and recorded as at a signalised intersection) were tabled by severity and police region for 2013 to 2017. The average annual count (rounded to the nearest integer) over the period is given in Table 11 as a measure of the crash population covered by this camera type. Overall crash reduction estimates by severity were applied to the annual counts to produce the absolute crash savings per year given in Table 12. These were then costed by the WTP and the HC approaches with results given in Table 13 and Table 14 respectively.

Table 11 Average annual post-activation red-light camera treatment crash counts by severity and police region

	Serious Casualty	Minor Injury	All Casualty
All*	62	120	183
Brisbane	31	60	91
Central	8	16	24
Northern	5	6	11
South Eastern	12	30	42
Southern	6	8	14

*sum of regions

Table 12 Average annual absolute crash savings associated with red-light cameras, by severity and police region

	Serious Casualty	Minor Injury	All Casualty†
All	15	21	36
Brisbane	8	10	18
Central	2	3	5
Northern	1	1	2
South Eastern	3	5	8
Southern	1	1	3

The casualty crash reductions of 16% (Table 10) associated with RLCs translated to the average annual prevention of 36 casualty crashes, 15 of which were serious, saving society about $13M per year using WTP crash cost valuations or $5M per annum using HC crash cost valuation.

Table 13 Average annual savings associated with red-light cameras, by severity and police region: Willingness to Pay approach

	Serious Casualty	Minor Injury	Casualty†
All*	$12,439,260	$2,285,067	$13,107,453
Brisbane	$6,032,681	$1,123,887	$6,100,470
Central	$1,753,353	$299,936	$1,765,331
Northern	$999,940	$120,053	$867,608
South Eastern	$2,281,968	$571,634	$2,519,377
Southern	$1,159,931	$159,448	$1,105,009

*Sum of regions, rounding errors apply

† All Casualty is modelled separately and is not the sum of serious and minor.

Table 14 Average annual savings associated with red-light cameras, by severity and police region: Human Capital approach

	Serious Casualty	Minor Injury	Casualty†
All*	$6,049,654	$397,139	$5,295,254
Brisbane	$3,003,473	$197,250	$2,625,970
Central	$848,466	$53,436	$751,143
Northern	$492,430	$20,451	$382,787
South Eastern	$1,134,066	$98,955	$1,044,886
Southern	$571,218	$27,048	$490,467

*sum of regions, rounding errors apply
† All Casualty is modelled separately and is not the sum of serious and minor.

5.2. RED-LIGHT SPEED CAMERAS (RLSCS)

Ten of the 14 RLSC sites evaluated were previously RLC sites. For these cameras, the period for which there was only an RLC period was evaluated with the RLCs in the previous section. The crash reduction associated with a RLSC upgrade period was evaluated and reported with the results in this section. For these ten cameras, the before treatment period is defined as the period where the RLC was installed and the post-period the time from which the upgraded RLSC was installed. However, five of the ten sites had RLCs installed and operational in 1992 so there was no opportunity to evaluate the effectiveness of the RLCs as data prior to RLC installation was unavailable. Furthermore, defining a pre-treatment period so far prior to the camera installation would draw questions about the representativeness of the comparison. Consequently, analysis for those five sites (site numbers 2005-2007 & 2010-2011) focused solely on assessing the crash effects of upgrading RLC sites to RLSC. For the other four sites (2002 & 2015-2017), the effect of the RLSCs was assessed against a no-camera pre-period. Defining pre-RLSC periods in these ways produced pre-periods of at least 9.5 years and operational periods of 0.4 to 6.4 years.

By analysing the RLCs and RLSCs in this way, all effects could be associated with the camera of influence, be compared with a closer prior period, and be directly combined without duplication or overlap. However, as an additional study, a comparison of RLSC and no-camera periods was made for all sites with an available period prior to cameras (all except 2005-2007 & 2010-2011). The results of this analysis are presented in Appendix 9.7.

The relative risk analyses were carried out for all RLSCs. Results of these analyses are found in Table 15. Large statistically significant reductions in casualty and serious casualty crashes were associated with upgrades from RLC to RLSC indicating that the addition of the speed component has road safety benefits. Smaller estimated minor injury crash reductions were associated with RLC upgrades to RLSC although none of these estimates reached statistical significance. Estimates of the crash effects of RLC to RLSC upgrades against the time period prior to RLC installation were generally uninformative with none of the serious casualty or all casualty crash estimates achieving statistical significance. Consequently, the evaluation was only able to provide evidence on the effectiveness of RLC to RLSC upgrades, and not a measure of the total effect of a RLSC installation from an unenforced intersection for these upgraded sites.

Table 15 Estimated relative crash risks, (95% confidence interval and p-value) associated with red-light speed camera installation (Using all sites uniquely within the combined fixed camera models)

Estimate (95% CI) Significance	Serious Casualty	Minor Injury	All Casualty†
Referenced to no-camera period			
Combined: 2002, 2015-2017	0.52 (0.22,1.24) 0.14	1.66 (1.00,2.73) 0.05	1.16 (0.76,1.77) 0.49
Brisbane (2002, 2016)	0.47 (0.19,1.21) 0.12	1.59 (0.96,2.64) 0.07	1.12 (0.73,1.74) 0.60
South Eastern Urban (2015)‡			
Southern Urban (2017)	1.75 (0.17,18.27) 0.64	7.62 (0.45,127.97) 0.16	3.30 (0.58,18.88) 0.18
Referenced to red-light camera period			
Combined: 2001,2003-2007,2010-2012 and 2014	**0.47** (0.28,0.80) **0.01**	0.84 (0.58,1.21) 0.35	**0.69** (0.51,0.93) **0.01**
Brisbane (2001)	0.46 (0.14,1.53) 0.20	0.66 (0.23,1.93) 0.45	0.56 (0.25,1.25) 0.16
Central Urban (2005, 2007)	0.56 (0.15,2.04) 0.38	0.79 (0.3,2.09) 0.64	0.69 (0.32,1.49) 0.34
Northern Urban (2004, 2006)	0.67 (0.26,1.73) 0.41	0.98 (0.53,1.82) 0.96	0.87 (0.52,1.46) 0.61
South Eastern Urban (2003)	0.41 (0.15,1.12) 0.08	0.90 (0.49,1.65) 0.72	0.71 (0.42,1.2) 0.20
Southern Urban (2010,2011,2012,2014)	*	0.36 (0.05,2.73) 0.32	0.18 (0.02,1.33) 0.09

‡ A operation period of 0.4 years prevented estimation of the relative risk. *Regression estimate could not be estimated

† All Casualty is modelled separately and is not the sum of serious and minor.

Results of homogeneity tests indicated that there was no statistical evidence that the crash effects associated with the upgrade of RLC to RLSC differed between sites at any level of crash severity which indicates that the average crash reductions estimated across all sites associated could be considered to apply equally to all sites. Consequently, the overall average results were used in estimating absolute crash savings and their associated community costs.

Average annual crashes identified within the defined halo of influence of a RLSC (<100m from camera and recorded as at a signalised intersection) by severity and police region across the period of focus, 2013 to 2017 are given in Table 16. Average crash reductions associated with RLC to RLSC upgrade by severity were applied to the annual counts to produce the absolute crash savings per year given in the main results. It should be noted that the estimates for casualty crash savings in

Table 19 do not result from the summation of the serious casualty and minor injury models. A separate model was fitted to all casualty crashes which is likely to be more accurate than simply summing the serious casualty and minor injury crash models given it is based on greater crash numbers. Table 17 shows the average annual crash savings estimated across 2013 to 2017 which were then costed by the WTP and the HC approaches with results given in Table 18.

Table 16 Average annual post-activation red-light speed camera treatment crash counts by severity and police region

	Serious Casualty	Minor Injury	Casualty
All*	4.6	15.8	20.4
Brisbane	1.2	7.2	8.4
Central	0.8	1.4	2.2
Northern	1.2	3.2	4.4
South Eastern	1.2	3.6	4.8
Southern	0.2	0.4	0.6

* Sum of regions

Table 17 Average annual absolute crash savings associated with red-light speed cameras, by severity and police region

	Serious Casualty	Minor Injury	Casualty†
All*	5.2	3.0	9.2
Brisbane	1.4	1.4	3.8
Central	0.9	0.3	1.0
Northern	1.4	0.6	2.0
South Eastern	1.4	0.7	2.2
Southern	0.2	0.1	0.3

* Sum of regions
† Estimated from an all casualty crash model

Table 18 Average annual savings associated with red-light cameras, by severity and police region

	Willingness to pay			Human Capital		
	Serious Casualty	Minor Injury	Casualty†	Serious Casualty	Minor Injury	Casualty†
All*	$4,306,698	$329,100	$3,223,861	$2,124,790	$57,253	$1,385,330
Brisbane	$1,086,736	$148,654	$1,295,214	$541,050	$26,090	$557,530
Central	$806,321	$28,475	$366,904	$390,187	$5,073	$156,117
Northern	$1,131,221	$68,070	$785,692	$557,080	$11,595	$346,645
South Eastern	$1,093,883	$75,357	$666,887	$543,626	$13,045	$276,584
Southern	$188,537	$8,545	$109,165	$92,847	$1,449	$48,454

*sum of regions, rounding errors apply
† Estimated from an all casualty crash model

5.2.1. Crash type analysis for red-light (RLCs) and red-light speed cameras (RLSCs)

After the exclusion from analysis of sites with none of at least one of the three crash types analysed (rear-end, right-through and other) in the pre-camera installation period, regression analysis was able to produce crash reduction estimates disaggregated by crash type. Right-through crashes were crashes at the intersection where one vehicle was turning right, or approaching at a right angle, and would cross the path of another vehicle travelling straight through the intersection.

Figure 3 displays the estimated relative risks with 95% confidence intervals for the RLCs and RLSCs referenced to a period of no-camera, as well as for the RLSCs, referenced to a period of RLSC from RLC. From this figure, some trends are evident:

- There was no clear evidence that either RLC or RLSC were associated with a statistically significant change in *rear-end* crashes, particularly for higher crash severities.
- Both RLCs and RLSCs were likely to reduce *right-through* injury crashes. RLCs and RLSCs were significantly associated with serious and casualty crash reductions.
- The *right-through* injury crash reductions trended to a greater reduction associated with RLSCs.

Data further disaggregated into regions and urbanisation proved too unstable for regression analysis.

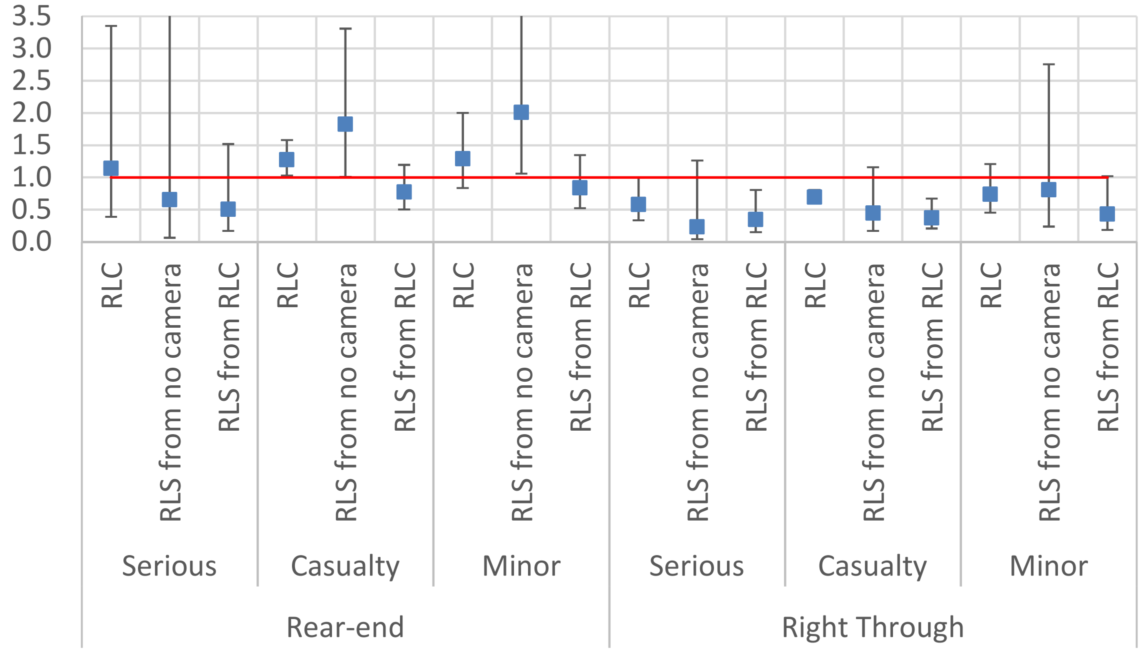


Figure 3 *State-wide relative risk estimates by crash type for each fixed intersection camera type*

A meta-analysis by Erke (2009) found a 40% increase in rear-end crashes associated with RLCs. This study provided no evidence that this was the case for CDOP RLCs, with RLC and RLSC generally having no associated effects identified on rear end crashes.

Research by MUARC (Budd, Scully and Newstead, 2011) found RLSCs to be associated with a 44% reduction in right-through casualty crashes. Results in this evaluation found reductions in *right-through* associated with RLSC of

- 63% (95% CI: 33% to 79%, p=0.001) for casualty crashes;
- 65% (95% CI: 19% to 85%, p=0.01) for fatal and serious injury crashes; and
- 57% (95% CI: -2% to 82%, p=0.055) for minor injuries;

and with RLCs of

- 31% (95% CI: 19% to 40%, p<0.0001) for casualty crashes;
- 42% (95% CI: 0% to 67%, p=0.05) for fatal and serious injury crashes; and
- 26% (95% CI: -21% to 55%, p= 0.23) for minor injuries.

5.3. FIXED SPOT SPEED CAMERAS (FSSCS)

The estimated effectiveness of fixed speed cameras is presented in three groups: the effects of the PtP speed camera systems (site 4001 and 403), the combined effects of the tunnel speed cameras (sites 1003 to 1010 and 1013 to 1016) and by region and overall effects of all other FSSCs at non-tunnel mid-block sites (sites 1001, 1002, 1011, 1012 and 3001 to 3009). Table 19 and Table 20 present a summary of the fixed speed camera effectiveness estimates, all of which, except the Clem 7 Tunnel cameras in Table 20, and one other estimate were not statistically significant. However, there was weak evidence (p=0.06) of a casualty crash reduction associated with the combined PtP cameras. There were no fixed speed cameras in the Northern region, nor in the urban Southern region.

Estimated crash risks at Clem 7 and Airport-Link camera sites were relative to the chosen above ground comparison routes: Port of Brisbane Motorway and Southern Cross Way and were determined from Cross-sectional Treatment-Control analysis. A statistically significant reduction in risk was associated with the tunnel cameras, largely stemming from the Clem 7 tunnel result which was statistically significant on its own for each crash severity considered. To some degree these estimates should be treated with caution because the control roads, although adjusted for traffic volume and distance, were not tunnels. However, the results do indicate that the road safety environment created in the tunnels whether partially or wholly through the use of fixed speed cameras, is much safer than that observed at comparable above ground motorways.

In this analysis, some potential for mis-identification of crashes on the Southern Cross Way and Gateway Motorway was observed through comparing the GPS co-ordinates for a crash compared to the listed road name. For this analysis, the motorway matching the GPS co-ordinate for the crash was used to identify motorway crashes instead of using street name as per the previous study. This may be the reason estimated crash reductions on the Clem 7 are slightly different from the previous evaluation (Serious casualty RR: 0.15, Minor Injury RR: 0.25 and Casualty RR: 0.21). Results are now more consistent with the 2013-2015 evaluation (Serious casualty RR: 0.04, Minor Injury RR: 0.19 and Casualty RR: 0.12).

Table 19 Estimated relative crash risks associated with fixed spot speed cameras (excluding point-to-point and tunnel cameras)

Estimate (95% CI) Significance	Serious Casualty	Minor Injury	All Casualty†
All	1.14 (0.95,1.38) 0.16	0.97 (0.85,1.1) 0.60	1.02 (0.91,1.13) 0.75
Brisbane	1.49 **(1.01,2.2)** **0.04**	0.84 (0.65,1.08) 0.18	1.00 (0.81,1.23) 0.99
Central Urban	1.40 (0.8,2.48) 0.24	1.00 (0.67,1.5) 0.98	1.11 (0.8,1.53) 0.54
Central Rural	1.12 (0.58,2.14) 0.70	0.80 (0.45,1.44) 0.46	0.89 (0.58,1.37) 0.60
South Eastern Urban	0.82 (0.57,1.18) 0.28	0.87 (0.68,1.11) 0.25	0.85 (0.70,1.04) 0.12
South Eastern Rural	1.03 (0.66,1.59) 0.91	1.30 (0.96,1.76) 0.09	1.21 (0.94,1.55) 0.13
Southern Rural	1.38 (0.83,2.29) 0.22	1.18 (0.76,1.83) 0.46	1.26 (0.91,1.76) 0.16

† Estimated from an all casualty crash model

Table 20 Estimated relative crash risks associated with point-to-point spot and average speed, and tunnel fixed speed cameras (*relative risk estimate, 95% C.I., statistical significance*)

	Serious Casualty	Minor Injury	All Casualty†
Tunnel			
Both	**0.09** (0.04, 0.22) <0.0001	**0.19** (0.09, 0.39) <0.0001	**0.14** (0.08, 0.24) <0.0001
Clem 7	**0.07** (0.02, 0.19) <0.0001	**0.11** (0.05, 0.25) <0.0001	**0.09** (0.05, 0.17) <0.0001
Airport-Link	0.64 (0.15, 2.68) 0.54	0.53 (0.13, 2.13) 0.37	0.53 (0.20, 1.42) 0.21
Point-to-Point			
Both	0.80 (0.56,1.14) 0.22	0.77 (0.55,1.08) 0.13	0.79 (0.62,1.01) 0.06
Central (Bruce Hwy)	0.85 (0.59,1.23) 0.39	0.77 (0.53,1.12) 0.18	0.82 (0.63,1.06) 0.13
South Eastern (Mt Lindsay Hwy)	0.36 (0.09,1.44) 0.15	0.75 (0.33,1.74) 0.51	0.59 (0.29,1.2) 0.15

† Estimated from an all casualty crash model

Annual crashes identified within the defined halo of influence of a fixed speed camera (≤1000m in either direction on the same road) were tabled by severity and police region for 2013 to 2017. The average annual count over the period is given in Table 21 as a measure of the crash population covered by this camera type. Note that the crash reductions by severity were applied to the actual annual counts to produce the absolute crash savings per year given in the main results. Table 22 shows the average annual saving across 2013 to 2017 which were then costed by the WTP and the HC approaches with results given in Table 23 and Table 24 respectively. It should be noted that the estimates for the non-tunnel mid-block speed cameras are based on relative risk estimates that did not reach statistical significance so should be treated with caution. Negative values in the table indicate an estimated crash or crash cost increase. Again, it is stressed that these are based on relative risk estimates that did not achieve statistical significance meaning there is no robust evidence that the true impact on crashes and costs are different from zero.

Table 21 Average annual post-activation fixed speed camera treatment crash counts by severity and police region

	Serious Casualty	Minor Injury	Casualty
All Tunnel	1	2	4
Point-to-Point	18	17	35
Central	17	15	32
South Eastern	1	2	3
All other fixed*	41	75	116
Brisbane	11	18	29
Central Urban	5	10	15
Central Rural	4	4	8
South Eastern Urban	8	19	27
South Eastern Rural	8	18	26
Southern Rural	6	6	11

*sum of regions, rounding errors apply.

Table 22 Average annual absolute crash savings associated with fixed speed cameras, by severity and police region

	Serious Casualty	Minor Injury	Casualty†
All Tunnel	12	10	22
Point-to-Point	4	5	9
Central	3	4	7
South Eastern	1	1	2
All other fixed*	-5	3	-2
Brisbane	-4	4	0
Central Urban	-1	0	-1
Central Rural	-0.4	1	1
South Eastern Urban	2	3	5
South Eastern Rural	-0.2	-4	-4
Southern Rural	-2	-0.8	-2

*sum of regions, rounding errors apply. † Estimated from an all casualty crash model
NB: Negative values indicate and estimated crash increase (based on statistically non-significant relative risk estimates)

Table 23 Average annual savings associated with fixed speed cameras, by severity and police region: Willingness to Pay approach

	Serious Casualty	Minor Injury	Casualty†
All Tunnel	$9,716,920	$1,107,811	$7,652,730
Point-to-Point	$3,873,838	$550,086	$4,593,783
Central	$2,953,166	$477,859	$3,990,567
South Eastern	$920,672	$72,227	$603,216
All other fixed*	-$4,727,346	$257,823	-$1,253,016
Brisbane	-$2,862,844	$382,262	$18,018
Central Urban	-$1,234,735	-$4,890	-$523,979
Central Rural	-$391,126	$119,253	$555,802
South Eastern Urban	$1,428,478	$320,596	$1,461,401
South Eastern Rural	-$170,936	-$458,749	-$1,486,332
Southern Rural	-$1,496,183	-$100,648	-$1,277,926

*sum of regions † Estimated from an all casualty crash model
NB: Negative values indicate and estimated crash cost increase (based on statistically non-significant relative risk estimates)

Table 24 Average annual savings associated with fixed speed cameras, by severity and police region: Human Capital approach

	Serious Casualty	Minor Injury	Casualty†
All Tunnel	$4,837,735	$194,428	$3,294,147
Point-to-Point	$1,851,830	$95,315	$2,030,120
Central	$1,399,672	$83,007	$1,778,859
South Eastern	$452,158	$12,308	$251,261
All other fixed*	-$2,296,970	$48,164	-$546,918
Brisbane	-$1,425,316	$67,090	$7,756
Central Urban	-$597,501	-$871	-$222,952
Central Rural	-$185,377	$20,715	$247,758
South Eastern Urban	$709,909	$55,498	$606,101
South Eastern Rural	-$83,950	-$78,172	-$619,112
Southern Rural	-$714,735	-$16,095	-$566,470

*sum of regions, rounding errors apply † Estimated from an all casualty crash model

5.3.1. Homogeneity of fixed camera type and site

As has been reported throughout the results for fixed cameras, analysis was conducted to estimate whether there was statistical evidence to support differing (non-homogeneous) crash effects between different camera types and individual cameras. Analysis is based on a chi-squared test of the difference in model fit between a model estimating average effects across all cameras and a model fitting effects specific to each camera type. A significant result indicated non-homogeneous crash effects associated with different camera types or specific cameras.

Tests of homogeneity of camera and regional crash effects were undertaken for the three injury severity groups across the four fixed camera types: (i) red-light, (ii) red-light speed from no-camera, (iii) red-light speed from RLC, and (iv) fixed speed and PtP. The tunnel cameras were analysed separately so were excluded from this study of homogeneity. Results indicate whether camera effectiveness varies by fixed camera type or police region across all fixed camera crashes and if camera effectiveness at specific sites or within police regions varies within a specific camera type. The significance values for the tests of homogeneity of camera types are presented in Table 25 with a low significance value indicating non-homogeneous crash effects across cameras. Evaluation of homogeneity for RLSCs have been carried out on the cameras with a no prior camera period, as well as for all RLC to RLSC upgrades.

There was no statistical evidence to support differential regional effects within a camera type for RLC, fixed and RLSC upgrades from RLC. In contrast, there was strong statistical evidence to show that crash effects were different for different fixed spot camera types. There is no evidence to support heterogeneity of crash effects across RLSC sites, nor across PtP sites, however there was evidence to suggest that the crash effects of RLCs are dependent upon the site of the camera within Queensland.

Table 25 Significance probabilities from tests of homogeneity by injury severity for fixed camera analyses: (X^2, *d.f.*)

		Serious Casualty	Minor injury	Casualty
Camera Type		0.003	0.07	0.001
		(16.1,4)	(8.5,4)	(13.1,4)
Camera sites		<0.0001	<0.0001	<0.0001
		(150.9,75[#])	(189.7, 79[‡])	(259.7,80)
Red-Light †		<0.0001	<0.0001	<0.0001
Red-Light Speed †		(124.6,52)	(130.6,52)	(192.7,52)
(all from no-camera)	*2001-2004, 2012,*	0.52	0.26	0.18
	2014-2017	(6.2,7[‡])	(7.7,6[*])	(11.4,8)
All upgraded from RLC	*2001, 2003-2007,*	0.69	0.33	0.21
	2010/11,2012,2014	(5.6,8)	(9.1,8)	(10.9,8)
Point-to-Point†		0.22	0.96	0.40
		(1.5,1)	(0.003,1)	(0.72,1)
Fixed Speed †		0.50	<0.0001	<0.0001
		(11.3,12)	(40.2,12)	(39.5,12)
Regions		0.84	0.49	0.97
		(1.4,4)	(1.0,4)	(0.6,4)
Red-Light †		0.15	0.83	0.21
Red-Light Speed †		(6.7,4)	(1.5,4)	(5.8,4)
(all from no-camera)		0.50	0.32	0.26
		(2.5,3)	(3.5,3)	(4.04,3)
All upgraded from RLC		0.55	0.85	0.44
		(3.1,4)	(1.4,4)	(3.7,4)
Point-to-Point†		0.22	0.96	0.40
		(1.5,1)	(0.003,1)	(0.72,1)
Fixed Speed †		0.14	0.51	0.59
		(5.5,3)	(2.3,3)	(1.9,3)

† Within model of one camera type
#2012, 2015, 2016, 84 and 116 dropped to allow convergence ‡ similarly 2012 *similarly 2014 and 2015

5.4. MOBILE SPEED CAMERAS

The final evaluation design for the mobile speed camera program detailed in Section 3.3.2 of this report was utilised to estimate the crash benefits of the mobile camera program in Queensland. As described in the evaluation design, data were prepared as time series for analysis. Interrogation of the data revealed a quarterly time period for data aggregation as being the most appropriate to support the analysis. Using quarterly time periods, crash counts in each quarter were sufficiently large enough to ensure model stability but quarter to quarter variation on operations was large enough to ensure reasonable analysis power. Use of monthly counts was investigated but led to too many small cell sizes.

Figure 3 shows an example of the resulting data series for one of the Queensland police regions, Southern Region. Colour coding indicates the comparable treatment and control pairs within urban and rural areas with the dotted line of each pair being the control area data series and the solid line the treatment series. As evident, each region has two treatment and control pairs resulting in ten treatment and control pairs (strata) for analysis across the five police regions.

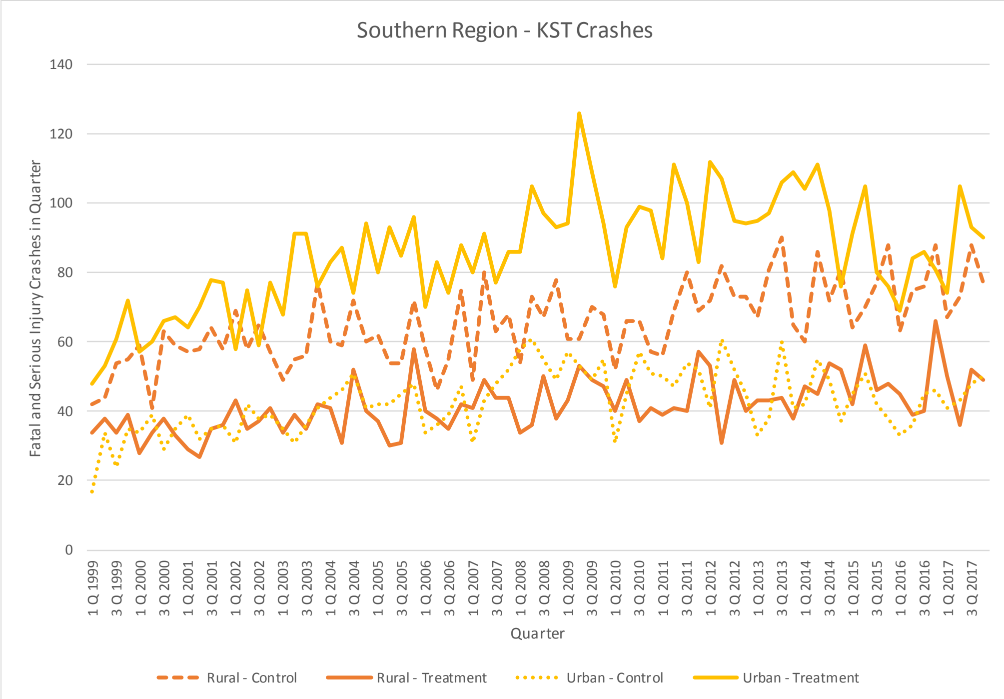


Figure 3 *Quarterly fatal and serious injury crash counts by treatment and control area in rural and urban sectors: Southern Region*

Quarterly mobile speed camera program delivery measures were prepared for inclusion in the model. As described in Section 2.2.3, three measures of speed camera program delivery were used in the model: quarterly hours of overt car-based mobile speed camera operations, quarterly hours of car-based covert mobile speed camera operations, quarterly hours of portable or LTI mobile speed camera use all of which was considered overt. Figure 2 shows the quarterly mobile speed camera delivery measures across the whole of Queensland. For use in the analysis model, data series were derived for each stratum with the mobile speed camera operations delivery for each stratum determined though matching the site data for each camera with the sector in which the site was placed, and then aggregating the data across sectors based on their stratum membership. Trends in program delivery measures for each stratum are not shown here but the general trends in each stratum are broadly similar to the overall trends seen for Queensland as a whole in Figure 2 albeit with different patterns of quarterly variation.

When assigning quarterly delivery data against the crash data within each stratum and treatment and control pair, only the treatment time series data had operations appearing against them consistent with the treatment sectors being defined as those where a mobile speed camera operation had taken place. All the quarterly control data series crash counts had zero mobile speed camera operations delivery assigned to them. In formulating the analysis model, consideration was given to taking the natural log of the mobile speed camera delivery measures to create an econometric elasticity model. Such a model is more easily translated to other contexts since it is relatively scale independent for the delivery measures. However, since all the control series data had zero delivery in each cell, it was not possible to apply the log transformation to the delivery measures. Consequently, the simple log-linear form of the model was used as described.

5.4.1. Analysis model results

Results of application of the analysis model to the quarterly crash data series for each stratum and treatment control pair are summarised in the following tables. Two levels of crash severity were analysed: fatal and serious injury crashes combined, and all casualty crashes. Non-injury crashes have not been reported in Queensland since 2010 so could not be modelled. In addition, a third set of models were estimated for the probability that a casualty crash was serious or fatal (i.e. the estimated by proportion of all casualty crashes that are serious or fatal). The model structure for this additional analysis was the same as described in Equation 3 but with the log transform substituted by a logit transform, and the outcome being modelled being the proportion of casualty crashes in each stratum, treatment control pair and quarter that were serious casualty or fatal crashes. The purpose of the third model set was to formally test whether there were differential associations between the mobile speed camera delivery measures and combined fatal/serious or minor crash outcomes. Where there was no difference, the all casualty crash result, which has narrower statistical confidence limits, could be used to represent the impact of the program across all crash severity levels. Where there was a detected difference, specific estimates could be used for each crash severity level.

For each crash severity considered, two separate models were estimated. The first estimated the average association between the mobile speed camera program outputs and crash outcomes across all ten strata. The second estimated average effects within urban and rural areas across all five police regions. Models were also fitted that estimated average effects across urban and rural areas within each police region and overall effects across urban and rural areas within each police region. Both these analyses lacked sufficient power for the results to achieve statistical significance so the results are not reported here.

Table 26 presents the results of applying the evaluation framework model for mobile speed cameras to all casualty crashes. Information in Table 26 includes the label of the measure of mobile speed camera operation delivery included in the model, the parameter associated with that measure in the model of Equation 3, and the following measures associated with the parameter estimate: the standard error, the upper and lower 95% confidence, the significance probability and the chi-squared value and degrees of freedom (a measure of improvement in model fit) from which the significance values were estimated. The larger the absolute parameter estimate in Table 26, the stronger the association between the hours of mobile camera enforcement and quarterly road trauma counts. Negative parameter estimates indicate a decrease in quarterly road trauma counts associated with an increase in quarterly mobile speed camera hours. The top section of Table 26 gives the model output estimating average association between each of the three mobile speed camera delivery measures across all ten analysis strata. The bottom section of Table 26 gives the model results estimating average effects across urban and rural strata separately.

Table 26 Crash effects evaluation model parameter estimates for the mobile speed camera program considering all casualty crashes

Whole State	Estimate	SE	LCL	UCL	Chi-Sq.	df	Sig Prob
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region	-2.921E-05	7.3848E-06	-4.369E-05	-1.474E-05	15.650	1	<0.001
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region	-7.133E-05	1.6610E-05	-1.04E-04	-3.877E-05	18.442	1	<0.001
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region	-1.557E-06	9.5793E-06	-2.033E-05	1.722E-05	0.026	1	0.871
Urban and Rural							
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Urban	-2.394E-05	7.8639E-06	-3.94E-05	-8.526E-06	9.267	1	0.002
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Rural	-5.664E-05	2.2273E-05	-1.00E-04	-1.299E-05	6.467	1	0.011
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Urban	-7.499E-05	1.7522E-05	-1.09E-04	-4.065E-05	18.316	1	0.000
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Rural	-9.267E-05	5.7149E-05	-2.05E-04	1.934E-05	2.629	1	0.105
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Urban	-2.621E-06	9.7434E-06	-2.17E-05	1.648E-05	0.072	1	0.788
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Rural	1.02E-04	6.6054E-05	-2.71E-05	2.32E-04	2.401	1	0.121

Table 26 shows statistically significant association between quarterly hours of both covert and overt mobile speed camera hours and quarterly counts of all casualty crashes on average across all ten strata. The association with covert hours was much stronger as shown by the much larger negative parameter estimate. No statistically significant association between hours of portable / LTI camera operation and all casualty crashes was estimated in the model for Queensland as a whole. When considering average effects across urban and rural strata separately (bottom of Table 26), covert operations were once again more strongly associated with all casualty crashes compared to overt operations. There was also a significant difference in the level of association for each mobile speed camera enforcement delivery mode between urban and rural areas, with rural areas showing the stronger association with all casualty crashes. No statistically significant associations were observed between portable / LTI operations and all casualty crashes.

Table 27 gives the analogous model output to Table 26 but for the models considering serious casualty crashes (fatal and serious injury crashes combined). Table 28 presents the results of the logistic regression analysis which tests whether the analogous parameters from Tables 26 and 27 are statistically different. Considering the difference measure first, Table 28 shows no statistically significant difference in the association between all casualty crashes and fatal and serious injury crashes for car-based mobile speed camera operations. For portable / LTI mobile speed camera operations, Table 28 shows the association with fatal and serious crashes is much stronger than with all casualty crashes. Table 27 shows statistically significant association between quarterly portable / LTI speed camera hours and serious casualty crash counts on average across the state (top of Table 27). Results by urban and rural areas in the bottom of Table 27 show the overall portable / LTI camera association across the state results entirely from a strong association in urban areas. The association in rural areas was not statistically significant. No statistically significant associations between the car-based mobile speed camera operations and serious casualty crashes were estimated in Table 27. However, Table 28 shows that there was no statistically significant difference between effects on all casualty crashes and serious and fatal crashes meaning the significant all casualty crash estimates can be applied equally across all crash severity levels. The lack of statistical association for the car-based operations for serious casualty crashes is most likely a result of limited statistical power for this analysis rather than a reflection of no actual association given parameter magnitudes and relative values were still consistent with the overall casualty crash effect estimates.

Table 27 Crash effects evaluation model parameter estimates for the mobile speed camera program considering all serious casualty (crashes resulting in death or seriously injury) crashes

Whole State	Estimate	SE	LCL	UCL	Chi-Sq.	df	Sig Prob
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region	-1.286E-05	1.2451E-05	-3.727E-05	1.154E-05	1.067	1	0.302
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region	-3.696E-05	2.6155E-05	-8.823E-05	1.430E-05	1.997	1	0.158
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region	-3.134E-05	1.5263E-05	-6.125E-05	-1.422E-06	4.215	1	0.040
Urban and Rural							
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Urban	-1.80E-06	1.36E-05	-2.85E-05	2.49E-05	0.018	1	0.895
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Rural	-6.30E-05	3.17E-05	-1.25E-04	-8.20E-07	3.943	1	0.047
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Urban	-3.10E-05	2.83E-05	-8.64E-05	2.44E-05	1.204	1	0.272
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Rural	-1.15E-04	7.59E-05	-2.64E-04	3.33E-05	2.313	1	0.128
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Urban	-3.47E-05	1.56E-05	-6.53E-05	-4.01E-06	4.911	1	0.027
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Rural	4.87E-05	8.61E-05	-1.20E-04	2.17E-04	0.320	1	0.571

Table 28 Crash effects evaluation model parameter estimates for the mobile speed camera program considering the odds of a serious casualty crash per casualty crash

Whole State	Estimate	SE	LCL	UCL	Chi-Sq.	df	Sig Prob
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region	2.515E-05	1.5674E-05	-5.571E-06	5.587E-05	2.575	1	0.109
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region	3.207E-05	3.4392E-05	-3.533E-05	9.948E-05	0.870	1	0.351
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region	-5.287E-05	1.9785E-05	-9.165E-05	-1.409E-05	7.141	1	0.008

Urban and Rural							
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Urban	2.82E-05	1.68E-05	-4.71E-06	6.12E-05	2.82E+00	1	0.093
Deployment time (quarterly hours) of Overt Car Mobile Speed Cameras in given Region - Rural	-2.67E-05	4.49E-05	-1.15E-04	6.13E-05	3.53E-01	1	0.552
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Urban	5.74E-05	3.64E-05	-1.39E-05	1.29E-04	2.49E+00	1	0.115
Deployment time (quarterly hours) of Covert Car Mobile Speed Cameras in given Region - Rural	-1.12E-04	1.17E-04	-3.41E-04	1.17E-04	9.25E-01	1	0.336
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Urban	-5.55E-05	2.01E-05	-9.50E-05	-1.60E-05	7.59E+00	1	0.006
Deployment time (quarterly hours) of Portable / LTI Speed Cameras in Given Region - Rural	-2.08E-04	1.36E-04	-4.74E-04	5.83E-05	2.34E+00	1	0.126

In summary, analysis results showed significant association between the quarterly hours of mobile speed camera operations and quarterly crash counts in areas with mobile speed camera enforcement compared to control areas without mobile speed camera enforcement. The association between covert and overt mobile speed camera operations was consistent across crash severity levels with stronger associations measured for covert versus overt operations, stronger effects in rural versus urban areas and different relative effects between covert and overt operations between urban and rural areas. Reflecting these differences, the model estimates in the bold black box in Table 26 have been used to estimate the crash effects of overt and covert car-based mobile camera operations in urban and rural areas. Statistically significant associations between portable / LTI mobile speed cameras was only identified for serious and fatal crashes in urban areas. The bold black box in Table 27 indicates the model estimate that was used for measuring the crash effects of portable / LTI cameras on serious and fatal crashes in urban areas.

Efficacy of utilising the above modelling results to estimate the casualty crash effects of the Queensland mobile speed camera program related to operation of each camera type depends on how well the models fitted predict crash outcome. Lack of model fit would suggest that other factors not represented by the mobile speed camera operations measures are impacting program effectiveness. If this was the case, basing the estimated road safety benefit of the program only on these measures would give a biased measure of effectiveness.

Figure 4 shows the observed and fitted quarterly crash counts in the treatment group across all ten strata from the all casualty crash analysis model with separate urban and rural effects for each mobile speed camera program output measure. Fits for the urban and rural effects model were chosen since parameter estimates from this model have been used to represent program crash effects related to covert and overt car-based operations. As evident from the figure, the model provides highly accurate estimation of the observed data meaning the speed camera operations measures in the data combined with the control area data are providing a highly accurate representation of the data. Concordance between the observed and modelled data, as represented by the square of the correlation between the two series, was very high at 99.7%. From this it can be concluded that the casualty crash model is highly efficacious for estimating program crash effects.

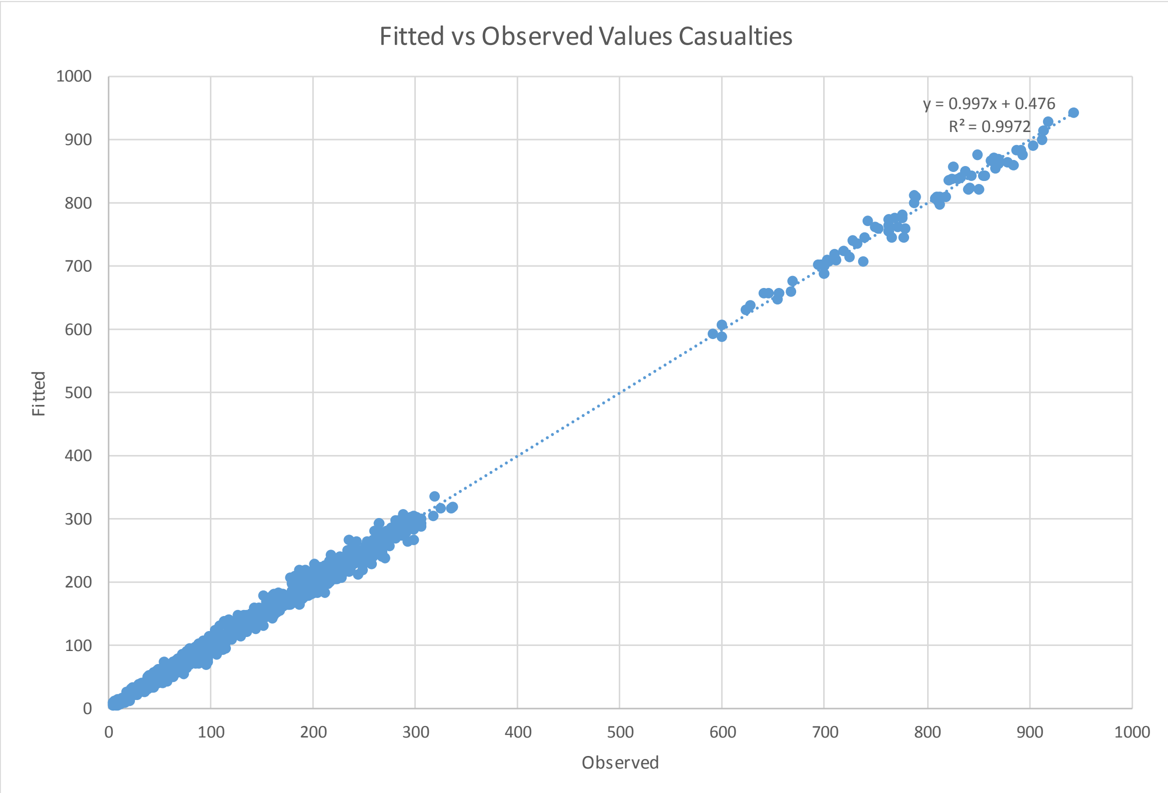


Figure 4 *Observed versus fitted quarterly treatment area casualty crash counts for model with urban and rural program effect estimates*

Figure 5 provides the analogous model fit data for the fatal and serious injury crash count model. Estimates from this model represent the effect of the potable / LTI cameras on serious injury and fatal crashes in urban areas so fit of this model is also critical. Figure 5 shows that the fit of this model to the observed data is also extremely good with a concordance measure of 99.0% showing this model is also efficacious for representing mobile speed camera effects on fatal and serious injury crashes.

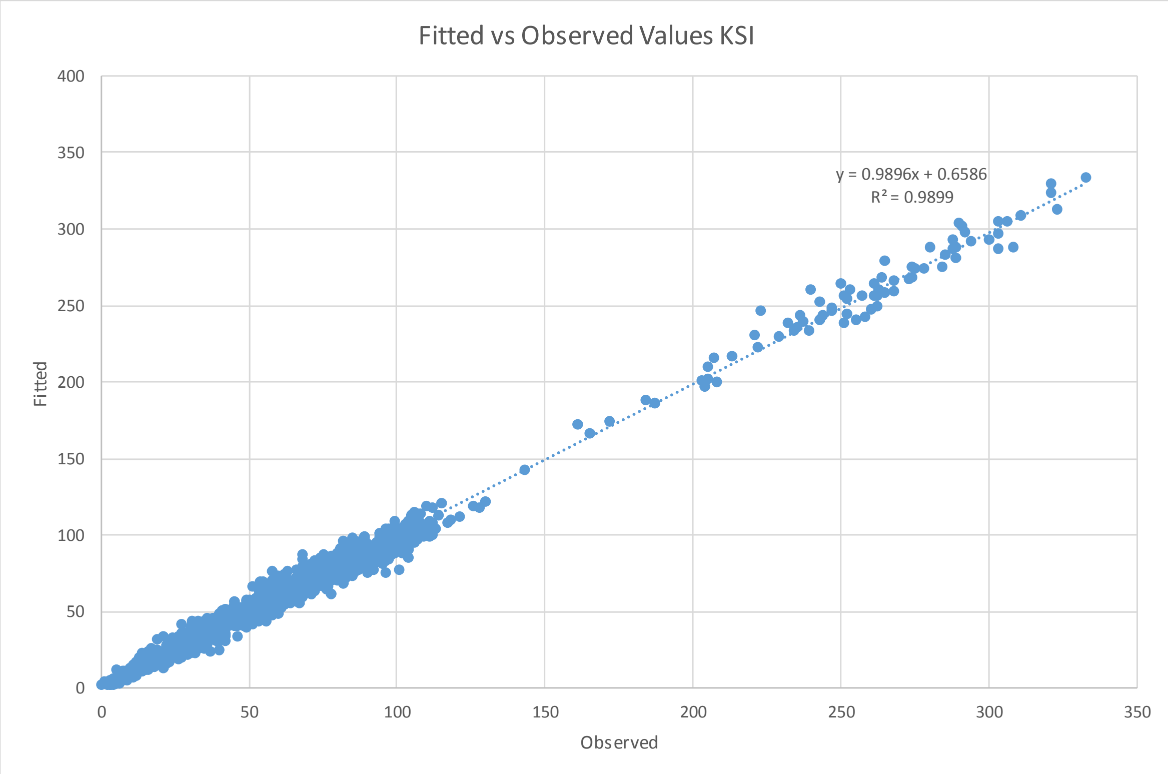


Figure 5 *Observed versus fitted quarterly treatment area fatal and serious injury crash counts for model with urban and rural program effect estimates*

Although the models used to represent the effects of the mobile speed camera delivery measures fit the data very well, there was still some concern that the evaluation model may not represent the impact of the initial introduction of the program on crash frequency. This concern stemmed from the program delivery measures only being available from January 1999, around 20 months after program commencement.

To investigate the potential intervention effects of the Queensland mobile speed camera program, a modification of the analysis model of Equation 3 was fitted to the crash data series from January 1993 to December 1998 with a simple intervention term representing the introduction of the program in April 1997. The model was unable to detect statistically significant effects associated with program introduction.

Further investigation of aggregate information on operations in the early period after program implementation show the hours of enforcement in this period were typically very low. Estimates from the full analysis model reported above would suggest any crash effects in the early period after program implementation would be very small, consistent with the intervention model being unable to detect these effects. Consequently, it was concluded that the fitted models based on 3 chosen camera output measures adequately represented the full impact of the Queensland mobile speed camera program on crash outcomes.

Deriving a sense of the relative impact on each of the three mobile speed camera operations types on crash outcomes using the key parameter estimates from Tables 27 and 28 is difficult. To assist with interpretation, the parameters have been converted to percentage reduction in crashes associated with operation of each camera type in each area over a range of total monthly output hours across Queensland as a whole. The relationships for overt car-based, covert car-based and portable / LTI operations are shown in Figures 6, 7 and 8 respectively.

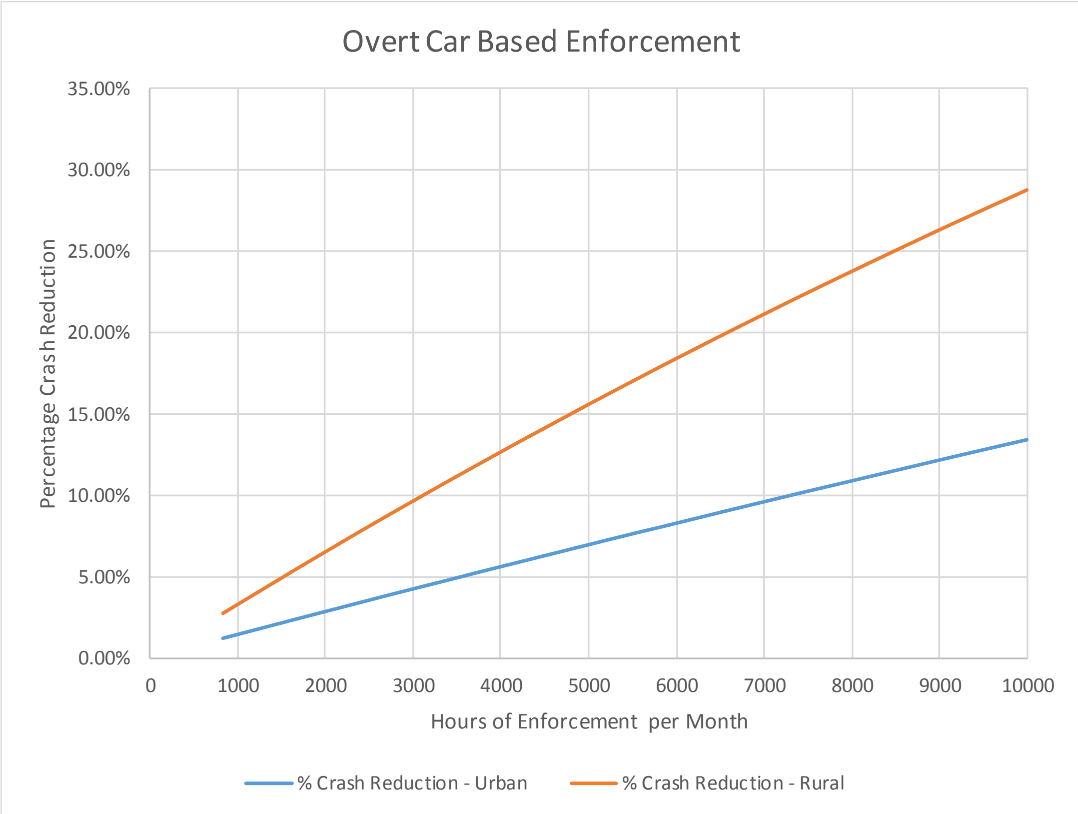


Figure 6 *Relationship between monthly hours of overt car-based mobile speed camera hours across Queensland and estimated percentage casualty crash reductions in urban and rural areas*

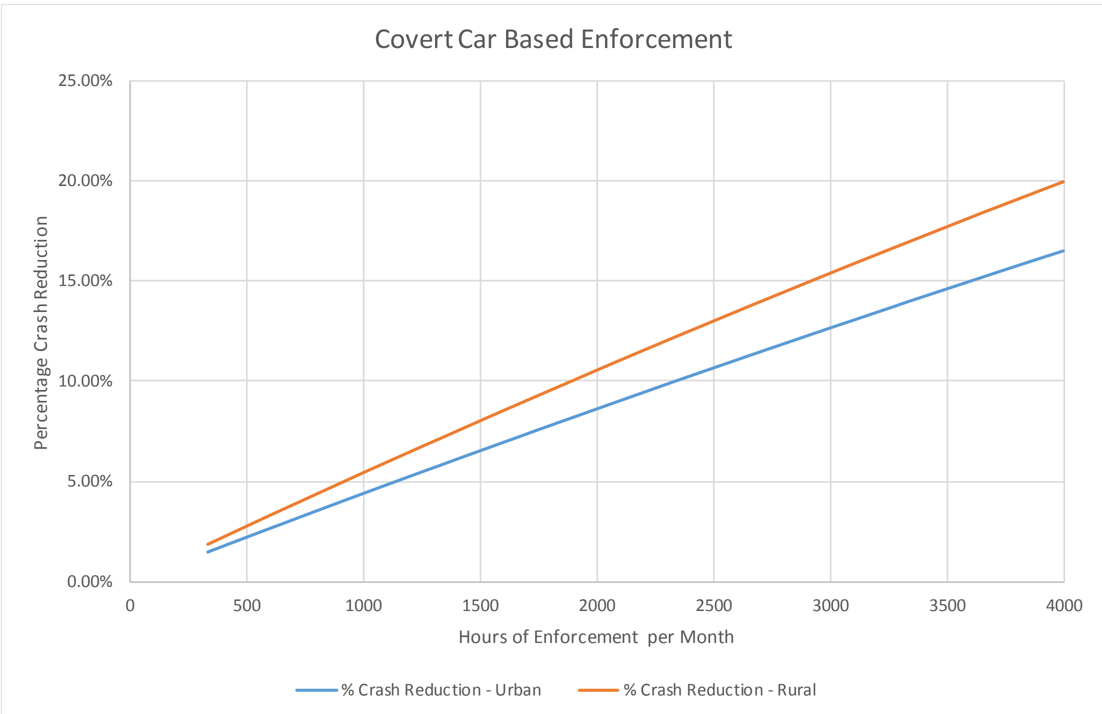


Figure 7 *Relationship between monthly hours of covert car-based mobile speed camera hours across Queensland and estimated percentage casualty crash reductions in urban and rural areas*

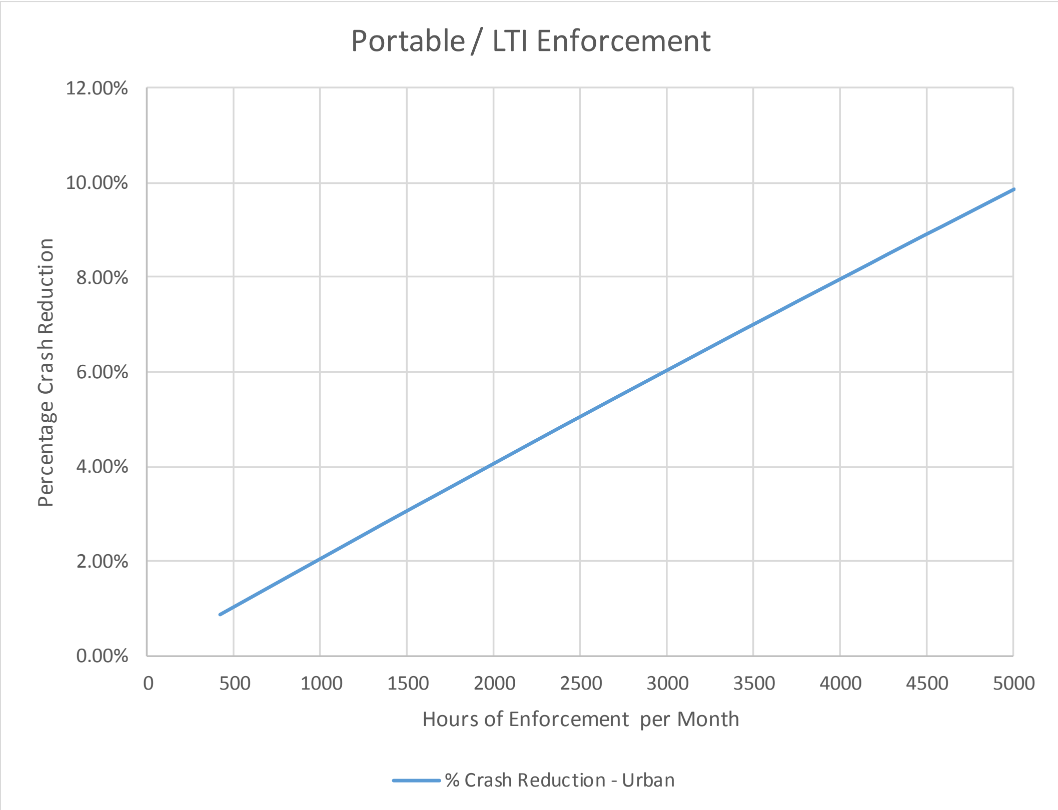


Figure 8 *Relationship between monthly hours of portable / LTI mobile speed camera hours across Queensland and estimated percentage serious casualty crash reductions in urban areas*

Comparison of the results in Figures 6-8 show some notable difference in the relative crash effects of each camera type per hour of enforcement as well as difference between urban and rural operation. Both Figures 5 and 6 show higher percentage crash reductions per hour of enforcement in rural areas compared to urban areas for car-based operations. Notably, the difference between urban and rural areas is much narrower for covert car-based enforcement. Covert enforcement also produces much greater percentage crash reductions per hour of enforcement than overt enforcement. For example, in urban areas a 10% reduction is achieved at 7,200 hours of enforcement per month for overt enforcement compared to 2,300 hours for covert enforcement. In rural areas, the comparable figures are 3,100 hours for overt enforcement and 1,800 hours for covert enforcement. Portable / LTI enforcement in urban areas is slightly more efficient than car-based overt operations with a 10% reduction being achieved at around 5,000 hours of enforcement per month but with benefits only accrued for serious casualty (fatal and serious injury) crashes.

5.4.2. Crash and crash cost savings associated with the mobile speed camera program over time

Results of modelling presented above provide estimates of the relationship between levels of operation of each camera type in urban and rural areas and the corresponding percentage reduction in crashes relative to no enforcement. In order to utilise the estimates to derive the impact of the Queensland mobile speed camera program on crashes in a particular time period, the level of camera operations at the particular time point were applied to the observed crash frequency in that time period to estimate the expected crash frequency had the mobile speed camera program not been in operation. From this, it was possible to derive the absolute crash savings in the time period associated with operation of each camera type and in aggregate. Equation 5 gives the formula for estimating the crash savings, ΔC_{sgt}, in time period *t* for region *s* and treatment and control group *g*. In the equation, C_{sgt} is the observed crash count in the stratum and time period, Measures O_{sgt}, V_{sgt} and L_{sgt} are the hours of each speed camera operation type enforcement in the stratum in time period. Parameters A, B and C represent the association between the hours of mobile speed camera enforcement of each type respectively and crash counts in each time period estimated from the model. Crash savings in the control group will be zero since the speed camera operations hours for all camera types in the control group are zero.

$$\Delta C_{sgt} = C_{sgt}\left(\frac{1}{\exp(A.O_{sgt})\exp(B.V_{sgt})\exp(C.L_{sgt})} - 1\right)\ldots \text{(Equation 5)}$$

Crash savings across aggregate time periods or strata can be calculated by summing the individual stratum and time period savings estimated from Equation 5. Marginal effects of each camera type in each time period and stratum can be estimated by applying Equation 6 as an example.

$$\Delta C_{sgt} = C_{sgt}\left(\frac{1}{\exp(A.O_{sgt})} - 1\right)\ldots \text{(Equation 6)}$$

As demonstrated by the form of Equation 5 which related to the original form of the analysis model, total savings across all camera types are calculated by multiplying the effects of individual cameras, as distinct from simply adding the effects. These methods have been applied to estimate the annual crash savings associated with the Queensland mobile speed camera program by police region and by specific camera type and urban or rural environment.

Table 29 shows the estimated annual fatal crash savings associated with the Queensland mobile speed camera program by police region. Figure 9 gives the corresponding information in Table 29 graphically. Table 30 and corresponding Figure 10 give estimated fatal crash savings associated with the program by year, camera type and urban or rural location. Analogous information for serious injury crash savings and minor injury crash savings are given in Tables 31-34 and Figures 11-14.

Yearly trends in absolute crash savings associated with the Queensland mobile speed camera program can be seen in Figures 9 to 14. After significant growth in effectiveness of the program from 1999 to 2003, reflecting significant growth in total hours of enforcement across the state, effectiveness plateaued over the next ten years. Increasing effects on fatal crashes were observed from 2013 to 2017 corresponding to an increase in enforcement hours and in particular an increase in the number of hours of covert enforcement. Trends over these last four years in serious injury and minor injury crashes have been less clear with the exception that for all crash severities, the greatest crash reductions were estimated for 2017. Greatest estimated effects in 2017 appear to correspond to further increases in the use of covert enforcement and perhaps better targeting of the program to the crash problem. As evident from the charts, the greatest crash benefits have been estimated in Brisbane and Central regions where crash numbers, reflecting population concentration, are highest. In 2017, the greatest contributions of covert enforcement in urban and rural areas was estimated with the addition of significant crash savings associated with portable / LTI camera usage in both 2016 and 2017.

Table 29 Estimated fatal crash savings associated with the Queensland mobile speed camera program by year and police region

Year	Brisbane	Central	Northern	South Eastern	Southern	Total
1999	0.99	0.92	0.34	0.20	0.59	3.05
2000	1.21	1.91	0.45	0.54	1.18	5.28
2001	2.81	3.28	0.76	0.88	1.77	9.49
2002	2.54	4.02	0.97	0.86	1.28	9.66
2003	4.45	6.75	1.11	1.29	1.33	14.93
2004	3.95	5.16	0.85	1.23	1.94	13.13
2005	3.98	6.73	2.14	1.19	2.32	16.35
2006	5.15	6.23	2.29	1.56	2.82	18.06
2007	4.95	7.50	1.48	1.92	2.53	18.39
2008	2.84	5.96	1.97	1.45	2.35	14.58
2009	3.15	7.66	2.11	0.98	1.57	15.47
2010	3.55	6.02	1.70	0.88	1.74	13.89
2011	4.49	5.53	0.90	1.88	2.50	15.29
2012	3.48	7.87	2.57	1.49	2.36	17.77
2013	4.77	6.69	2.13	1.41	3.06	18.06
2014	4.69	4.92	1.87	1.25	2.55	15.28
2015	5.69	5.04	2.58	0.99	2.81	17.11
2016	6.50	4.90	1.90	1.68	3.44	18.43
2017	8.23	7.36	2.25	1.97	3.15	22.97

Table 30 Estimated fatal crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation

Year	Covert - Rural	Overt - Rural	Portable / LTI - Rural	Covert - Urban	Overt - Urban	Portable / LTI - Urban
1999	0.00	1.60	0.00	0.00	1.45	0.00
2000	0.00	3.11	0.00	0.00	2.17	0.00
2001	0.00	5.04	0.00	0.00	4.45	0.00
2002	0.00	5.55	0.00	0.00	4.11	0.00
2003	0.00	7.79	0.00	0.00	7.14	0.00
2004	0.00	6.65	0.00	0.00	6.48	0.00
2005	0.00	9.71	0.00	0.00	6.64	0.00
2006	0.00	9.30	0.00	0.00	8.77	0.00
2007	0.00	10.26	0.00	0.00	8.12	0.00
2008	0.00	8.48	0.00	0.00	6.09	0.00
2009	0.00	9.71	0.00	0.00	5.77	0.00
2010	0.41	7.46	0.00	1.42	4.59	0.00
2011	1.95	5.93	0.00	3.54	3.80	0.07
2012	2.65	7.19	0.00	3.37	4.08	0.48
2013	2.78	6.80	0.00	2.97	3.78	1.72
2014	2.06	4.92	0.00	3.05	3.43	1.82
2015	2.09	5.12	0.00	2.48	4.16	3.26
2016	2.54	3.99	0.00	2.38	4.51	5.00
2017	4.46	4.81	0.00	5.31	4.21	4.17

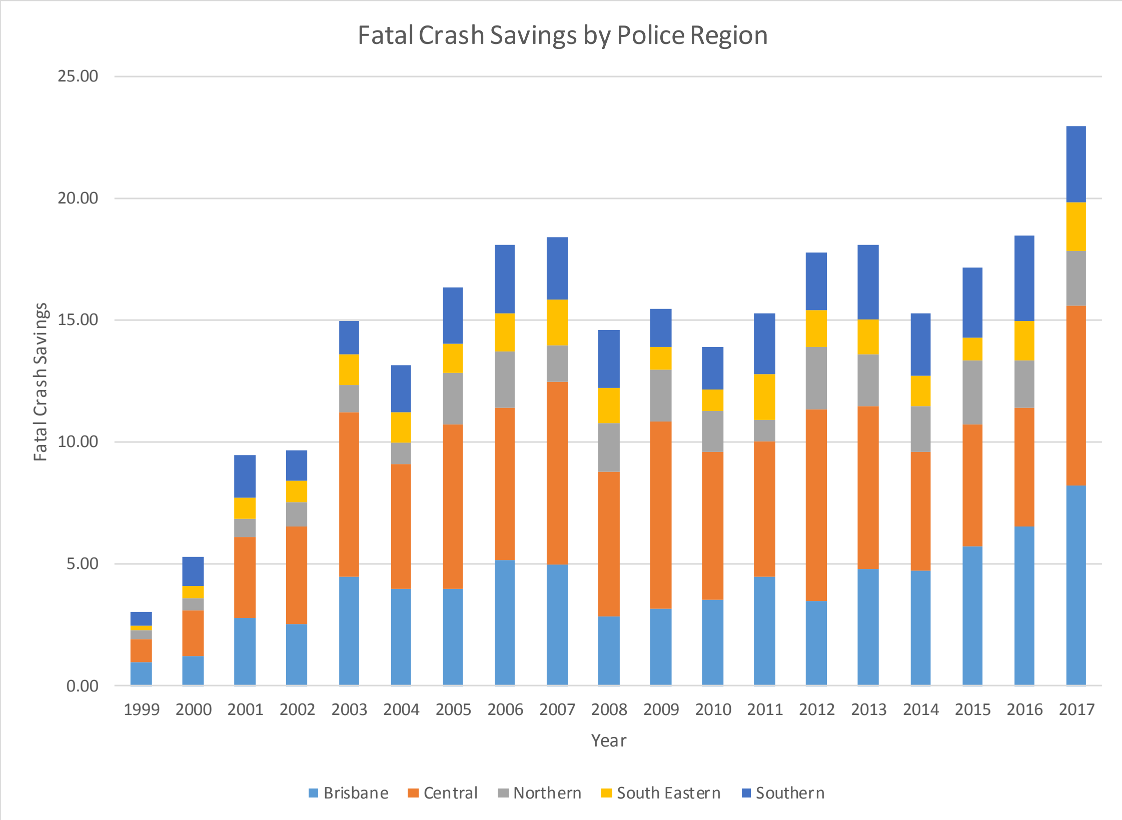


Figure 9 *Estimated fatal crash savings associated with the Queensland mobile speed camera program by year and police region*

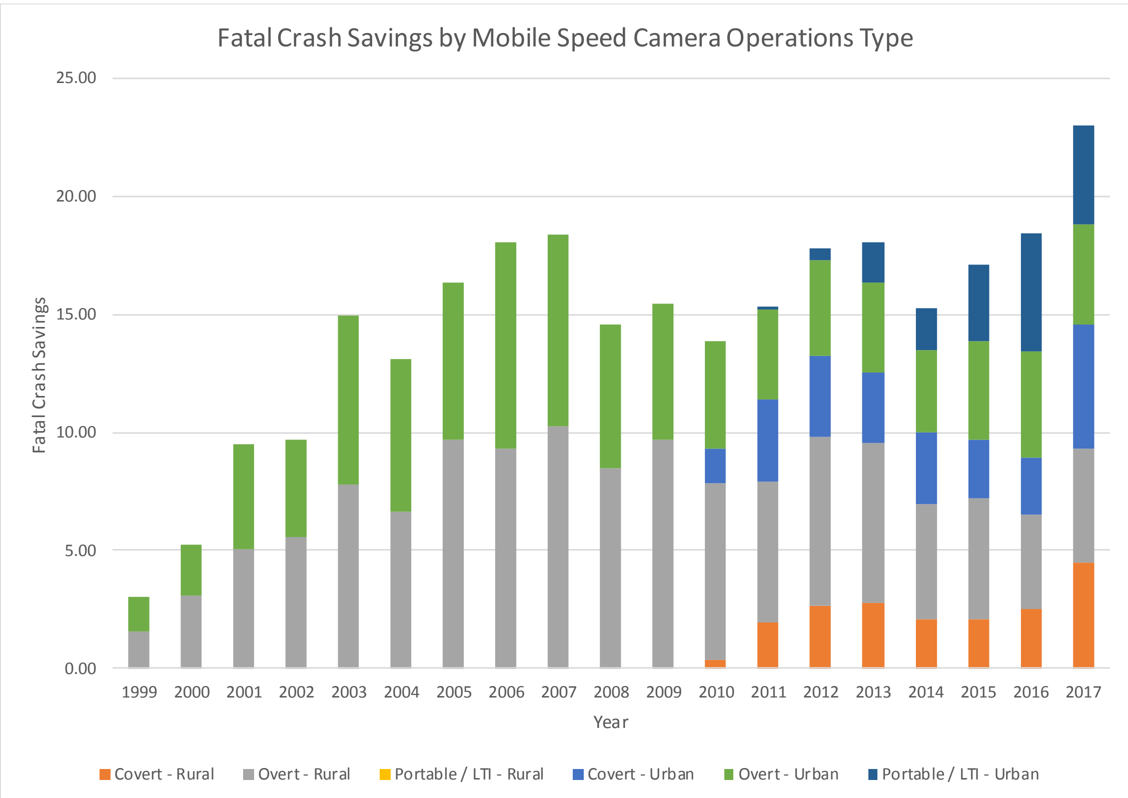


Figure 10 *Estimated fatal crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation*

Table 31 Estimated serious injury crash savings associated with the Queensland mobile speed camera program by year and police region

Year	Brisbane	Central	Northern	South Eastern	Southern	Total
1999	21.05	7.49	3.76	4.16	5.40	41.86
2000	37.64	13.95	7.45	8.79	11.22	79.05
2001	74.57	27.37	10.65	18.95	17.52	149.07
2002	85.28	34.73	13.67	18.53	17.47	169.68
2003	130.91	52.34	20.37	33.57	26.99	264.18
2004	136.16	56.23	23.24	30.05	27.12	272.79
2005	147.49	64.62	30.55	27.45	31.22	301.34
2006	148.53	57.27	31.39	27.41	30.62	295.22
2007	149.52	65.58	28.15	28.38	33.27	304.90
2008	147.05	68.69	29.05	31.29	34.44	310.51
2009	153.66	67.89	26.44	28.70	38.21	314.90
2010	215.24	72.91	34.14	37.22	39.55	399.06
2011	248.56	90.88	48.14	48.43	47.68	483.69
2012	254.07	93.24	45.38	41.53	50.37	484.60
2013	344.14	118.78	65.30	61.51	59.90	649.63
2014	331.64	116.06	63.85	67.83	65.23	644.61
2015	300.07	106.52	60.01	69.24	68.85	604.69
2016	272.38	88.76	51.74	71.38	59.87	544.12
2017	382.93	107.58	65.38	77.30	79.72	712.91

Table 32 Estimated fatal crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation

Year	Covert - Rural	Overt - Rural	Portable / LTI - Rural	Covert - Urban	Covert - Urban	Portable / LTI - Urban
1999	0.00	11.10	0.00	0.00	30.76	0.00
2000	0.00	21.54	0.00	0.00	57.50	0.00
2001	0.00	35.55	0.00	0.00	113.52	0.00
2002	0.00	40.34	0.00	0.00	129.33	0.00
2003	0.00	60.07	0.00	0.00	204.11	0.00
2004	0.00	64.59	0.00	0.00	208.20	0.00
2005	0.00	79.54	0.00	0.00	221.79	0.00
2006	0.00	71.43	0.00	0.00	223.79	0.00
2007	0.00	75.53	0.00	0.00	229.37	0.00
2008	0.00	75.44	0.00	0.00	235.07	0.00
2009	0.00	75.40	0.00	0.00	239.50	0.00
2010	5.08	71.87	0.00	81.95	240.16	0.00
2011	22.67	69.27	0.00	187.86	199.74	4.16
2012	24.51	66.60	0.00	161.94	205.67	25.88
2013	33.15	79.85	0.00	185.03	239.32	112.27
2014	32.61	73.97	0.00	195.45	221.68	120.90
2015	28.26	66.98	0.00	133.25	209.55	166.66
2016	31.04	45.33	0.00	94.20	175.25	198.29
2017	51.42	54.64	0.00	229.37	195.38	182.10

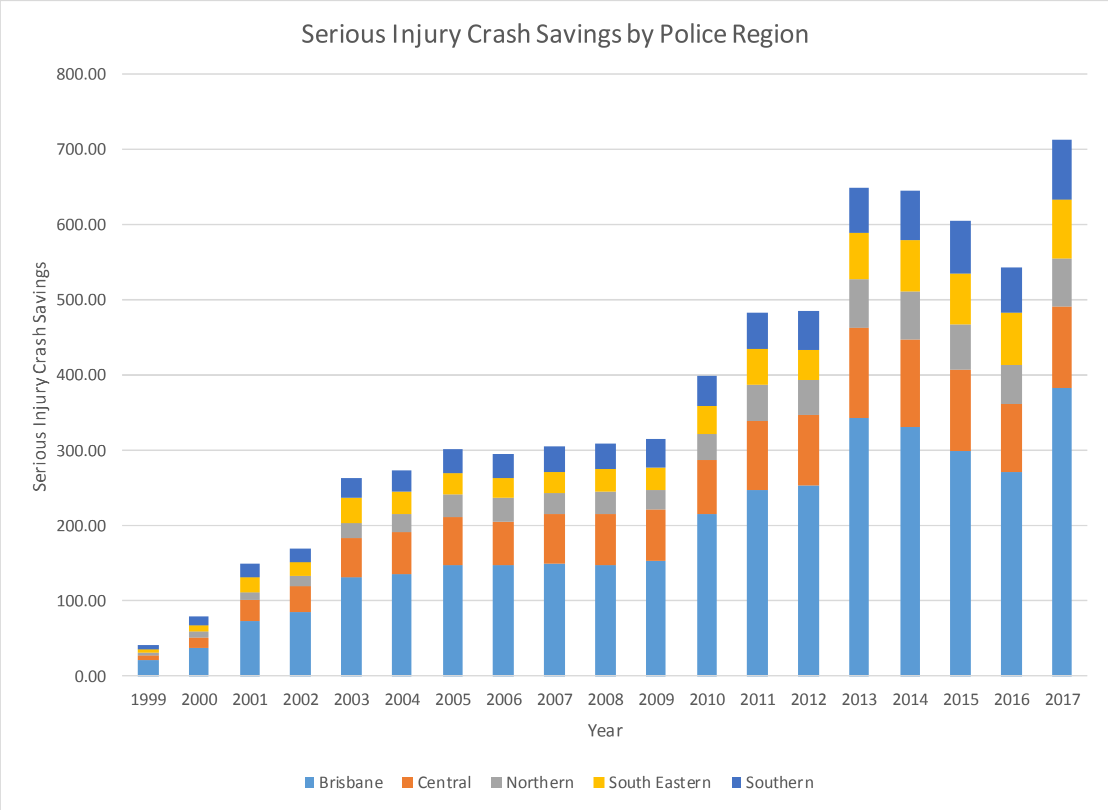


Figure 11 *Estimated serious crash savings associated with the Queensland mobile speed camera program by year and police region*

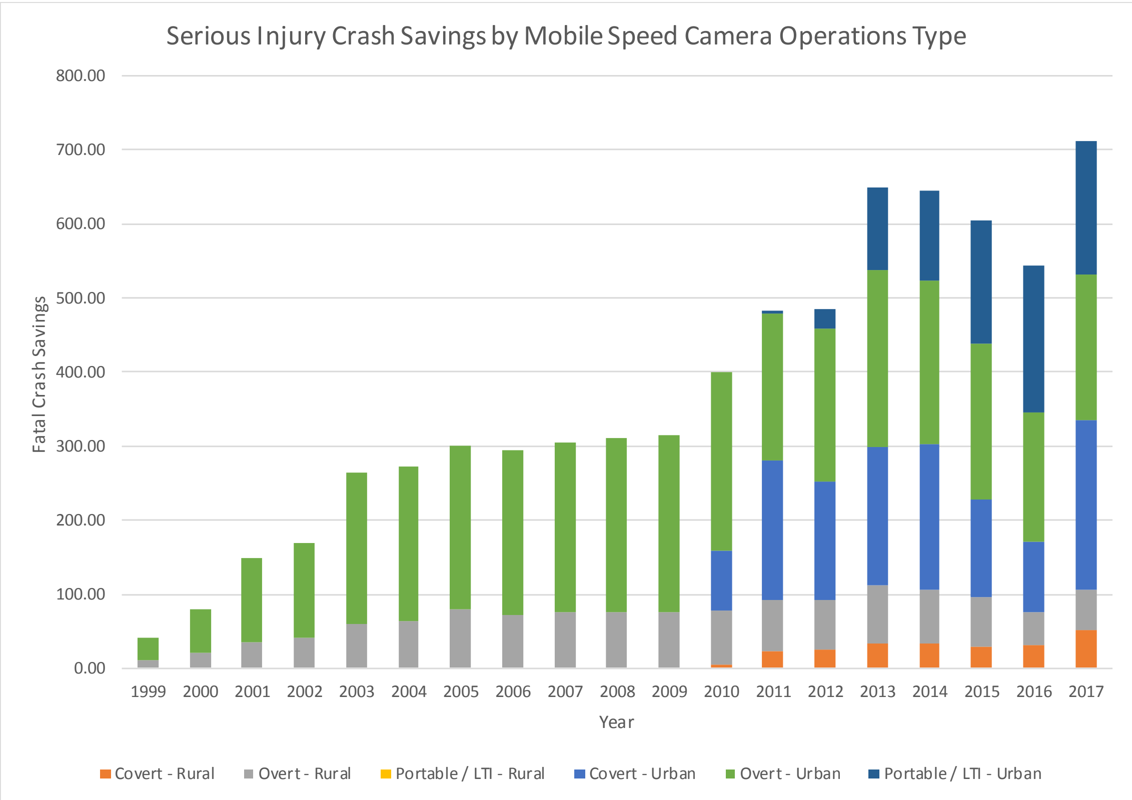


Figure 12 *Estimated serious crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation*

Table 33 Estimated minor injury crash savings associated with the Queensland mobile speed camera program by year and police region

Year	Brisbane	Central	Northern	South Eastern	Southern	Total
1999	57.87	12.84	6.54	8.04	10.13	95.41
2000	101.16	22.72	11.08	19.20	18.22	172.38
2001	230.04	44.52	18.33	44.06	34.25	371.21
2002	228.59	58.01	21.69	42.86	32.78	383.93
2003	338.06	76.62	31.24	62.42	47.02	555.37
2004	308.05	74.08	33.32	51.34	43.87	510.65
2005	297.68	86.22	36.72	50.54	49.92	521.08
2006	332.84	94.75	43.87	52.32	51.11	574.89
2007	320.64	107.65	46.53	56.02	58.73	589.57
2008	292.46	93.01	40.22	55.52	57.72	538.92
2009	271.07	92.02	36.83	52.08	50.33	502.33
2010	376.49	100.93	42.92	63.47	52.48	636.30
2011	443.45	103.23	56.04	81.56	56.68	740.96
2012	410.01	106.18	47.43	68.53	54.98	687.14
2013	396.94	113.56	56.76	71.55	57.79	696.60
2014	413.73	108.90	55.60	92.56	56.48	727.27
2015	337.47	96.33	47.51	72.79	59.34	613.43
2016	287.43	52.97	41.49	68.17	46.90	496.95
2017	509.53	87.01	42.03	77.89	67.06	783.52

Table 34 Estimated minor crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation

Year	Covert - Rural	Overt - Rural	Portable / LTI - Rural	Covert - Urban	Covert - Urban	Portable / LTI - Urban
1999	0.00	15.16	0.00	0.00	80.25	0.00
2000	0.00	27.77	0.00	0.00	144.61	0.00
2001	0.00	49.58	0.00	0.00	321.63	0.00
2002	0.00	57.27	0.00	0.00	326.66	0.00
2003	0.00	70.65	0.00	0.00	484.72	0.00
2004	0.00	72.17	0.00	0.00	438.49	0.00
2005	0.00	92.99	0.00	0.00	428.08	0.00
2006	0.00	96.83	0.00	0.00	478.06	0.00
2007	0.00	105.66	0.00	0.00	483.91	0.00
2008	0.00	86.46	0.00	0.00	452.46	0.00
2009	0.00	85.87	0.00	0.00	416.46	0.00
2010	5.67	83.72	0.00	138.78	408.13	0.00
2011	22.38	66.46	0.00	313.94	338.18	0.00
2012	22.71	61.11	0.00	264.97	338.35	0.00
2013	27.58	66.78	0.00	265.80	336.45	0.00
2014	27.42	62.75	0.00	299.66	337.44	0.00
2015	23.32	55.61	0.00	203.83	330.68	0.00
2016	23.26	32.41	0.00	150.36	290.92	0.00
2017	38.28	40.39	0.00	373.32	331.53	0.00

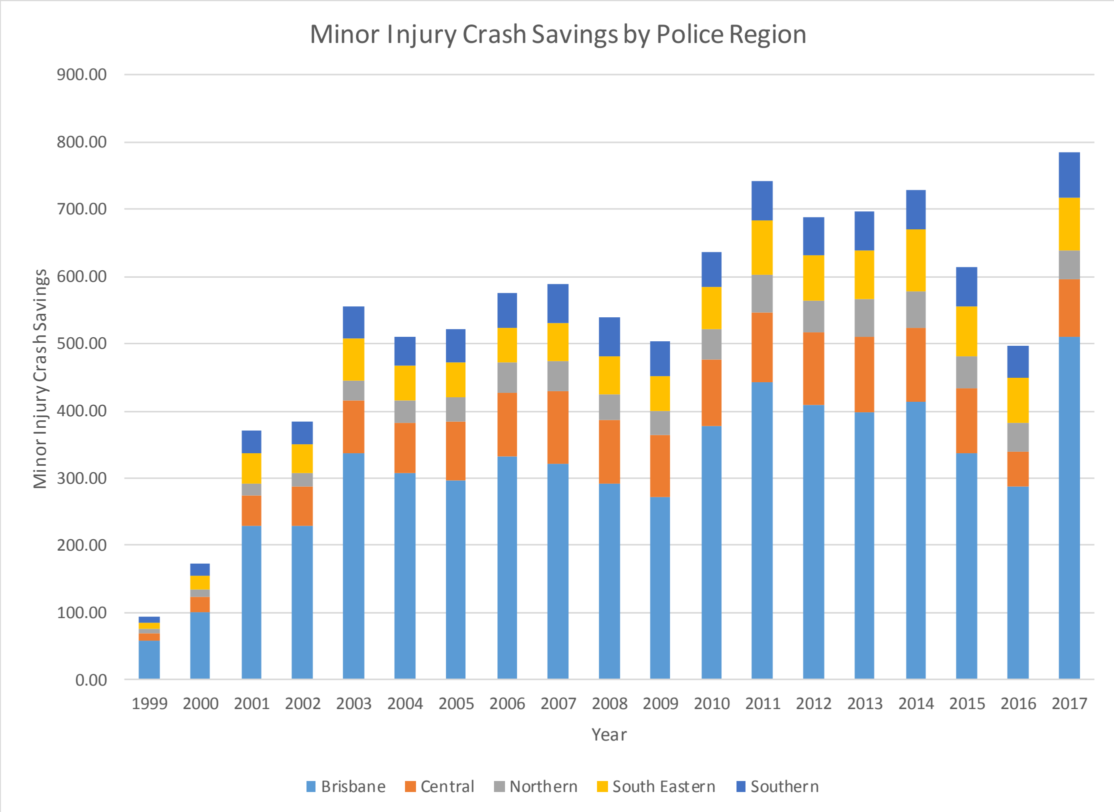


Figure 13 *Estimated minor crash savings associated with the Queensland mobile speed camera program by year and police region*

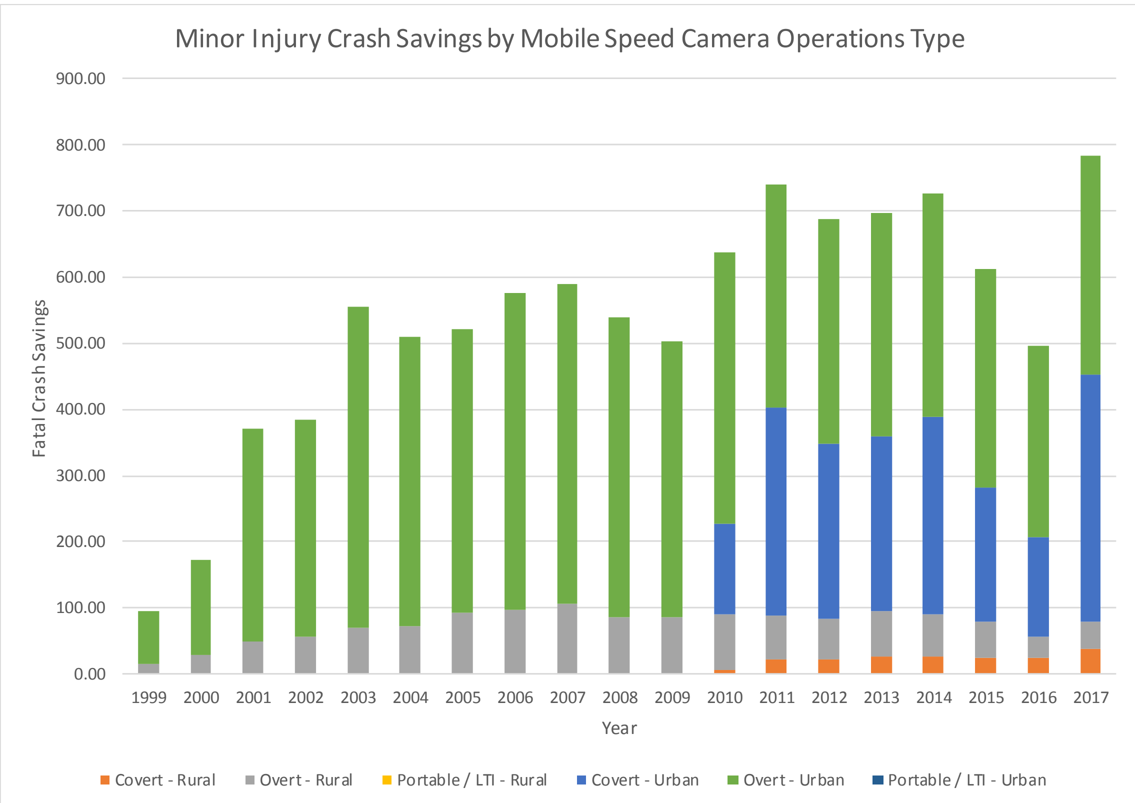


Figure 14 *Estimated minor crash savings associated with the Queensland mobile speed camera program by year camera type and level of urbanisation*

In order to estimate savings to the community through crash reductions associated with the Queensland mobile speed camera program, the estimated crash savings given in Tables 29-34 were converted to community cost savings using the per crash cost values given in Table 1 of Section 2.3. It was not necessary to use the average crash cost tables by severity and region derived for fixed cameras since estimated crash savings by individual severity and region were produced directly for the mobile speed camera program. Two sets of estimates were produced, the first based on the WTP valuation of crashes and the second based on crash costs derived using the HC methodology. The former is presented in Table 35 with the later presented in Table 36. Reflecting the relative costs by crash severity of the two methods, WTP estimates of savings associated with the mobile camera program are more than double those based on HC methodology.

Reflecting the growth in crash savings over the life of the program from 1999 to 2017, crash cost savings associated with the program have also increased significantly over this time. In 2017, it was estimated that the program was associated with cost savings to the community of $676M based on the WTP methodology or $309M based on HC costs, the greatest cost savings estimated for any year of the program. Also evident from the tables is that the vast majority of the savings, around 87% were estimated to be derived from estimated savings in fatal and serious injury crashes. Over half of the estimated savings also derived from the Brisbane region, not due to fatal crash savings being predominant in this area, but due to the high proportion of serious injury crash savings derived from this region. This result highlights the importance of not only targeting fatalities with a mobile speed camera program but particularly targeting the high proportion of serious injuries occurring in dense urban areas.

Table 35 Estimated community cost savings associated with the Queensland mobile speed camera program by year crash severity and region: Willingness to pay cost basis

Year	Brisbane	Central	Northern	South Eastern	Southern	Total
Fatal and Serious Injury Crashes						
1999	$17,719,888	$6,760,044	$3,299,033	$3,502,197	$4,818,875	$36,100,036
2000	$31,225,722	$12,752,803	$6,352,146	$7,496,549	$9,963,791	$67,791,011
2001	$62,203,304	$24,637,578	$9,177,223	$15,936,652	$15,505,757	$127,460,514
2002	$70,592,284	$31,149,650	$11,763,678	$15,592,426	$15,071,167	$144,169,205
2003	$108,817,426	$47,499,357	$17,269,268	$28,023,001	$22,769,326	$224,378,378
2004	$112,626,504	$49,354,800	$19,365,260	$25,138,878	$23,355,882	$229,841,325
2005	$121,763,044	$57,353,056	$26,280,216	$23,029,518	$26,960,237	$255,386,071
2006	$123,544,000	$51,050,430	$27,075,966	$23,288,890	$26,882,313	$251,841,599
2007	$124,176,230	$58,744,420	$23,823,660	$24,358,979	$28,780,898	$259,884,185
2008	$120,490,601	$60,012,624	$24,942,002	$26,312,829	$29,575,653	$261,333,709
2009	$126,057,150	$60,739,391	$22,954,181	$23,859,836	$31,975,884	$265,586,442
2010	$175,878,233	$63,450,024	$28,814,858	$30,626,492	$33,191,184	$331,960,791
2011	$203,417,073	$77,503,810	$39,422,659	$40,441,398	$40,338,509	$401,123,449
2012	$207,040,117	$81,284,642	$38,545,338	$34,584,338	$42,389,550	$403,843,985
2013	$280,484,954	$100,870,915	$54,202,269	$50,575,035	$50,608,083	$536,741,256
2014	$270,369,333	$97,251,469	$52,832,269	$55,532,616	$54,491,443	$530,477,130
2015	$245,797,072	$89,681,393	$50,312,358	$56,452,634	$57,611,706	$499,855,164
2016	$224,191,566	$75,293,390	$43,118,468	$58,725,900	$50,892,268	$452,221,592
2017	$314,450,860	$92,403,526	$54,368,817	$63,723,156	$66,619,594	$591,565,953
Minor Injury Crashes						
1999	$6,251,007	$1,386,799	$706,397	$868,241	$1,093,955	$10,306,399
2000	$10,927,712	$2,454,043	$1,197,096	$2,073,746	$1,968,372	$18,620,968
2001	$24,850,310	$4,809,309	$1,980,404	$4,759,180	$3,700,281	$40,099,483
2002	$24,693,651	$6,266,441	$2,343,231	$4,629,740	$3,540,810	$41,473,874
2003	$36,518,451	$8,277,271	$3,375,003	$6,742,850	$5,079,294	$59,992,868
2004	$33,276,431	$8,002,449	$3,599,081	$5,545,519	$4,739,371	$55,162,850
2005	$32,156,754	$9,313,792	$3,966,289	$5,459,359	$5,392,521	$56,288,715
2006	$35,955,082	$10,235,673	$4,738,572	$5,652,012	$5,520,594	$62,101,933
2007	$34,637,117	$11,628,460	$5,026,384	$6,051,337	$6,344,053	$63,687,351
2008	$31,592,731	$10,046,876	$4,344,238	$5,996,965	$6,235,670	$58,216,481
2009	$29,282,507	$9,939,909	$3,978,055	$5,625,445	$5,437,245	$54,263,160
2010	$40,670,344	$10,902,382	$4,636,696	$6,856,657	$5,669,104	$68,735,183
2011	$47,903,571	$11,151,200	$6,053,553	$8,809,973	$6,122,816	$80,041,112
2012	$44,291,009	$11,470,437	$5,123,650	$7,403,382	$5,939,165	$74,227,643
2013	$42,878,871	$12,267,382	$6,131,808	$7,729,050	$6,242,450	$75,249,562
2014	$44,692,753	$11,763,935	$6,006,298	$9,998,289	$6,101,649	$78,562,924
2015	$36,454,689	$10,405,988	$5,132,347	$7,862,919	$6,409,671	$66,265,615
2016	$31,049,396	$5,721,716	$4,481,845	$7,363,902	$5,066,087	$53,682,946
2017	$55,041,770	$9,398,842	$4,540,267	$8,413,659	$7,243,889	$84,638,427

All Casualty Crashes						
1999	$23,970,896	$8,146,842	$4,005,430	$4,370,437	$5,912,830	$46,406,435
2000	$42,153,433	$15,206,846	$7,549,242	$9,570,295	$11,932,163	$86,411,979
2001	$87,053,614	$29,446,887	$11,157,627	$20,695,831	$19,206,038	$167,559,997
2002	$95,285,935	$37,416,091	$14,106,910	$20,222,167	$18,611,976	$185,643,079
2003	$145,335,877	$55,776,628	$20,644,270	$34,765,850	$27,848,620	$284,371,246
2004	$145,902,935	$57,357,249	$22,964,341	$30,684,398	$28,095,252	$285,004,175
2005	$153,919,798	$66,666,848	$30,246,504	$28,488,877	$32,352,759	$311,674,787
2006	$159,499,082	$61,286,103	$31,814,538	$28,940,901	$32,402,907	$313,943,532
2007	$158,813,347	$70,372,880	$28,850,044	$30,410,316	$35,124,951	$323,571,537
2008	$152,083,332	$70,059,501	$29,286,240	$32,309,794	$35,811,323	$319,550,190
2009	$155,339,657	$70,679,300	$26,932,236	$29,485,281	$37,413,128	$319,849,602
2010	$216,548,577	$74,352,406	$33,451,554	$37,483,150	$38,860,288	$400,695,974
2011	$251,320,643	$88,655,009	$45,476,212	$49,251,371	$46,461,325	$481,164,561
2012	$251,331,126	$92,755,079	$43,668,988	$41,987,721	$48,328,715	$478,071,628
2013	$323,363,825	$113,138,297	$60,334,077	$58,304,085	$56,850,533	$611,990,818
2014	$315,062,085	$109,015,404	$58,838,567	$65,530,905	$60,593,092	$609,040,054
2015	$282,251,761	$100,087,381	$55,444,705	$64,315,553	$64,021,377	$566,120,778
2016	$255,240,963	$81,015,106	$47,600,312	$66,089,802	$55,958,355	$505,904,538
2017	$369,492,630	$101,802,368	$58,909,084	$72,136,815	$73,863,483	$676,204,381

Table 36 Estimated community cost savings associated with the Queensland mobile speed camera program by year crash severity and region: Human capital cost basis

Year	Brisbane	Central	Northern	South Eastern	Southern	Total
Fatal and Serious Injury Crashes						
1999	$8,822,141	$3,365,600	$1,642,479	$1,743,627	$2,399,157	$17,973,003
2000	$15,546,244	$6,349,195	$3,162,521	$3,732,282	$4,960,639	$33,750,880
2001	$30,968,948	$12,266,227	$4,569,033	$7,934,327	$7,719,799	$63,458,334
2002	$35,145,541	$15,508,371	$5,856,743	$7,762,948	$7,503,431	$71,777,033
2003	$54,176,563	$23,648,344	$8,597,792	$13,951,716	$11,336,087	$111,710,502
2004	$56,072,975	$24,572,107	$9,641,317	$12,515,808	$11,628,114	$114,430,321
2005	$60,621,754	$28,554,171	$13,084,042	$11,465,628	$13,422,602	$127,148,197
2006	$61,508,432	$25,416,305	$13,480,220	$11,594,760	$13,383,806	$125,383,523
2007	$61,823,198	$29,246,885	$11,861,005	$12,127,522	$14,329,048	$129,387,658
2008	$59,988,247	$29,878,282	$12,417,790	$13,100,279	$14,724,730	$130,109,327
2009	$62,759,645	$30,240,115	$11,428,120	$11,879,016	$15,919,725	$132,226,621
2010	$87,563,899	$31,589,648	$14,345,956	$15,247,908	$16,524,782	$165,272,193
2011	$101,274,568	$38,586,559	$19,627,226	$20,134,422	$20,083,197	$199,705,971
2012	$103,078,361	$40,468,909	$19,190,436	$17,218,387	$21,104,341	$201,060,435
2013	$139,644,092	$50,220,260	$26,985,500	$25,179,621	$25,196,075	$267,225,548
2014	$134,607,862	$48,418,259	$26,303,423	$27,647,835	$27,129,470	$264,106,849
2015	$122,374,154	$44,649,371	$25,048,843	$28,105,881	$28,682,945	$248,861,195
2016	$111,617,495	$37,486,065	$21,467,245	$29,237,665	$25,337,561	$225,146,030
2017	$156,554,583	$46,004,630	$27,068,418	$31,725,632	$33,167,671	$294,520,934
Minor Injury Crashes						
1999	$1,097,097	$243,393	$123,978	$152,383	$191,997	$1,808,848
2000	$1,917,893	$430,702	$210,099	$363,958	$345,464	$3,268,116
2001	$4,361,411	$844,069	$347,575	$835,271	$649,426	$7,037,752
2002	$4,333,916	$1,099,806	$411,254	$812,553	$621,438	$7,278,967
2003	$6,409,255	$1,452,721	$592,338	$1,183,419	$891,453	$10,529,186
2004	$5,840,256	$1,404,488	$631,665	$973,279	$831,794	$9,681,483
2005	$5,643,745	$1,634,638	$696,113	$958,157	$946,427	$9,879,080
2006	$6,310,379	$1,796,435	$831,654	$991,969	$968,905	$10,899,342
2007	$6,079,067	$2,040,880	$882,167	$1,062,054	$1,113,428	$11,177,595
2008	$5,544,755	$1,763,300	$762,445	$1,052,511	$1,094,406	$10,217,417
2009	$5,139,294	$1,744,527	$698,178	$987,307	$954,276	$9,523,580
2010	$7,137,942	$1,913,448	$813,774	$1,203,393	$994,969	$12,063,526
2011	$8,407,426	$1,957,117	$1,062,443	$1,546,215	$1,074,599	$14,047,799
2012	$7,773,395	$2,013,145	$899,238	$1,299,348	$1,042,367	$13,027,493
2013	$7,525,555	$2,153,015	$1,076,177	$1,356,505	$1,095,596	$13,206,847
2014	$7,843,904	$2,064,656	$1,054,149	$1,754,773	$1,070,884	$13,788,366
2015	$6,398,064	$1,826,327	$900,764	$1,380,000	$1,124,944	$11,630,099
2016	$5,449,396	$1,004,203	$786,596	$1,292,418	$889,135	$9,421,749
2017	$9,660,232	$1,649,565	$796,850	$1,476,659	$1,271,355	$14,854,661

All Casualty Crashes						
1999	$9,919,238	$3,608,993	$1,766,456	$1,896,009	$2,591,154	$19,781,851
2000	$17,464,137	$6,779,897	$3,372,620	$4,096,239	$5,306,103	$37,018,996
2001	$35,330,359	$13,110,296	$4,916,608	$8,769,598	$8,369,225	$70,496,086
2002	$39,479,457	$16,608,177	$6,267,997	$8,575,502	$8,124,869	$79,056,001
2003	$60,585,817	$25,101,065	$9,190,129	$15,135,136	$12,227,540	$122,239,688
2004	$61,913,232	$25,976,595	$10,272,981	$13,489,087	$12,459,908	$124,111,803
2005	$66,265,499	$30,188,810	$13,780,154	$12,423,785	$14,369,029	$137,027,277
2006	$67,818,812	$27,212,740	$14,311,873	$12,586,730	$14,352,710	$136,282,865
2007	$67,902,265	$31,287,765	$12,743,172	$13,189,576	$15,442,475	$140,565,253
2008	$65,533,001	$31,641,582	$13,180,236	$14,152,790	$15,819,136	$140,326,744
2009	$67,898,939	$31,984,641	$12,126,298	$12,866,322	$16,874,001	$141,750,201
2010	$94,701,841	$33,503,096	$15,159,730	$16,451,301	$17,519,751	$177,335,719
2011	$109,681,994	$40,543,676	$20,689,668	$21,680,636	$21,157,796	$213,753,770
2012	$110,851,756	$42,482,055	$20,089,674	$18,517,735	$22,146,708	$214,087,928
2013	$147,169,647	$52,373,275	$28,061,677	$26,536,126	$26,291,670	$280,432,395
2014	$142,451,767	$50,482,915	$27,357,572	$29,402,608	$28,200,354	$277,895,215
2015	$128,772,218	$46,475,698	$25,949,607	$29,485,881	$29,807,889	$260,491,293
2016	$117,066,890	$38,490,268	$22,253,842	$30,530,083	$26,226,696	$234,567,779
2017	$166,214,815	$47,654,195	$27,865,268	$33,202,290	$34,439,027	$309,375,596

5.5. STATE-WIDE ESTIMATES OF CDOP EFFECTIVENESS IN 2017

A primary objective of this study was to estimate the overall effects of the CDOP in the 2017 calendar year. Each of the sections above has estimated the impacts of the various elements of the CDOP on crash frequency and cost, estimating total crash savings and their associated cost. Since the evaluation design has estimated discrete effects of each CDOP element, the overall impact of the program in 2017 can be estimated by summing estimates from the individual elements to give the state-wide impact. Table 37 shows the resulting estimated crash savings across all CDOP elements by region and for the whole of Queensland. Savings are presented for serious casualty crashes (fatal and serious injury), minor injury crashes and total casualty crash savings, the sum of the previous categories.

Table 37 Overall crash savings associated with the CDOP in 2017 by region, crash severity and in total.

	Serious Casualty	Minor Injury	Casualty†
Brisbane	409	535	944
Central	119	95	215
Northern	70	44	114
South Eastern	86	84	170
Southern	82	67	151
Total	767	826	1594
% Attributable to Mobile Speed Cameras	96%	95%	95%

Table 37 shows that the CDOP was associated with a total saving of 1,594 casualty crashes in 2017. Of these, 767 were serious casualty crashes and nearly 60% of the total savings derived from the Brisbane region. Comparing the relative contributions of each CDOP element to the overall savings given in Table 37 showed that 95% of the overall program casualty crash savings came from the mobile speed camera program, with a corresponding 96% for serious casualty crashes.

Using all reported crashes by region and severity in Queensland in 2017, the crash savings associated with the CDOP in 2017 in Queensland from Table 37 have been converted to percentage savings in total crashes across the state. Results are presented in Table 38 and show an overall reduction in casualty crashes across Queensland of 11.2% and 12.2% for serious casualty crashes. Estimates in Table 38 give the total contribution of the CDOP in 2017 to meeting the objectives of the broader Queensland road safety strategy which will be discussed further in the next section.

Table 38 Percentage savings in total reported crashes associated with the CDOP in 2017 by region, crash severity and in total.

	Serious Casualty	Minor Injury	Casualty†
Brisbane	21.8%	16.1%	18.2%
Central	8.8%	7.9%	8.4%
Northern	8.6%	7.1%	8.0%
South Eastern	7.8%	5.1%	6.2%
Southern	7.2%	5.9%	6.6%
Total	12.2%	10.4%	11.2%

Tables 39 and 40 give the community cost savings associated with the CDOP as a whole based on the WTP and HC cost basis respectively. These correspond to the overall crash savings presented in Table 37 and are derived by summing the estimated cost savings across the individual CDOP elements. Analogous to Table 37, the proportion of total cost savings resulting from the mobile speed camera element of CDOP are given in Tables 39 and 40. As shown, the mobile speed camera program was estimated to account for 95-96% of total community cost savings associated with the CDOP as a whole. As evident from the tables, total community cost savings associated with the CDOP in 2017 were just over $703M using the WTP cost basis and just over $320M using the HC cost basis.

Table 39 Overall crash cost savings associated with the CDOP in 2017 by region, crash severity and in total: Willingness to Pay cost basis.

	Serious Casualty	Minor Injury	Casualty†
Brisbane	$ 328,424,353	$ 57,804,384	$ 384,559,062
Central	$ 96,290,505	$ 10,319,475	$ 107,956,993
Northern	$ 56,499,978	$ 4,728,390	$ 60,562,384
South Eastern	$ 69,277,221	$ 8,994,724	$ 75,901,364
Southern	$ 66,471,879	$ 7,311,234	$ 73,799,731
Total	$ 617,175,323	$ 89,168,314	$ 703,529,192
% Attributable to Mobile Speed Cameras	96%	95%	96%

Table 40 Overall crash cost savings associated with the CDOP in 2017 by region, crash severity and in total: Human Capital cost basis.

	Serious Casualty	Minor Injury	Casualty†
Brisbane	$ 163,511,525	$ 10,145,090	$ 172,700,218
Central	$ 47,860,077	$ 1,810,925	$ 50,365,120
Northern	$ 28,117,928	$ 828,896	$ 28,594,700
South Eastern	$ 34,481,441	$ 1,578,293	$ 34,762,010
Southern	$ 33,117,001	$ 1,283,757	$ 34,411,478
Total	$ 307,087,973	$ 15,646,960	$ 320,833,529
% Attributable to Mobile Speed Cameras	96%	95%	96%

5.6. RESULTS IN THE CONTEXT OF THE GOSPA ROAD SAFETY FRAMEWORK

Having assessed the impact of the CDOP on crashes and crash costs in 2017, the final objective of the project was to place the road safety benefits derived from CDOP into the broader context of the overall Queensland road safety strategy. The Queensland Government frames its road safety strategy around the GOSPA concept. GOSPA is an acronym representing the various level of detail in which a road safety strategy is formulated from the broad goal of the program to the specific actions implemented. Each letter in the GOSPA acronym is defined as follows:

- **G**OALS: the overarching goal of the strategy, generally a statement of the broad intent of the strategy (e.g. a goal to reduce trauma resulting from road crashes)
- **O**BJECTIVES: the specific measurable outcome the strategy is aiming for (e.g. a 30% reduction in deaths from road crashes) against which the objectives can be assessed
- **S**TRATEGY FOCUS AREAS: a statement of target areas on which the strategy will focus to achieve its goals and objectives (e.g. driver licensing, speed management, drug and alcohol use)
- **P**ROGRAMS: the specific programs that will be put in place under each strategy focus area to achieve the goals and objectives (e.g. a program of automated traffic enforcement)
- **A**CTIONS: specific activities and deliverables that will be achieved under each program (e.g. installation of ten new speed and RLCs, 50% increase in the hours of mobile speed camera use)

Queensland's current road safety strategy is set out in the document "Safer Roads, Safer Queensland: Queensland's Road Safety Strategy 2015-2021" which can be found at https://www.tmr.qld.gov.au/Safety/Road-safety/Strategy-and-action-plans. Supporting the overall strategy document are a series of action plans. Most directly relevant to the evaluation of CDOP in 2017 is the first action plan for the strategy covering the period 2015-2017. A summary of key actions and deliverables planned under the broader strategy are detailed in the action plan, a number relating to the CDOP. A further initiative supporting the current Queensland road safety strategy and relevant to CDOP is the initiative entitled "The Queensland Speed Conversation" which aims to change community perceptions about speeding and speed enforcement. Entering a dialogue with the community and encouraging dialogue within the community about the issue is a stated objective of the initiative, although it does detail a range of specific actions to address speeding that are relevant to CDOP which are summarised in Table 41 along with the more general action items listed in the strategy action plan. This initiative was implemented in 2017 so retrospective assessment of the results of the current evaluation against the objectives of the initiative is less relevant. Instead, assessment of the consistency between the current results and the intent of the initiative is the focus here.

The Queensland road safety strategy 2015-2021 and the strategies and actions relevant to the CDOP detailed in the 2015-2017 action plan are summarised in Table 41 using the GOSPA framework. Attempts have been made to capture the essence of the strategic elements rather than to quote extensively from the strategy and action plans.

Table 41 Elements of the Queensland road safety strategy relevant to the CDOP summarised under the GOSPA framework

GOSPA ELEMENT	ELEMENTS OF QUEENSLAND ROAD SAFETY STRATEGY AND SUPPORTING ACTION PLANS RELEVANT TO CDOP
Goals	• To reduce the burden of road trauma on communities. • Ultimately committed to a vision of zero deaths through adoption of a Safe Systems approach the cornerstones of which are safe roads and roadsides, safe speeds, safe vehicles and safe road users. These four factors determine the forces exerted during the crash, and therefore the seriousness of the outcome
Objectives	• Reduce fatalities from 303 (average 2008-2010) to 200 or fewer by 2020 • Reduce hospitalised casualties from 6,670 (average 2008-2010) to 4,669 or fewer by 2020.
Strategy Focus Areas	• Under the safe system framework: Safe Speeds and Safe Road Users pillars • Critical inputs to the safe system framework acknowledged as: ○ Enforcement strategies to encourage compliance and manage non-compliance with the road rules ○ Understanding crashes and risks through data analysis, research and evaluation
Programs	• Queensland Camera Detected Offence Program
Actions	Action Area 2 of the 2015-17 action plan. **Enforcement:** Enforcement to deter and detect, through highly visible or covert strategies, using technology and complemented by other efforts. Specific action items relevant to CDOP being: **16.** Better manage speeds on Queensland roads, including • enhance enforcement of speed limits at road works • installing ten new combined RLSCs • implementing four new PtP speed enforcement systems • research and evaluation (including an evaluation of the Camera Detected Offence Program) • marked and non-marked police vehicles **25.** Upgrade remaining wet film mobile speed cameras to digital technology to enhance reliability. CDOP related action items form the 'Queensland Speed Conversation' **9 Choose** enforcement sites based on crash history and impact of speed cameras. **10 Review** mobile speed camera sites to reassess current sites and include new sites with a history of speed crashes. **11 Ensure** appropriate speed enforcement on major roads and managed motorways. **12 Incorporate** a PtP camera system for all new motorway upgrades. **13 Investigate** the feasibility to allow PtP cameras to operate on road sections with multiple speed zones. **15 Develop** and implement a four-year plan for enforcement using best practice.

Outcomes of the CDOP evaluation presented in this report have been assessed against the strategic objectives summarised in Table 41 to assess the measured impact of CDOP in contributing to strategic road safety goals in Queensland. Since the evaluation is focused specifically on assessing the impact of the actions implemented under CDOP, the impact on the strategy as a whole has been considered in reverse of the GOSPA framework

5.6.1. Actions

Assessment of each of the specific action items described in the strategy and summarised in Table 41 follows based on the evidence derived from the evaluation presented in this report. For the actions included in the 2015-2017 action plan, assessment has been made of whether the action was achieved as well as the likely effectiveness of the action. For the actions listed in the Queensland Speed Conversation initiative, comment on the likely future benefits of these actions based on evaluation evidence has been made.

Action	Assessment of Action from Evaluation
From the 2015-2017 action plan	
• enhance enforcement of speed limits at road works	Enhanced enforcement of speed limits at roadwork sites has been targeted specifically through the introduction of speed camera trailers that can be left operational at speed camera sites for extended periods of time. Introduction of the speed camera trailers only occurred from late 2017 and hence fall largely outside of the time period covered by this evaluation. Consequently, no evidence on the effectiveness of this automated enforcement type was produced by the evaluation. Future evaluation of trailer speed cameras is recommended after some enforcement history has been obtained.
• installing ten new combined RLSCs	The majority of combined RLSCs evaluated in this study were upgrades of previous RLC sites with only four being total new installations. On this basis, it appears the ten new sites aimed for have not been fully implemented. Evaluation evidence suggested that RLC to RLSC upgrades are associated with a statistically significant crash reduction of 53% estimated for serious casualty crashes. Evidence on the effectiveness of new RLSC installations from this evaluation was inconclusive due to the limited number of cameras installed. However, interstate evaluations have found statistically significant crash reductions of 26% intersection-wide suggesting additional well targeted installations of this technology at signalised intersections is warranted.
• implementing four new PtP speed enforcement systems	During the evaluation period in 2017, two PtP speed camera systems were still in operation although at the time of publishing this evaluation only the Bruce Highway system remained, the Mt Lindsay Highway system having been removed due to road upgrades. The target of four new systems had not been realised. Evidence from the evaluation showed a statistically significant 21% reduction in casualty crashes associated with the system supporting the further expansion of the enforcement type to other suitable road lengths.
• marked and non-marked police vehicles	Although this objective most likely does not apply only to car-based mobile speed camera operations, evidence on the relative merits of overt versus covert car-based mobile speed camera operations has been derived from the evaluation. Evaluation evidence has shown that the crash reductions per hour of enforcement achieved by covert camera operations are significantly larger than those achieved through overt operations in both urban and rural areas, supporting the continued and expanded use of covert mobile speed camera operations in Queensland.
• research and evaluation (including an evaluation of the CDOP)	This study meets this objective and has provided valuable evidence on both the effectiveness of the program in reducing road trauma in Queensland but also the relative effectiveness of different CDOP elements and, for the first time, an assessment of the relative impacts of different mobile speed camera types.
From the Queensland Speed Conversation	

9 Choose enforcement sites based on crash history and impact of speed cameras and **10 Review** mobile speed camera sites to reassess current sites and include new sites with a history of speed crashes.	Changes to the sector-based selection of speed camera operation sites and the expansion of enforced sites is reflected in the last years considered in the evaluation. Analysis completed in the evaluation showed the mobile speed camera sites enforced are well targeted covering around 74% and 62% of fatal crashes in urban and rural areas respectively with the corresponding figures for serious injury crashes being 82% and 64%. Continued selection of new sites based on the current criteria is likely to maintain this coverage and, combined with the demonstrated effectiveness of the CDOP, likely to provide significant road safety benefits. Although crash coverage is important to program effectiveness, use of the most appropriate enforcement type in each area is equally important and can also be informed by the outcomes of the evaluation (see points 11 and 15 below).
12 Incorporate a PtP camera system for all new motorway upgrades.	Significant crash reductions associated with the PtP camera program were estimated in the evaluation supporting the future expansion of this CDOP element. Whether the additional systems are best placed on motorway upgrades or should be targeted to existing high-risk rural road lengths needs to be assessed through risk analysis of the new motorways compared to crash history on existing road lengths.
13 Investigate the feasibility to allow PtP cameras to operate on road sections with multiple speed zones.	As noted above, the technology has been proven effective in reducing crash rates, where installed. If the technology and supporting legislation can allow installation on roads with multiple speed limits this will provide the potential to expand the set of candidate sites on which this technology can be implemented based on demonstrated crash history and suitability of site.
11 Ensure appropriate speed enforcement on major roads and managed motorways and **15 Develop** and implement a four-year plan for enforcement using best practice.	Evidence on the relative effectiveness of each CDOP element derived through this evaluation provides the best-practice evidence basis on which the CDOP can be optimised through a strategic enforcement model based on analysis of crash types by location with enforcement effectiveness estimates overlaid.

5.6.2. Programs and strategic focus area

Evidence presented in this study confirms that the CDOP remains a key road safety program for the enforcement of speeding and red-light running at intersections. Expansion of the fixed elements of the CDOP continue albeit at a rate less than that documented in the early action plans, particularly for PtP systems and new RLSCs. Focus on the mobile camera program has continued to be strong which is appropriate given the vast majority of road trauma savings come from this CDOP element. Enhancements to the mobile speed camera program in recent years have included:

- revised methodology for site selection and enforcement scheduling;
- increased use of covert operations which analysis here has shown the be associated with higher crash reductions compared to overt operations;
- increased use of portable / LTI devices which are were found to be associated with serious casualty crash reductions in urban areas; and
- Increased hours of enforcement generally.

All these changes have led to the highest estimated crash reductions associated with CDOP in 2017. Based on the results of this evaluation and the significant estimated road trauma savings associated with CDOP it is clear that it remains a key program under the safe system pillars of safe speeds and safe people.

5.6.3. Objective and goals

Reducing the burden of road trauma on Queensland communities is the stated goal of the Queensland road safety strategy with a long-term vision of zero serious road trauma facilitated through the adoption of the safe systems philosophy. Specific objectives set for the strategy were a 33% reduction in fatalities from 303 to 200 by 2020 and a reduction in serious injuries from 6,670 to 4,669, or 30%. Estimates from the evaluation show that CDOP was associated with a 12.2% reduction in serious casualty crashes in 2017 which represents a significant proportion of the objective of 30-33% overall reduction by 2020. As such, CDOP is clearly consistent with the objectives of the Queensland road safety strategy. It is also fully aligned with the safe system principles of safe speeds and safe people having a clear impact on the compliance of the Queensland driving population with the set parameters of system use in posted speed limits.

An additional point on strategic targets is worth noting here. To achieve a 30-33% reduction from a fixed target over a 6-year period requires the aggregate effects of programs to achieve greater reductions than the target due to likely travel exposure increases over the strategy period. Queensland population growth has averaged around 1.5% in recent years and it is expected that travel growth would increase proportionately. Over a 6-year strategy period, this would mean that the real crash reduction target of a road safety strategy would be around 40%. Even at this required reduction, the associated crash reductions estimated for the CDOP have achieved over a quarter of the required reduction as a single program. Furthermore, estimated associations between CDOP enforcement types and crash reductions show there is a great deal of further potential in the CDOP to contribute even more to achieving strategic goals. This is particularly so for the mobile speed camera program where further expansion in hours of enforcement and particularly covert use of cameras shows high potential to achieve greater benefits.

6. DISCUSSION

The aim of this project was to estimate the road safety benefits, both crash savings and cost savings to the community associated with the Queensland Camera Detected Offence Program (CDOP) in the calendar year 2017. Estimates of effects were required overall, by CDOP element, by police region and by crash severity. Over the life of CDOP, two specific evaluation frameworks have been developed. The first was developed specifically to measure the road safety impacts of the mobile speed camera program in Queensland (Newstead and Cameron 2003). With the expansion in scope to consider fixed speed camera elements, a new evaluation framework was developed (Newstead 2012) which carried over elements of the original mobile speed camera evaluation framework adding additional constructs to accommodate the fixed elements of CDOP. Application of this framework to evaluate the CDOP proved successful for some years. However, significant changes to the operation of the mobile speed camera component of CDOP and a need to evaluate the individual impact of these changes meant the existing evaluation framework was inadequate. In response, a key objective of this study was to develop a new evaluation framework for CDOP that could estimate crash effects of specific sub-components of the mobile speed camera program in Queensland.

The following sections consider the success of the new framework in assessing the road safety benefits of CDOP, particularly in the calendar year 2017. Strengths and limitations of applying the new framework are considered along with the significance of the results from applying the framework in terms of the effectiveness of CDOP and implications for future operation and expansion of the program. Requirements for future evaluation of the program are also considered.

6.1. NEW EVALUATION FRAMEWORK

A primary objective of developing the new CDOP evaluation framework was to be able to quantify the road safety impacts of changes in the operation of the mobile speed camera program. Changes of importance are given in Section 2.2.3 but of particular focus were quantifying the progressive increase in enforcement hours, a progressive move to covert car-based camera operations for up to 30% of total enforced hours, and the introduction of the Poliscan portable / LTI speed cameras.

The evaluation framework developed previously for the CDOP used a time-series-based quasi-experimental design to assess the crash effects of the mobile speed camera program. Treatment areas were defined as those within a proximity of sites that a camera had been deployed at some time after program implementation with control areas defined as the remaining areas. Stratification of the analysis by police region and urban / rural environment was employed to control for the confounding effects of these factors. Program crash effects were measured from the design by comparing the difference in long term trends between treatment and control data series.

A number of limitations were evident in this design. First, the treatment of time-based trends in the design was relatively crude being represented as a long-term log-linear trend. It became apparent that the longer the post-implementation period of the program became, the greater the bias this design produced in estimated program crash effects. A second problem was that this evaluation design made no specific reference to the type of cameras being used (overt, covert or portable) nor the number of hours enforced within particular strata. Consequently, it was impossible to determine from the analysis outcomes what specific program characteristics were driving the measured crash outcomes. Some post-hoc analysis of the association between program operational delivery was attempted but showed limited success in determining associations between various operation measures and crash outcomes.

To overcome these limitations, the current study reviewed the design of the mobile speed camera evaluation framework, informed by a literature review on alternative designs and their strengths and weaknesses and how well each addressed the required attributes of the new framework. In reviewing the literature, it became evident that comprehensive evaluations of mobile speed camera programs were rare, the primary examples having been carried out in other jurisdictions within Australia. As a result of the review, a modification of the case-crossover design framework was identified as having great potential to produce an effective evaluation framework that could relate mobile camera operations to crash outcomes at a local geographical level whilst also providing some measure of the temporal relationship between operations at a site and subsequent crash effects.

Conceptually the new evaluation framework was sound and had all the required elements. To apply this design, it was necessary to analyse the data at the level of the sector geographical area to reflect the specific relationship between operations and outcomes. In practice this created a model analysis data mesh that was too onerous for current statistical software to be able to estimate the underlying statistical models supporting the design. Despite collapsing the time mesh for the analysis this problem could not be overcome. Future improvements in statistical software and computing platforms may make this approach viable in the future but the framework could not successfully be applied for this study.

An alternative evaluation framework was developed that sat somewhere between the previous evaluation framework and the initial idea for a new framework. It was developed based on experience evaluating the Western Australian mobile speed camera program, being based on an adjusted quasi-experimental framework, including specific measures of mobile speed camera program outputs in the analysis framework. Selection of treatment and comparison areas for the study was similar to the previous design although it recognised the new sector-based approach to enforcement site selection and made reference to provided speed camera scheduling data to make sure enforcement had taken place within the sector at some time since program implementation. Access to detailed mobile speed camera operations data for this evaluation also meant precise measures of the number of hours of camera enforcement by mobile camera type (overt, covert and portable) could be calculated and related to sites within specific enforcement sectors. Variation in enforcement patterns within sectors over time provided a sufficient natural experiment to be able to relate operation variance to outcome variance. A further improvement in the framework was the treatment of the control information. Instead of reflecting simple long-term trends in the control series, period to period variation in the series was fully captured in the model through more extensive parameterisation.

In practice, the final revised evaluation framework implemented for evaluation of the mobile speed camera program proved highly effective in application. The supporting statistical models were viable to estimate and interpret. In addition, the framework was able to estimate relationships between each of the mobile camera operation types and crash outcomes separately for urban and rural areas. Model fit to the data, a measure of model efficacy, was also extremely high as evidenced by the model fits charted in Figures 4 and 5.

Deriving specific relationships between operational measures of the mobile speed camera program and crash outcomes has two specific advantages. First, it allows easy annual monitoring of the program performance through the analysis of operation outcomes achieved based on the current model calibration. Whilst is it recommended that model calibration is checked periodically, perhaps every three to four years, interim evaluations between calibrations will be comparatively straight forward to undertake. Second, the relationships estimated in the evaluation will be more useful in strategic modelling work to estimate the potential benefits of future program expansion with specific ability to assess expansion by environment and camera type by crash severity.

As noted in the development of the new framework, the previous evaluation framework for fixed camera elements of CDOP was considered to represent current best practice and had no significant limitations identified. As such, the same evaluation framework and methodology as used in the previous CDOP for fixed elements was carried through to the current evaluation framework.

6.2. CRASH AND COMMUNITY COST IMPACTS BY CAMERA TYPE

6.2.1. Intersection cameras

The RLC element of the CDOP has been in operation in Queensland for over 20 years meaning there was a large number of sites and extensive crash data on which to base the analysis. Consequently, the evaluation results for the 128 unique RLC intersections are likely to be highly robust. The test run of the evaluation framework by Newstead and Cameron (2012) showed particularly strong associated effects for targeted intersection crashes: RR = 0.58 (0.48-0.69, p<0.00005) and, in contrast to previous studies, the test run evaluation showed no increase in rear-end crashes. This might be as a result of the close proximity of each of the RLC sites to a mobile speed camera site, hence ensuring general speed compliance at RLC enforced intersections which could prevent rear-end crashes. Unfortunately, the absence of RLCs not in close proximity to a mobile speed camera site prevented explicit assessment of the potential synergistic effects of the mobile camera site on RLC crash effects. Estimated effects of RLCs from this updated evaluation were similar to those of the previous evaluation ($RR_{casualty}$ = 0.84, 95% CI: 0.76 to 0.92), but less than that of the 2012 evaluation. However, when only the targeted (right-through) crashes were examined the casualty relative risk associated with RLCs was not statistically different from the 2012 estimate at RR = 0.69 (0.60 to 0.81, p<0.0001).

Despite the large number of sites on which the RLC evaluation was based, even the extended crash data available for this evaluation were insufficient to allow estimation of yearly crash effects associated with the program. Consequently, only average crash effects over the post-implementation period were estimated and it was assumed that the average crash effects applied equally over each post-intervention year in estimating the 2017 crash effects associated with the RLCs. This assumption is probably not unreasonable given RLCs are a static and generally highly visible technology which should achieve stable crash effects after an initial short familiarisation period. The estimated crash effects translated to a savings of 36 casualty crashes associated with RLCs per year of which 15 were serious casualty crashes, translating to an annual saving to society of around $5.2M (HC) or $13M (WTP).

Fourteen RLSCs, all but four being upgrades of previous RLC only sites, were considered in the analysis. Statistical analysis power for the new installations was low due to the small number of cameras and the limited after installation period, so results of the analysis were inconclusive. However, analysis of similar installations across a wider number of sites in Victoria (Budd, Scully et al. 2011) has shown new installations of these cameras to reduce crashes across the whole of the intersection installed by around 25%. Although it could not be shown here, it is likely that this CDOP element produces road safety benefits, based on the Victorian experience. For the ten cameras upgraded from straight RLCs. statistically significant reductions in all casualty (Relative Risk = 0.69) and serious casualty crashes (Relative Risk = 0.47) were estimated demonstrating the value of converting all existing red-light only cameras to combined RLSCs. Based on the estimated effects in this evaluation, upgrade of the ten RLCs to RLSCs was associated with annual casualty crash savings of nine with an annual community cost saving of $3.2M (WTP).

6.2.2. Fixed mid-block speed cameras

Nine analogue fixed speed cameras were made active during the period of observed crash data (prior to July 2017). In addition, the PtP speed camera systems (also operating in spot speed mode) on a segment of the Bruce Highway between Landsborough and the Glass House mountains and on a segment of the Mt Lindesay Highway passing through Maclean, fixed speed digital cameras in the Clem 7, Legacy Way and Airport-Link tunnels and digital fixed speed cameras in four additional locations were made active. The Legacy Way cameras could not be evaluated because insufficient crashes have been recorded there in the available data period for robust evaluation post-camera installation.

Despite the additional post camera installation crash data available for this evaluation of CDOP compared to previous evaluations, evaluation results for the non-tunnel fixed mid-block spot speed cameras was inconclusive. None of the overall crash effect estimates for this camera type achieved statistical significance likely due to the relatively small number of installations and the types of roads on which they are sited. An unpublished evaluation of similar camera types on a major Victorian freeway estimated statistically significant crash reductions of around 30% so it is likely that the same cameras in Queensland also produce road safety benefits. However definitive effect estimates in Queensland will need to wait for future evaluation with greater crash history at current sites and perhaps further installations.

In contrast to previous evaluations of CDOP, statistically robust estimates of casualty crash effects associated with PtP cameras were obtained in this study. Casualty crash reductions of 21% were estimated, similar to the effect estimated for the Hume Highway system in Victoria. Given the length of road covered by the system, this corresponded to a saving of 32 casualty crashes on the Bruce Highway system that remains, of which 17 were serious casualty crashes with total cost savings (willingness to pay) of around $4.6M per annum estimated.

Estimates of tunnel fixed speed camera effectiveness were obtained through cross sectional comparison of the Clem 7 and the Airport-Link routes with the Port of Brisbane Motorway and the Southern Cross Way. These control sections, although not tunnels, had suitable crash volume data available, were similarly located, had similar speed limits and freeway traffic characteristics. The comparability of these sites might be questionable given that they are not tunnels however the broad characteristics of the roads are very similar. Based on the comparisons made, the Clem 7 and Airport-Link fixed speed cameras were found to be associated with a substantial (86%) reduction in casualty crashes. This is likely to reflect high speed compliance in the tunnels related to the likely extensive knowledge of the cameras by drivers. To some degree, the crash reductions might also reflect the tunnel environment which is perceptually different to regular motorways due to being enclosed. Regardless of the cause, analysis suggests the operating environment in the tunnels has achieved a high level of safety. Whether this is entirely due to the speed cameras is unknown but these are likely to play an important part. The total contribution of the tunnel cameras in terms of casualty crashes saved per year is 22 of which 12 were serious or fatal corresponding to economic savings (willingness to pay) of $7.6M. These are broadly comparable with a PtP system even though these cameras do not operate PtP but are possibly spaced closely enough to achieve similar coverage.

TMR has noted that for all fixed speed camera modes there is sometimes a significant delay between installation of the camera and its activation when enforcement commences. Presented results are based only on activation date because installation date data were only available for a selection of fixed digital speed cameras and consequently associated crash data in the installation to activation period was limited. As noted, there may be some unaccommodated crash effects in the period between installation and activation which may have contaminated the defined pre-activation data period. Consequently, crash effects for the fixed camera elements to which this delay applies may be slightly underestimated. This underestimation is likely to be small given the proportion of time that the 'installation to operation' period makes of the total, extensive, pre-activation period. Installation dates were not provided for analogue fixed speed cameras and could not be used for RLSCs. The installation to activation period for the five digital speed camera sites analysed, and not in tunnels, ranged from only one to two months, which is less than 1% of the pre-activation observation time. Activation and signage were coincident for the tunnel digital cameras.

6.2.3. Mobile speed cameras

As noted, the new evaluation framework developed for the mobile camera program proved highly efficacious, identifying statistically significant relationships between hours of each type of mobile speed camera and crash outcomes as well as fitting the observed crash data very well. Hours of operation of both overt and covert car-based mobile speed cameras were statistically significantly associated with all casualty crashes with no difference in association between high and low severity crashes. Relationships were estimated to differ between urban and rural areas with generally higher percentage crash reductions per hour of enforcement in rural areas compared to urban areas. This result mirrors that found in evaluating the mobile speed camera program in Western Australia (Newstead, Budd et al. 2018). Furthermore, covert car-based mobile operations were found to produce around double the crash savings per hour of enforcement compared to overt operations although the difference between overt and covert effectiveness varied between urban and rural settings, being much more pronounced in urban areas. Associations between portable / LTI speed cameras and crash outcomes were only found in urban areas and only for serious casualty crashes where the level of effectiveness per hour enforced was similar to that of overt car operations. It is possible that mechanism of effect of the portable cameras may be mainly specific deterrence achieved by the camera operators targeting the higher-level speeding drivers, thus in turn reducing the higher injury severity crashes compared with the minor injury severity crashes. Over a Quarter, these targeted drivers mostly will have had time to receive their speeding infringement notice and change their extreme behaviour during the same Quarter.

Results of this analysis have some potential implications for operational practice in the type and area of mobile speed camera scheduling. Based on analysis results, further increasing the proportion of covert mobile speed camera operations, particularly in urban areas, beyond the current 30%, is likely to produce additional road safety benefits. Use of portable / LTI cameras would seem to be most warranted in urban areas even though there is currently significant use of these cameras in rural areas (see Figure 2). The impact of portable cameras being confined to more serious crashes is not seen as a particular limitation given the majority of cost savings to the community potentially come from reducing serious casualty crashes. These crashes are also the primary focus of the Queensland road safety strategy. The evaluation has also produced evidence to articulate the value of recent changes to the CDOP with the crash and economic savings associated with the program in 2017 higher than any previous year.

As summarised in Section 5.5, the total impact of the mobile speed camera program on road trauma in Queensland is substantial. In 2017 the program was associated with a saving of 23 fatal crashes, 713 serious injury crashes and 784 minor injury crashes with a total value to the community of $676M (WTP) or $309M (HC). Savings associated with the mobile speed camera program represented around 95% of total crash and community cost savings attributable to the CDOP as a whole. This is because mobile speed cameras are the CDOP technology that covers by far the largest proportion of the crash population in Queensland.

One apparent incongruence between this evaluation and previous evaluations is the total crash savings associated with the mobile speed camera program. The previous evaluation estimated crash and cost savings in 2015 and 2016 that were significantly higher than those estimated in the current evaluation. However, results derived from the previous evaluation were based on an evaluation framework that was no longer adequate for the task due to the limitations in representing comparison area crash trends noted previously. Estimates derived from this evaluation are considered much more likely to be accurate based on the close fit of the model to the observed data and the establishment of specific relationships between operational outputs from the program and crash outcomes that provide a stronger level of evidence on the cause and effect relationship between operations and outcomes. Despite the estimates of crash effects associated with the mobile speed camera program being smaller in the current evaluation, the effects are still substantial and continue to confirm the mobile speed camera program as being an important road safety countermeasure in Queensland and a centrepiece of the CDOP.

6.3. OVERALL CDOP IMPACTS

The overall crash reductions associated with CDOP in 2017 was 12.2% for serious casualty crashes and 11.2% for all casualty crashes reflecting largely the crash reductions associated with the mobile speed camera program which produces the bulk of measured crash effects (95%) for the CDOP. Translation of the percentage crash savings into absolute crash savings was achieved by applying the estimated percentage crash savings to the observed crashes at camera sites in 2017. This method assumes the camera program is last in the order of factors reducing crashes, operating after other non-camera-based factors represented by crashes at the analysis control sites. This gives the most conservative estimates of absolute crash savings associated with CDOP but is the most defensible since it does not rely on projecting road trauma in the absence of all other factors including CDOP. Using this methodology, it was estimated that CDOP was associated with absolute casualty crash savings of 1,594 in 2017 of which 767 were fatal or serious injury crash savings. Conversion of the estimated crash savings into (2017 $) cost savings estimated annual savings of around $703M in 2017 associated with the program valued using WTP estimates or $320M using HC crash costs. About 88% of the total savings stem from savings in fatal and serious injury crashes which are appropriately the focus of the Queensland road safety strategy.

There was significant variation in estimated CDOP effects between regions of Queensland. By far the greatest effects for the program were estimated in the Brisbane area where many of the fixed speed camera elements are located, and the covert and portable mobile speed camera operations have the highest effectiveness. It is also where the crash density is highest consequently achieving the highest coverage of the crash population.

Overall, evaluation of the Queensland CDOP shows it aligns closely with the goals and objectives of the Queensland road safety strategy. It aligns specifically on the key safe system pillars of safe speeds and safe people, and has proven to be an effective program with the actions producing measurable reductions in road trauma hence reducing the burden of road trauma on Queensland communities. Estimated overall serious casualty crash reductions associated with the program in 2017 of 12.2% of the total, represent a significant proportion of the total strategy target reductions of 30-33% reduction in serious casualties by 2021 reinforcing the high value of the program in the context of the broader strategy.

6.4. FUTURE CDOP EVALUATION

Reformulation of the CDOP evaluation framework in this project will change the requirements for future evaluation of the Queensland CDOP. Calibration of the relationship between mobile speed camera operation types with crash outcomes can be carried forward to future evaluations in the short term. Future estimates of the effectiveness of the mobile camera program can be derived by applying the estimated relationships from this evaluation to future observed crash populations covered by the program via summaries of enforced hours by camera type and region. This simplified process will allow more timely evaluation of program effects in the future. If additional fixed camera sites are implemented these will need to be accommodated in the updates but, again, existing estimates of effectiveness by camera type can be used.

Given that the CDOP is constantly evolving in terms of technology types used, their level of implementation and operational practices, it is recommended that the relationship between each camera type and crash outcomes be recalibrated at regular time intervals, perhaps every three years, to makes sure the most robust estimates of camera effectiveness are being used to monitor program crash effects over time.

Evaluation results from this study have produced important new findings on the relationships between quarterly operation hours by mobile camera type and the crash reductions produced by each, separately for urban and rural areas. During 2017, MUARC developed a safety camera strategy based on relationships between camera operations and crash outcomes established from previous evaluations of CDOP and mobile speed camera evaluation outcomes from Victoria. Resulting from this work was the Speed Camera Resource Allocation Model (SCRAM) developed for Queensland that was an evolution of a similar model developed for Victoria (known as TERAM). New relationships between mobile speed camera operations and crash outcomes established in this study could be incorporated into SCRAM to produce a higher resolution strategic model to inform future optimising and expansion of CDOP.

7. CONCLUSIONS

The study has estimated the road trauma effects associated with the Queensland CDOP in 2017. It is based on an updated evaluation framework for the mobile speed camera component of the CDOP which has provided more robust estimates of associated crash effects and directly links levels of operation of the mobile speed camera program by specific camera type to observed crash outcomes.

Evaluation results show that the Queensland CDOP was associated with sustained crash reductions across Queensland in the year 2017 with correspondingly large economic benefits to the community accruing from its operation. Both fixed and mobile elements of the program produced significant crash reductions. Crash effects associated with RLCs, tunnel cameras and upgrades of RLCs to combined RLSCs estimated in the evaluation were robust. In contrast, the evidence of effectiveness for some of the more recently implemented fixed camera types, including PtP cameras, fixed mid-block spot speed cameras and new intersection RLSCs, remains weaker due to insufficient post-implementation history and small number of camera installations. Despite the expansion of the number of fixed cameras in use under the CDOP, the mobile camera program continues to produce around 95% of the measured benefits associated with CDOP, reflecting the high proportion of the crash population it covers.

Overall crash reductions in Queensland associated with CDOP in 2017 were 12.2% for serious casualty crashes and 11.2% for all casualty crashes. It was estimated that CDOP was associated with absolute casualty crash savings of 1,594 in 2017 of which 767 were fatal or serious injury savings. Conversion of the estimated crash savings into (2017 $) cost savings estimated annual savings of around $703M in 2017 associated with the program, valued using WTP estimates or $320M using HC crash costs. About 88% of the total savings stem from savings in fatal and serious injury crashes which are the focus of the Queensland road safety strategy.

For the first time, the study also provided valuable evidence on the mechanisms of crash reduction effects associated with the mobile speed camera program. Hours of operation of both overt and covert car-based mobile speed cameras were statistically significantly associated with all casualty crashes, with no difference in association between high and low severity crashes. Relationships were estimated to differ between urban and rural areas with generally higher percentage crash reductions per hour of enforcement in rural areas compared to urban areas. Furthermore, covert car-based mobile operations were found to produce around double the crash savings per hour of enforcement compared to overt operations, although the difference between overt and covert effectiveness varied between urban and rural settings, being much more pronounced in urban areas. Associations between portable / LTI cameras and crash outcomes were only found in urban areas and only for serious casualty crashes where the level of effectiveness per hour enforced was similar to that of overt car-based operations.

8. FURTHER RESEARCH

Development of a new evaluation framework for the CDOP in this study has addressed many of the needs for further research noted in previous evaluations of the CDOP. Future priorities for further evaluation of the program are as follows:

- Undertake annual monitoring of crash effects associated with the CDOP based on calibrated relationships between camera types and crash outcomes derived from this study. Future estimates of effectiveness of the mobile camera program can be derived by applying the estimated relationships from this evaluation to future observed crash populations covered by the program via summaries of enforced hours by camera type and region. This simplified process will allow more timely evaluation of program effects in the future. If additional fixed camera sites are implemented these will need to be accommodated in the updates but, again, existing estimates of effectiveness by camera type can be used.

- Periodic recalibration of the relationships between CDOP camera types and crash outcomes should be carried out every three to four years to inform the annual monitoring task and make sure estimates of overall program effects are based on the most current and robust estimates of the relationship between various camera type operations and crash outcomes. This will be particularly important not only for the mobile camera program but for camera types with currently limited or no evidence of effectiveness including PtP, fixed mid-block spot speed cameras and mobile trailer cameras.

- The Speed Camera Resource Allocation Model (SCRAM) developed previously for Queensland to inform optimisation and expansion of CDOP should be updated based on the results of the current CDOP evaluation. Evaluation results from this study have produced important new findings on the relationships between quarterly operation hours by mobile camera type and the crash reductions produced by each, separately for urban and rural areas. The new relationships between mobile speed camera operations and crash outcomes established in this study should be incorporated into SCRAM to produce a higher resolution strategic model to inform future optimising and expansion of CDOP.

9. APPENDIX

9.1. CAMERA TYPES

The authors again ask the reader to refer to Newstead and Cameron (2012) for a detailed literature review of camera modes of operation, effectiveness and scope. This section contains a brief summary of camera types as presented in or summarised from Newstead and Cameron (2012).

9.1.1. Red-light cameras (RLCs)

Red-light cameras have been operational in Queensland since 1991. Prior to December 2012, the majority of fixed RLCs operated on wet film technology. They are designed to detect vehicles infringing a red traffic signal at an intersection. They can enforce both through traffic as well as right turning traffic where there is full or partial control of the right turn phase by the signals. Installation of the camera is such that it generally only enforces one leg of the intersection driven by the need for the traffic signals to be in view of the camera for evidentiary reasons with two photographs of the infringing vehicle being taken to verify it is moving.

Sites for camera placement are understood to be chosen on the basis of high rates of red-light infringing characterised by specific crash types related to these infringements such as right turn against and right-angle crashes. Red-light cameras are placed and operated in an overt manner with the cameras being clearly visible on pole mountings on the roadside. In Queensland there is no accompanying signage to alert motorists of the presence of the camera (apart from eight trial sites). Infringement notices issued from the cameras also clearly denote the location at which the infringement occurred.

The effects of the cameras on crashes are likely to be highly localised to the sites where the cameras are placed. 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 used in Victoria, or the visibility of the cameras from other legs. Primary mechanisms of deterrence associated with RLCs 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.

9.1.2. Fixed spot speed cameras (FSSCs)

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. Effects of fixed spot cameras used in conjunction with high visibility signage have been estimated as highly localised to within 3km of the camera site. High visibility signage has been speculated as the primary mechanism of deterrence and infringement notices issued act as a secondary deterrence for infringing drivers.

Halo effects are expected within one kilometre either side of a CDOP fixed camera. CDOP fixed camera signage is preferably within one kilometre of the camera and preferably includes two (but at least one sign) on all routes to the camera. Extra signage is used when other factors affect the visibility of the signs. The signs are installed in the following order:

1. ‘FIXED SPEED CAMERA AHEAD FOR ROAD SAFETY’ (placed furthest from the camera site)

2. ‘FIXED SPEED CAMERA 24 HOURS FOR ROAD SAFETY’ (placed closest to the camera site)

9.1.3. Combined red-light speed cameras (RLSCs)

Combined red-light speed cameras at signalised intersections detect both red-light running and speeding infringements. The principal reason for installing these combination cameras is to reduce red-light running crashes and also to reduce the risk and severity of the remaining crashes, particularly rear-end crashes which have been found in some studies to elevate when using only red-light enforcement. The first objective is the same as for traditional RLCs whilst 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 FSSCs. Geographical reach in effectiveness and likely deterrence mechanism is likely to be similar to both single function camera types.

It was considered likely that the effects of the combined RLSCs will be highly localised to the intersection and perhaps the leg on which the camera is installed. Possible halo effects on other intersection legs and up and down each intersecting road for some distance are also possible. Spread of the halo might be related to the use of accompanying signage. TMR advised that the fixed digital RLSCs are signed where it is safe and practical to do so. Thus, CDOP crash effects are expected to be localised to the site with deterrence driven primarily by the camera presence and also by the issuing of infringement notices.

9.1.4. Point-to-point (PtP) cameras

Point-to-point camera technology uses a number of cameras mounted at staged intervals along a particular route. The cameras are able to measure the average speed between two points and/or the spot speed at an individual camera site.

Compared with traditional spot-speed fixed cameras, which have a site-specific effect, the PtP camera system has a link-long influence on drivers and their speeds, despite enforcement being visible only at the start and end of the enforced road length. It is likely that the CDOP PtP cameras provide deterrence along the full length of road between the PtP start and end gantries.

Point-to-point camera systems are signed in Queensland: with one prominent sign installed in the direction of enforcement within approximately one kilometre of the first camera in the PtP system and a second prominent sign installed in the direction of enforcement within approximately one kilometre of reaching the last camera in the PtP system. The presence of signage will most likely localise the effects of the PtP system to within the signed area with possible halo effects downstream of the covered link.

9.1.5. Mobile speed cameras

The mobile speed camera program in Queensland first commenced in May 1997. The use of mobile speed cameras in Queensland can generally be described as overt or covert with overt cameras operating from marked vehicles, tripod mounts, trailers and hand held devices; and signs advising motorists that they have passed a speed camera posted within ten meters of the camera; and covert deployments operating from a variety of unmarked vehicles. Whilst some operations using hand held devices are considered covert it is likely that they are not fully covert. Covert mobile speed cameras operate in both urban and rural areas.

The operation of cameras at particular locations is determined using a randomised scheduling procedure with some scope for variation. Locations for the deployment of cameras meet strict criteria, with crash history being the primary criterion used to identify sites. Other factors which contribute to the selection process include areas of high-risk speeding behaviour that have been checked and referred to the relevant committee, including consideration of Workplace Health and Safety issues for workers at locations where roadwork is in progress.

The general effect might in fact be an aggregate of localised effects in space over a wide number of locations that target the Queensland crash population. There is a strong spatial correlation with the mobile camera zones of operation with the bulk of crash effects being measured in areas within two kilometres of the operational camera zone centroids.

Another key development in the Queensland CDOP is the introduction of covert mobile camera operations in 2010. Based on the combined covert and overt operation of the Queensland mobile speed camera program, a range of likely mechanisms and distributions of effects might be expected. They include effects generalised and localised in space related to the mode of operation as well as effects generalised and localised in time related to both the presence of a camera and/or the receipt of an infringement notice.

9.2. FIXED SPEED CAMERA LOCATIONS AND OPERATIONAL DATA

Table 42 Fixed Speed Camera location and operational data

		ID	RLC Go-Live Date	Speed Camera Go-Live Date	Before Period (years)	RLC to RLSC period	After Period (years)
Fixed Spot Speed Cameras							
Analogue	Bruce Hwy, Burpengary	3001		14/12/2007	16.0		10
	Main Street, Kangaroo Point	3002		14/12/2007	16.0		10
	Pacific Mwy, Tarragindi	3003		22/02/2008	16.1		7.3
	Gold Coast Hwy, Broadbeach	3004		31/08/2010	18.7		8.0
	Gold Coast Hwy, Southport	3005		29/09/2009	17.7		8.3
	Warrego Hwy, Redwood	3006		31/08/2010	18.7		7.3
	Warrego Hwy, Muirlea	3007		24/12/2009	18.0		9
	Nicklin Way, Warana	3008		30/06/2010	18.5		7.5
	Sunshine Mwy, Mooloolaba	3009		24/02/2010	18.2		7.9
Digital	Gateway Mwy, Nudgee	1001		2/08/2011	19.6		6.4
	Pacific Mwy, Loganholme	1002		2/08/2011	19.6		6.4
	Nambour Connection Road (Northbound), Woombye	1011		10/01/2013	21.0		5.0
	Pacific Mwy, Gaven	1012		28/03/2013	21.2		4.8
Clem 7 tunnel		1003-1006		6/04/2010	18.3		7.7
Airport-Link tunnel		1007-1010		25/07/2012	20.6		5.4
Legacy Way Tunnel		1013-1016		25/06/2015	23.5		2.5
Point-to-Point (fixed spot and average speed cameras)							
	Bruce Hwy b/n Landsborough and the Glass House Mountains	4001-4002		2/08/2011	19.6		5.9
	Mt Lindesay Hwy, Maclean	403		21/07/2017	25.6		0.4
Red-light speed cameras							
	Waterworks Rd, Ashgrove (at i/s with Jubilee Tce)	2001	12/02/2002	2/08/2011	10.1	9.5	6.4
	Beaudesert Rd, Calamvale (at i/s with Compton Rd)	2002		2/08/2011	19.6		6.4
	Markeri St, Clear Island Waters (Bermuda St) - Gold Coast	2003	11/04/2001	1/07/2013	9.3	12.2	4.5
	Nathan St, Aitkenvale (at i/s with Bergin Rd) - Townsville	2004	26/06/2000	8/07/2013	8.5	13.0	4.5
	Musgrave St, Berserker (at i/s with High St) - Rockhampton	2005	10/11/1992	31/07/2013	0.9	20.7	4.4
	Mulgrave Rd, Mooroobool (at i/s with McCoombe St) - Cairns	2006	10/08/1992	11/07/2013	0.6	20.9	4.5
	Bruce Hwy, Mount Pleasant (at i/s with Sams Rd) - Mackay	2007	01/11/1992	15/07/2013	0.8	20.7	4.5
	James Street, South Toowoomba (at i/s with Neil Street)	2010	10/01/1992	25/07/2016	0.0	24.5	1.4
	James Street, South Toowoomba (at i/s with Pechey Street)	2011	10/01/1992	25/07/2016	0.0	24.5	1.4
	James Street, Rangeville (at i/s with MacKenzie Street)	2012	05/09/1997	25/07/2016	5.7	18.9	1.4
	Bridge Street, Wilsonton (at i/s with McDougall Street)	2014	01/06/2000	25/07/2016	8.4	16.2	1.4
	Kingston Rd, Waterford West (at i/s with Muchow Rd)	2015		21/07/2017	25.6		0.4
	Logan Road, Upper Mount Gravatt (at i/s with Newnham Rd)	2016		24/01/2017	25.1		0.9
	Morayfield Road, Morayfield (at i/s with Devereaux Drive)	2017		24/01/2017	25.1		0.9

9.3. CONTROL AND TREATMENT CRASH SELECTION

Table 43 Treatment and control Selection Criteria

	Treatment Crash coded as:	**Control Crash coded as:**
Red-light cameras (RLCs)	Signalised Intersection ≤100m from camera Not a FSSC, AvSpeed nor RLSC treatment crash Not at a nearby or underground intersection	Signalised intersection >100m from camera, not an RLC, RLSC or FSSC treatment crash and Matched to camera site by: • Intersection configuration (T, Y or X) • SLA and if needed surrounding SLA • Speed limit • Divided or undivided road • Pre-period Crash History ranging 2.5% to 197.5% of treatment site Not a RLSC control. Uniquely identified control intersections labelled with more than one SLA, speed limit or dividedness were only assigned to one control group.
Red-light speed cameras (RLSCs)	Signalised Intersection ≤100m from camera Not a FSSC, AvSpeed nor RLC treatment crash Not at a nearby or underground intersection	Signalised intersection >100m from camera, not an RLC, RLSC or FSSC treatment crash and Matched to camera site by: • Intersection configuration (T, Y or X) • SLA and if needed surrounding SLA • Speed limit • Divided or undivided road • Pre-period Crash History ranging 2.5% to 197.5% of treatment site Not an RLC control. Uniquely identified control intersections labelled with more than one SLA, speed limit or dividedness were only assigned to one control group.
Fixed Spot Speed Cameras (FSSCs) (except those at PtP site and tunnel sites)	On same road and not a ramp ≤1000m from camera Not an RLC, AVSpeed or RLSC treatment crash	On same road and not a ramp >1000m from camera Not an RLC, RLSC or FSS treatment crash And Matched to camera site by: • SLA or <2km from camera • On same road • Speed limit, but widened if 70, 90 or 110 RLC and RLSC control crashes may be on the same length of road as the potential FSSC control crash pool. These could not be FSSC control crashes.
Clem 7 and Airport-Link tunnels		Not a ramp, Not an RLC, RLSC or FSS treatment crash On Southern Cross Way or on Port of Brisbane Motorway
Average Speed cameras and FSSCs at the same site	On same road and not a ramp Between average speed cameras and 5km along road North and South of them. Not a FSSC, RLC or RLSC treatment crash.	On same road and not a ramp >100m from camera Not an RLC, RLSC or FSS treatment crash And Matched to camera site by: • On same road • A further 7.2km North/South of treatment section for 4001/2 and a further 5km for 403
Mobile Speed Cameras	Sector in which a mobile speed camera operation has taken place since the commencement of the program Not a RLC, FSS, AvSpeed or RLSC treatment site	Not a MSC, RLC, RLSC, AvSpeed or FSS treatment site and sector where mobile speed cameras have never been operated. And matched by police region and urban rural status of sector as defined by TMR protocol.

9.4. CRASH COSTS BY SEVERITY YEAR AND POLICE REGION

Table 44 2017 Average crash costs by severity, crash year and police region according to the distribution of mobile camera crashes

		Willingness to pay 2017			Human Capital 2017		
		Serious Injury Crash	Minor Injury Crash	Casualty Crash	Serious Injury Crash	Minor Injury Crash	Casualty Crash
Brisbane	2013	$759,832	$110,597	$367,931	$384,354	$18,959	$163,789
	2014	$755,590	$110,556	$352,153	$382,825	$18,959	$155,245
	2015	$815,149	$115,281	$362,356	$404,287	$18,959	$154,991
	2016	$866,452	$112,463	$379,201	$422,773	$18,959	$161,816
	2017	$848,973	$107,657	$366,748	$416,475	$18,959	$157,891
Central Urban	2013	$900,013	$110,282	$438,258	$434,867	$18,959	$191,686
	2014	$902,552	$108,049	$450,664	$435,782	$18,959	$198,706
	2015	$743,426	$115,148	$377,013	$378,442	$18,959	$168,791
	2016	$765,618	$111,235	$401,396	$386,438	$18,959	$181,903
	2017	$855,875	$105,957	$440,554	$418,962	$18,959	$197,431
Central Rural	2013	$1,385,445	$108,991	$857,165	$609,789	$18,959	$365,265
	2014	$1,199,351	$111,516	$708,581	$542,731	$18,959	$306,435
	2015	$1,293,311	$117,248	$775,513	$576,589	$18,959	$331,075
	2016	$1,480,961	$113,970	$931,225	$644,208	$18,959	$392,764
	2017	$1,415,325	$99,979	$908,697	$620,556	$18,959	$388,840
Northern Urban	2013	$734,596	$116,803	$420,963	$375,260	$18,959	$194,378
	2014	$731,321	$106,849	$404,689	$374,080	$18,959	$188,333
	2015	$835,080	$111,772	$464,985	$411,469	$18,959	$210,633
	2016	$900,493	$113,433	$463,897	$435,040	$18,959	$204,233
	2017	$928,940	$104,553	$533,234	$445,290	$18,959	$240,651
Northern Rural	2013	$1,297,129	$112,305	$819,983	$577,965	$18,959	$352,845
	2014	$1,231,944	$104,488	$790,314	$554,476	$18,959	$344,711
	2015	$1,583,945	$107,589	$957,846	$681,317	$18,959	$400,422
	2016	$1,301,549	$118,445	$813,003	$579,557	$18,959	$348,067
	2017	$1,254,441	$106,261	$792,739	$562,583	$18,959	$343,983
South Eastern Urban	2013	$860,388	$113,560	$423,126	$420,588	$18,959	$185,437
	2014	$776,785	$108,827	$359,380	$390,462	$18,959	$158,311
	2015	$783,739	$111,384	$344,617	$392,968	$18,959	$148,699
	2016	$862,195	$109,818	$374,513	$421,239	$18,959	$160,486
	2017	$821,236	$102,902	$362,330	$406,480	$18,959	$158,913
South Eastern Rural	2013	$1,197,856	$116,883	$743,617	$542,193	$18,959	$322,323
	2014	$1,065,006	$110,938	$560,556	$494,321	$18,959	$242,980
	2015	$1,631,204	$119,381	$934,746	$698,347	$18,959	$385,370
	2016	$794,919	$111,168	$454,536	$396,997	$18,959	$208,803
	2017	$1,102,150	$104,166	$603,158	$507,706	$18,959	$263,332
Southern Urban	2013	$747,467	$110,636	$409,195	$379,898	$18,959	$188,174
	2014	$807,242	$108,962	$443,538	$401,438	$18,959	$202,221
	2015	$814,941	$114,230	$392,166	$404,212	$18,959	$171,769
	2016	$1,030,550	$111,538	$467,456	$481,905	$18,959	$198,250
	2017	$781,136	$107,293	$385,016	$392,030	$18,959	$172,719
Southern Rural	2013	$1,516,614	$107,605	$886,009	$657,055	$18,959	$371,473
	2014	$1,266,709	$107,776	$755,627	$567,003	$18,959	$325,319
	2015	$1,286,034	$112,432	$808,448	$573,967	$18,959	$348,112
	2016	$1,342,935	$107,762	$835,491	$594,471	$18,959	$358,034
	2017	$1,215,738	$110,564	$753,768	$548,636	$18,959	$327,228

Table 44 continued

		Willingness to pay 2016			Human Capital 2016		
		Serious Injury Crash	Minor Injury Crash	Casualty Crash	Serious Injury Crash	Minor Injury Crash	Casualty Crash
All regions	2013	$899,210	$111,430	$460,322	$434,578	$18,959	$203,028
	2014	$863,560	$109,476	$430,584	$421,731	$18,959	$190,470
	2015	$923,550	$114,180	$440,330	$443,348	$18,959	$189,974
	2016	$969,772	$111,847	$458,294	$460,004	$18,959	$197,062
	2017	$930,621	$106,179	$444,169	$445,896	$18,959	$193,987
All Urban	2013	$787,374	$111,547	$394,984	$394,278	$18,959	$176,365
	2014	$780,705	$109,497	$380,480	$391,875	$18,959	$169,514
	2015	$804,234	$114,121	$373,031	$400,353	$18,959	$162,047
	2016	$879,111	$111,767	$398,196	$427,335	$18,959	$171,395
	2017	$843,117	$106,331	$387,703	$414,365	$18,959	$169,961
All Rural	2013	$1,368,660	$110,494	$838,962	$603,741	$18,959	$357,543
	2014	$1,207,574	$109,311	$714,551	$545,694	$18,959	$309,237
	2015	$1,392,899	$114,688	$841,649	$612,475	$18,959	$356,511
	2016	$1,300,501	$112,510	$796,415	$579,180	$18,959	$341,468
	2017	$1,280,244	$104,826	$787,062	$571,880	$18,959	$339,885

9.5. PRIOR CRASH HISTORY AT FIXED CAMERA EVALUATION TREATMENT AND CONTROL SITES

9.5.1. Red-light cameras (RLCs)

Table 45 Mean number of casualty crashes **(any severity)** at treatment and control intersections prior to red-light camera installation

ID	*treatment*	*control*
20	6	22
25 &36	27	57
34&38	27	62
35&54	39	90
39	8	39
41	12	65
42	24	26
45	9	127
46	14	61
47	39	38
48	14	35
49	6	54
50	4	22
53 (2001)	25	76
55	41	88
56	11	79
57	29	131
58	16	80
59	20	45
61	47	290
75	18	117
84	8	36
94	22	138
113	20	66
114	19	37
116	8	21
115,117& 125	48	65
121	13	131

ID	*treatment*	*control*
122	8	8
123	15	15
124 (2003)	13	13
126	13	13
151/155 (2012)	18	18
156 (2013)	10	10
206 & 209	24	24
207	13	13
208 (2004)	8	8
210	10	10
255	5	5
355	35	35
407	15	15
408 &411	19	19
409	4	4
451,452,453&454	37	37
461 & 463	30	30
157 & 158 (2014)	9	9
460 and 462	15	15
43, 44 and 52	38	38
110, 118 & 119	48	48
62,63,64&65	18	18
69 & 500	41	41
40 & 60	9	9
2, 67 &68	17	17

9.5.2. Fixed spot (FSSCs), point-to-point (PtP) and red-light speed cameras (RLSCs)

Table 46 Mean number of casualty crashes **(any severity)** at treatment and control intersections prior to red-light speed camera installation

ID	*treatment*	*control*
2001 (from 53)	31	62
2002	97	199
2003 (from 124)	85	210
2004 (from 208)	20	81
2005 (from 252)	31	482
2006 (from 304)	91	341
2007 (from 353)	67	56
2010/2011 (from 153/154)	83	463
2012 (from 155)	8	152
2014 (from 157/158)	18	158
2015	52	249
2016	39	471
2017	28	185

Table 47 Frequency of treatment and control crashes **(by severity)** prior to fixed spot speed camera installation

	Casualty Crash		Serious Injury Crash		Minor Injury Crash	
ID	*treatment*	*control*	*treatment*	*control*	*treatment*	*control*
Fixed speed						
3001	46	162	13	51	33	111
3002	289	256	73	70	216	186
3003	172	164	40	55	132	109
3004	447	678	143	222	304	456
3005	319	250	89	77	230	173
3006	84	61	36	27	48	34
3007	43	199	18	85	25	114
3008	175	188	48	64	127	124
3009	101	131	33	62	68	69
1001	104	93	35	36	69	56
1002	144	322	57	116	86	250
1011	70	147	35	55	35	91
1012	120	305	44	119	76	165
Point-to-Point						
4001	588	315	265	136	323	179
403	674	581	297	211	377	370

9.6. COMPARISON OF ALL AVAILABLE RLSC WITH A NO PRIOR CAMERA PERIOD

An additional study, a comparison of RLSC and no-camera periods was made for all sites with available no-camera period crash data (all except 2005-2007 & 2010-2011). The results of this analysis are presented in Table 43. A large proportion of the sites with longer (4.5 to 6.4 years) camera operations are excluded from this analysis, leaving the analysis subjected to weakly evidenced estimates with large confidence intervals so that no crash *reductions* were observed statistical significance. The overall analysis is based on only nine camera sites, with six within regions other than Brisbane and only one to three cameras in each region. Thus, regional analyses are even more weakly evidenced. Overall, serious casualty crashes were reduced by 32% (not significantly) and minor injury crashes increased by 66%. When analysed according to the CDOP 2017 evaluation larger serious casualty reductions were observed, and minor injury crash reductions were associated with upgrades. Only for the four cameras without prior RLC, where three sites had less than a year of operations, were increases in minor injury crashes observed. Thus, it appears that this minor injury crash analysis is biased via leverage of some sites with short post-treatment periods, and there is in fact strong evidence of further reductions in minor injury crashes being associated with RLSCs. Furthermore, defining a pre-treatment period so far behind the camera installation would draw questions about the representativeness of the comparison for sites such as 2001, 2003, 2004, 2012 and 2014, where the no-camera period is mostly in the 1990's and the RLSC period begins more than nine years later.

Table 48 Estimated crash risks, (95% confidence interval and p-value) associated with the red-light speed cameras referenced against a no-camera period

Estimate (95% CI) Significance	**Serious Casualty**	**Minor Injury**	**All Casualty†**
Referenced to no-camera period			
Combined: 2001, 2002, 2003,2004,2012, 2014-2017	0.68 (0.38,1.2) 0.18	1.66 (1.15,2.4) 0.01	1.24 (0.91,1.67) 0.17
Brisbane (2001, 2002,2016)	0.59 (0.27,1.25) 0.17	1.42 (0.9,2.23) 0.13	1.06 (0.72,1.55) 0.78
Northern Urban (2004)	0.41 (0.06,2.77) 0.36	4.72 (1.3,17.2) 0.02	2.22 (0.81,6.11) 0.12
South Eastern Urban (2003, 2015)	1.54 (0.47,5.05) 0.47	1.97 (0.79,4.92) 0.15	1.89 (0.93,3.85) 0.08
Southern Urban (2012,2014,2017)	0.38 (0.05,3.17) 0.37	1.18 (0.24,5.83) 0.84	0.75 (0.21,2.65) 0.66

† Estimated from an all casualty crash model

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