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EVALUATION OF THE CRASH EFFECTS OF THE QUEENSLAND SPEED CAMERA PROGRAM

by

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Evaluation of the crash effects of the Queensland speed camera program

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Abstract:

A speed camera program was introduced in Queensland from 1 May 1997 utilising overt deployment of cameras in white commercial vans marked as a speed camera unit at sites chosen on the basis of crash history. Sites at which cameras are operated at on a particular day are chosen using randomised scheduling and have grown in number from 500 at program commencement to over 2,500 by June 2001. This study has investigated the crash effects of the speed camera program in Queensland over the period from its introduction in May 1997 to the end of June 2001 in areas within 6km of speed camera sites that had been used up to the end of the study period.

When operating at maximum coverage, the Queensland speed camera program was estimated to have produced a reduction in fatal crashes of around 45% in areas within 2km of speed camera sites. Corresponding reductions of 31%, 39% 19% and 21% were estimated for hospitalisation, medically treated, other injury and non-injury crashes respectively. This translates to an annual crash saving in the order of 110 fatal, 1100 hospitalisation, 2200 medically treated, 500 other injury and 1600 non-injury crashes. In terms of total annual road trauma in Queensland, these savings represent a 32% reduction in fatal crashes, a 26% reduction in fatal to medically treated crashes combined and a 21% reduction in all reported casualty crashes. The benefit cost ratio estimated for the program over the period from its introduction to June 2001 was 47.

Comparison of the estimated crash reduction associated with the Queensland speed camera program and program operational measures gave insight into the mechanisms of program effectiveness. Variations in estimated crash reduction over time were strongly related to the size of the overall program and the density of enforcement. Periods of program growth were also associated with larger crash reductions beyond that expected from the increasing size of the program alone. Higher levels of true randomness in selection of speed camera sites for operation was also associated with higher levels of crash reduction when comparing differential performance of the program across police regions in Queensland.

Key Words:
Speed camera, speed enforcement, statistical analysis, road trauma, injury, collision, evaluation, research report

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Preface

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EXECUTIVE SUMMARY

A speed camera program was introduced in Queensland from 1 May 1997. To maximise general deterrence, the operation of cameras under the Queensland program is overt. The cameras were deployed initially in white commercial vans and later in other models of vehicles, marked as a speed camera unit on the side of the vehicle and with a 700mm high sign placed five to ten metres past the vehicle, advising motorists of the camera presence. In the early stages of the program, cameras were deployed to 500 sites, on state controlled roads only where a speed limit review had been completed. Zones were chosen on the basis of crash history and were approved by Traffic Advisory Committees. The sites at which cameras were operated at on a particular day were chosen using a randomised scheduling procedure with some scope for variation. By June 2001, the number of speed camera sites in use had grown to over 2,500 with a proportionate increase in the total number of hours of camera use.

This study has investigated the effects on crashes of the speed camera program in Queensland across the period from its introduction in May 1997 to the end of June 2001. Due to the overt nature of the Queensland program, analysis has examined crash reductions associated with the program in areas within 6km of speed camera sites that had been used up to the end of the study period. A quasi-experimental study design was employed comparing crash trends in areas within 6km of the camera site to areas further than 6km from camera sites both before and after introduction of the program. A Poisson log-linear statistical analysis model was used to estimate the net crash savings associated with introduction of the program.

Analysis results showed evidence of larger crash reductions nearer to speed camera sites. Significant increases in crash reductions associated with the program were observed over time, reflecting the substantial growth of the program over the study period. As 73% of reported crashes in Queensland occurred within 2km of a speed camera site, estimated crash effects within this area were considered to be most indicative of program performance. When operating at maximum coverage, the Queensland speed camera program was estimated to have produced a reduction in fatal crashes of around 45% in areas within 2km of speed camera sites. Corresponding reductions of 31%, 39% 19% and 21% were estimated for hospitalisation, medically treated, other injury and non-injury crashes respectively. This translates to an annual crash saving in the order of 110 fatal, 1100 hospitalisation, 2200 medically treated, 500 other injury and 1600 non-injury crashes. In terms of total annual road trauma in Queensland, these savings represent a 32% reduction in fatal crashes, a 26% reduction in fatal to medically treated crashes combined and a 21% reduction in all reported casualty crashes. The benefit cost ratio estimated for the program over the period from its introduction to June 2001 was 47.

Comparison of the estimated crash reductions associated with the Queensland speed camera program and program operational measures gave insight into the mechanisms of program effectiveness. Variations in estimated crash reduction over time were strongly related to the size of the overall program as well as the density of enforcement. Periods of program growth were also associated with larger crash reductions beyond that expected from the increasing size of the program alone. Higher levels of true randomness in selection of speed camera sites for operation was also associated with higher levels of crash reduction when comparing differential performance of the program across police regions in Queensland. Finally, higher levels of site coverage per crash were also related to larger crash reductions although this is not reflected at higher severity crashes.

EVALUATION OF THE CRASH EFFECTS OF THE QUEENSLAND SPEED CAMERA PROGRAM

1. INTRODUCTION

1.1 BACKGROUND TO THE QUEENSLAND SPEED CAMERA PROGRAM

A speed camera program was introduced in Queensland from 1 May 1997. The program commenced with three operational camera units, with five more introduced two weeks after the program start, building to a total of fifteen units by the end of June 1997. Operations are overt, with the cameras being used in vehicles marked as a speed camera unit on the side of the vehicle. Additionally a 700mm high sign advising of the camera presence is placed within 5 to 10 metres past the vehicle. The camera units employ slant radar with bi-directional operation potential, meaning they can photograph vehicles moving towards or away from the camera and can be focused across multiple road lanes. Prior to the introduction of the speed camera program, a review of speed limits on Queensland state-controlled roads was undertaken. The review covered about 20% of the road network, the proportion corresponding to the length of state-controlled roads, estimated to be about 33,000km out of total 150,000km of road length in Queensland. Around 5% of the reviewed roads underwent a speed limit change. In conjunction with this, there has been the introduction of 110km/h zones, replacing 100 km/h zones, on over 1000km of Queensland roads. An internal evaluation by Queensland Transport (QT) of 110km/h zones has reportedly shown no crash effects, little change in average travel speed and reduced speed variation on the re-zoned roads.

A program of public education was undertaken prior to the introduction of the Queensland speed camera program, commencing around Christmas 1996. An amnesty period was declared before the start of the program, running for six weeks up to the 1st of May 1997, where cameras were used and motorists were notified if they had been detected speeding with only a warning notice and no fine being issued. During the amnesty, speed related mass media publicity campaigns were run featuring both the Victorian Transport Accident Commission's (TAC) 'Doctor' television advertisement and the New Zealand 'Sorry' television advertisement[1]. The TAC's 'Doctor' advertisement continued running after the commencement of the program with reduced exposure. A significant amount of other media coverage of the program was also obtained. The Queensland public had been aware of the impending introduction of the speed camera program for over four years prior to its introduction due to media coverage of the topic since the original Queensland Parliament Travelsafe Submission was drawn up (Queensland Parliament, 1994).

Speed cameras in Queensland can only be operated in approved locations. Crash history is the primary criterion for the selection of a potential speed camera zone. A zone is an area of land that is 1km in diameter in urban areas or 5km in diameter in rural areas and is chosen based on a high incidence of speed related casualty crash or non-intersection casualty crash problem based on analysis of recent crash data. Each zone of operation must

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[1] The TAC's doctor advertisement shows scenes of speed camera in operation interspersed with a doctor in a hospital emergence department explaining that he is sick of seeing 'victims' of car crashes who don't deserve to be there. The New Zealand sorry ad shows a man speeding in his car on a country road past a speed camera and then later colliding with a car containing a family with 3 young children. It then shows the man's wife, whilst the man is recovering from the crash in hospital, handing him the infringement notice from the speed camera and telling him to say sorry to the children in the other car.

have undergone a speed limit review and be approved by the Traffic Advisory Committee relevant to that zone (Queensland Transport, 2000). Within each approved speed camera zone, specific sites are defined where the camera may be placed for use. Sites are also nominated through secondary criteria including: roadwork sites and sites nominated through documented and validated public complaints and stakeholder knowledge of problem locations.

The number of zones in which a speed camera in Queensland could be operated in the initial stages of the program was around 500. Each camera is scheduled to operate at one or more of 3 sites per day. The 3 sites are chosen randomly using a scheduling procedure based on the Random Road Watch technique with the potential to vary these so long as justification is given and the change is approved by the relevant Senior Police Officer. Each camera was operated for up to 6 hours.

Speed camera- detected offence processing is carried out by the Police Traffic Camera Office, which operates similar to its Victorian equivalent. A 3-day turnover in processing of offences is aimed for although exact turnover times for the program were not available. Rejection rates at the commencement of the program were reported to be around 30% with expected monthly offence notices issued averaging around 20,000. By June 2001, offence notices issued averaged around 30,000 per month (mainly due to an increase in the number of operating hours of the cameras) whilst the rejection rate had reduced to around 20%.

From the onset of the program QT and the Queensland Police Service have used an output and outcome assessment process to monitor the extent of the implementation according to the plan and the extent of outcomes being achieved. Outcomes were assessed by a quasi-experimental evaluation design using control chart or scatterplot regression analysis. These studies were used to provide systematic feedback to operations. For example the monitoring process revealed that a plateau in site growth, at various times (see Fig. 3), was correlated with a reduced percentage of fatal crash reductions. This led to advice to accelerate growth in sites. Monitoring of the consequent site growth showed a renewed increase in the percentage of fatal crash reduction.

At least in part due to this management system approach, the speed camera program has grown substantially since its commencement. Two notable changes to the program are the ability to operate up to 9 specific sites within a speed camera zone and the expansion of the program to cover local government roads (Queensland Transport, 2000). Reflecting this, the number of approved zones has grown from the initial 500 to approximately 1500 by April 2001. The number of specific sites within a zone at which the camera may be deployed has also increased. In the early stages of the program there was an average of 1.2 camera sites per zone. By April 2001, this had increased to an average of 1.5 sites per zone. The number of hours of speed camera operation has also grown over the life of the program, from an average of around 1000 hours per month in the early stages of the program, to around 4000 hours per month by April 2001.

1.2 STUDY AIM

Queensland Transport commissioned the Monash University Accident Research Centre (MUARC) to undertake a comprehensive evaluation of the crash effects of the Queensland speed camera program, capitalising on experience gained by MUARC in evaluating the Victorian speed camera program and the Queensland Random Road Watch program.

The broad aim of this research was to establish the effect of the speed camera program on crash frequency in Queensland. The evaluation also aimed to investigate differential effects of the program by crash severity as well as over time. A secondary aim of the study was to establish the mechanisms of any established program effectiveness through relating the estimated crash changes to program operational measures.

2. EVALUATION DESIGN

2.1 LIKELY MECHANISMS OF PROGRAM EFFECT

As described above, speed cameras have been used at approximately 2500 sites across Queensland, with operation being scheduled using a randomised regime similar to that used to schedule operations under the Random Road Watch (RRW) program (see Leggett, 1997 and Newstead et al, 2001). This means the cameras are operated at random times with the location of operation chosen essentially at random across the 500 to 2500 approved sites operational at various stages of the program. Even with 2500 potential sites of operation available across the state, the coverage of the total road system by speed camera enforcement is relatively sparse. However, 70% of the speed-related crashes in Queensland occur within 6km of the speed camera sites (see Figure 1). The primary issues considered in proposing hypotheses of likely speed camera effects in Queensland were the likely permeation of the effects of the cameras across the state in both space and time.

Given the overt nature of speed camera operations in Queensland, along with the tightly defined allowable areas of operation, it is likely that the largest crash effects will be concentrated around areas where the speed cameras are operating. This is consistent with the hypothesised effects that were tested in the evaluation of the RRW program (Newstead et al, 2001), a program that has a similarly visible mode of operation scheduled within set areas.

While public awareness of each exact speed camera location is low, awareness of the general area in which they have seen a camera in operation is higher. It would seem appropriate then to hypothesise a localised area of influence about the camera site using some fixed radius about the speed camera operation sites.

Experience in evaluating the localised effects of the Victorian speed camera program (Rogerson et al, 1994) has suggested what the localised areas of influence from speed camera operations are likely to be. Based on this experience, along with consideration of the way in which zones of camera operation are defined, a localised influence in areas within a radius of 6km of operational speed camera sites was hypothesised for the Queensland speed camera program. Whilst this radius is greater than the 1km and 5km diameters of the approved speed camera zones, the hypothesised area of influence allowed statistical testing for a broader effect of the cameras beyond the defined areas of operation. Examination of the crash data showed that sufficient data was available to examine the hypothesised 6km radius of speed camera influence in three separate annuli. These were defined as 0 to <2km, 2km to < 4km, 4km to <6km. Assessing crash effects of the camera in each annulus separately allowed testing if the influence of the speed camera program on crash frequency diminishes with distance from the speed camera locations across the hypothesised 6km radius of influence.

In evaluating the speed camera program in Victoria, Cameron et al (1992) found strong general, or non-localised, effects of the program on casualty crash frequency and severity.

Whilst it is possible that there have been some general effects on crashes of the speed camera program in Queensland, the overt nature of operations along with the smaller number of sites operated suggest the effects will be primarily localised, albeit over a large proportion of the state's crashes. In addition, it would be difficult to estimate any generalised effects of the Queensland speed camera program independently from those of other major road safety programs that have been run in parallel. Such programs include Random Road Watch (RRW) and the implementation of the 50km/h local street speed limit in south-east Queensland.

2.2 STUDY DESIGN

The most appropriate analysis design for this section of the evaluation was considered to be a quasi-experimental design, comparing crash history at sites influenced by the hypothesised speed camera effects against that at appropriately chosen control sites. This is similar to the analysis methods used for evaluation of the Queensland RRW program (Newstead et al, 2001) and allows for the control of other factors affecting crashes in parallel to the program of interest. In the case of the speed camera evaluation, the treatment group or area of the quasi-experimental design is the area within 6km of speed camera sites operational within the time frame of the evaluation data.

One of the key issues in adopting a quasi-experimental design framework is the appropriate choice of control or comparison groups for use in the analysis. A key requirement of the control group used here is that it reflects the parallel effect of other factors influencing levels of road trauma apart from the speed camera program. The Queensland RRW program is one such factor. There were only between 500 and 2500 operational speed camera sites in the study period in comparison to the RRW program that covered the whole of Queensland, with varying density, from before the time of introduction of the speed camera program. Hence there is likely to be essentially the same influence of the RRW program on crashes both within and outside of areas hypothesised to be influenced by the speed camera program. Consequently, all areas outside of the hypothesised zone of influence of the speed camera program served as control areas. This also maximised the amount of crash data analysed and hence the power of the statistical analysis undertaken. Control areas were also matched by the level of urbanisation and Police region of operation relevant to the treated area.

One issue to note is that RRW operations, scheduled using Geographical Information System analysis techniques, vary in enforcement density between regions. Because of the way speed camera sites are chosen in Queensland, it is likely that speed cameras will be operating predominantly in areas of high-density RRW operations. This was not considered a problem in the evaluation design, as coverage of the speed camera program is less than the total state coverage of the RRW program. This means there were high-density RRW sites both concurrent with and separate from the speed camera sites, hence balancing the quasi-experimental design. Further, and fundamentally, the speed camera program started after RRW.

Matching control areas in the way described isolates measurement of the crash effects of the speed camera program from the RRW program crash effects. It also controls for any confounding effects of associated mass media publicity of the speed camera program, as this will be the same in both treatment and control areas given its broad coverage.

Furthermore, it serves to control for the influence of broader factors on road trauma levels, such as population change.

Advice from Queensland Transport regarding the introduction of the speed camera program described above, indicated that likely crash effects from the program would have been observed from the introduction of the public education program during Christmas 1996. Hence the 'before' period in the evaluation design was defined as January 1992 to December 1996. Five years before treatment crash history was used in order to minimise possible regression-to-the-mean effects caused by the non-random selection of the speed camera operation sites (Nicholson, 1986). Complete reported crash data was available up to June 2001 giving a post-implementation period from January 1997 to June 2001.

2.3 EVALUATION HYPOTHESES TESTED

The generic null hypothesis tested in this evaluation is that the introduction of the speed camera program in Queensland had no effect on crash frequency in areas within a 6km radius of speed camera sites that had been used up to June 2001. This has been assessed against the two-sided alternative hypothesis that the introduction of the speed camera program has led to a change in crash frequency in the defined areas of influence. As a result of the study design, the alternative hypothesis also allows for differential crash effects of the speed camera program within each 2km annulus around the speed camera sites. A two sided alternative hypothesis used in this evaluation makes no presumption about the direction of the crash effects of the speed camera program and hence gives the most conservative statistical significance values on the program crash effect estimates. If a one sided alternative hypothesis is considered more appropriate by the reader (for example, if it is hypothesised that the program only reduces crashes of each severity level), statistical significance values presented should be halved, whilst the point estimates of crash effects will remain the same.

3. DATA

3.1 CRASH DATA

QT staff provided data on all reported crashes in Queensland over the period January 1992 to June 2001 in unit record format. Each crash record had information in the following fields:

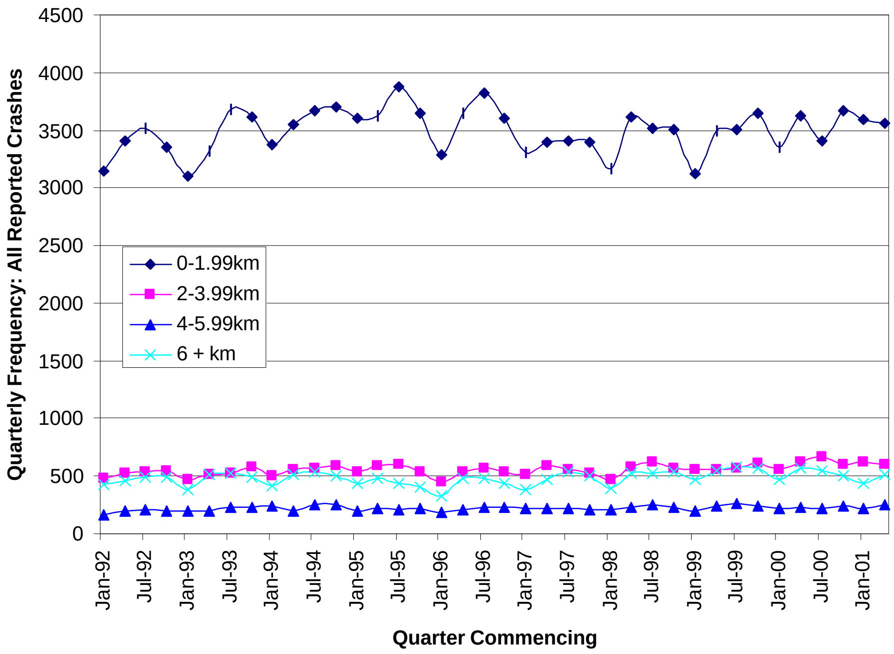
- Crash number
- Crash date
- Crash severity (fatal, serious injury, medically treated injury, other injury, no injury)
- Police region of crash
- Speed zone of crash
- Distance of crash from nearest operational speed camera site (km)

Data was defined as belonging to treatment or control groups using the distance of the crash from the nearest approved speed camera site. As noted, treatment group annuli were defined as: less than 2km from a speed camera site; 2km or more but less than 4km from a speed camera site and 4km or more but less than 6km from a speed camera site. Control areas were all those outside the defined treatment annuli. Before and after implementation periods were defined using the date of the crash.

QT assigned the distance of each crash in the data from the nearest approved speed camera site using Geographical Information System (GIS) software that related the physical location of crash and speed camera sites. As will be discussed further below, the number of sites at which speed cameras have been operated in Queensland has grown over the duration of the program. Ideally, crash data would have been labelled according to the distance to the nearest speed camera site that was operational at the time of the crash to be able to estimate the direct effects of speed camera presence on observed crashes. However, this was not possible because the GIS speed camera location information was dynamic, covering all speed camera sites that had been used up to the time of data interrogation as well as there being no facility for linking the crash and speed camera site records with respect to time. Consequently, the labelling of crash data with respect to the distance to the nearest speed camera site, referred to any speed camera site that had been used up to the time of matching the data (June 2001). This was irrespective of whether the camera site had been used operationally or not at the time of the crash. Implications for the interpretation of analysis stemming from this matching will be discussed later.

Figure 1 shows quarterly trends in all reported crashes in Queensland by distance from the nearest speed camera site that had been operational to the end of June 2001. It shows that around 73% of reported crashes in Queensland have occurred within 2km of a (eventual) speed camera site, rising to 85% when considering up to 4km from a speed camera site. It also shows that around 11% of crashes happened a distance of 6km or more from the nearest speed camera site (that became operational sometime during May 1997 to June 2001). This is important as it shows there is a sufficient number of crashes occurring in the area hypothesised as being uninfluenced by speed camera operations to be used as controls in the proposed analysis design.

Figure 1: *Number of police reported crashes in Queensland by distance from speed camera site*



3.2 SPEED CAMERA OPERATIONS DATA

QT provided the dates each speed camera site within each speed camera zone was commissioned for operation and decommissioned for operation if this had happened at the time of study. From this data, it was possible to compute the number of speed camera zones and sites that were operational in each month from January 1997 to June 2001 for each Queensland police region. QT also supplied the number of hours worked by speed cameras each month from January 1997 to June 2001 by police region as well as limited data on the number of infringement notices issued for speed infringements from speed camera operations. This latter data was somewhat incomplete in what was supplied with data for some specific months missing.

From the above data, measures of the number of sites in operation per speed camera zone and the number of hours worked per site and per zone each month by police region were calculated. Monthly data was also aggregated to give average values of each measure by quarter and by year after program implementation. Figures 2 to 5 respectively show the quarterly series of number of speed camera zones, sites, site density and hours of operation by police region in Queensland computed directly from the operations data supplied.

Figure 2: *Number of operational speed camera zones in Queensland by quarter and police region*

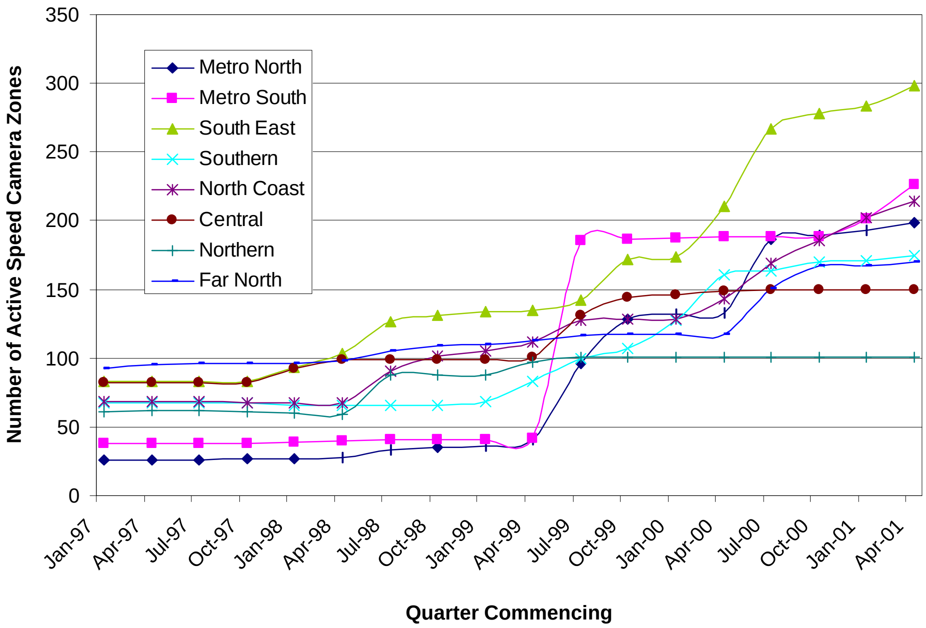


Figure 3: *Number of operational speed camera sites in Queensland by quarter and police region*

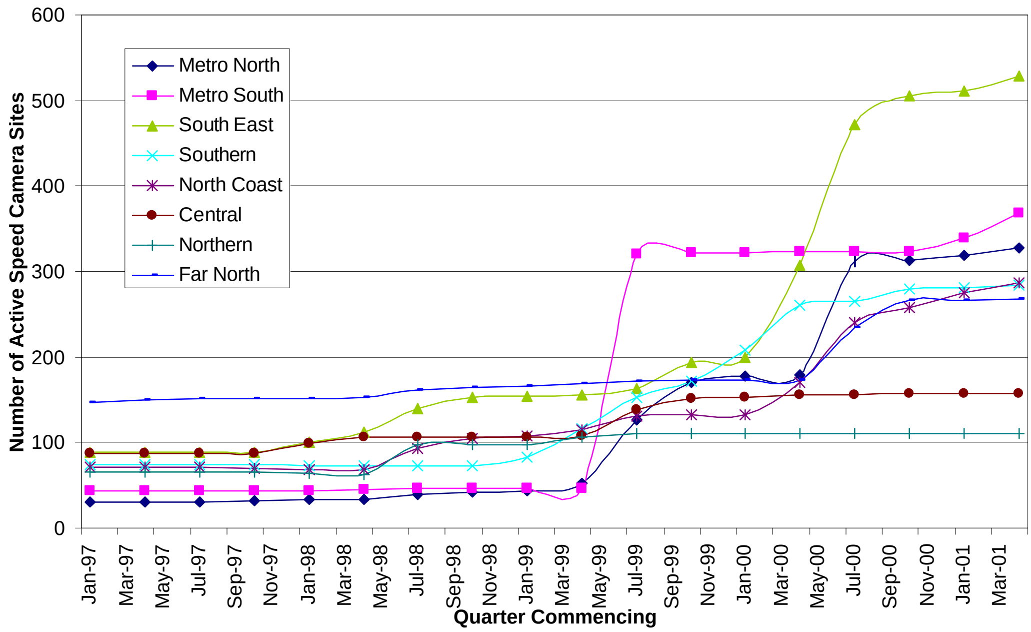


Figure 4: *Density of speed camera sites per zone in Queensland by quarter and police region*

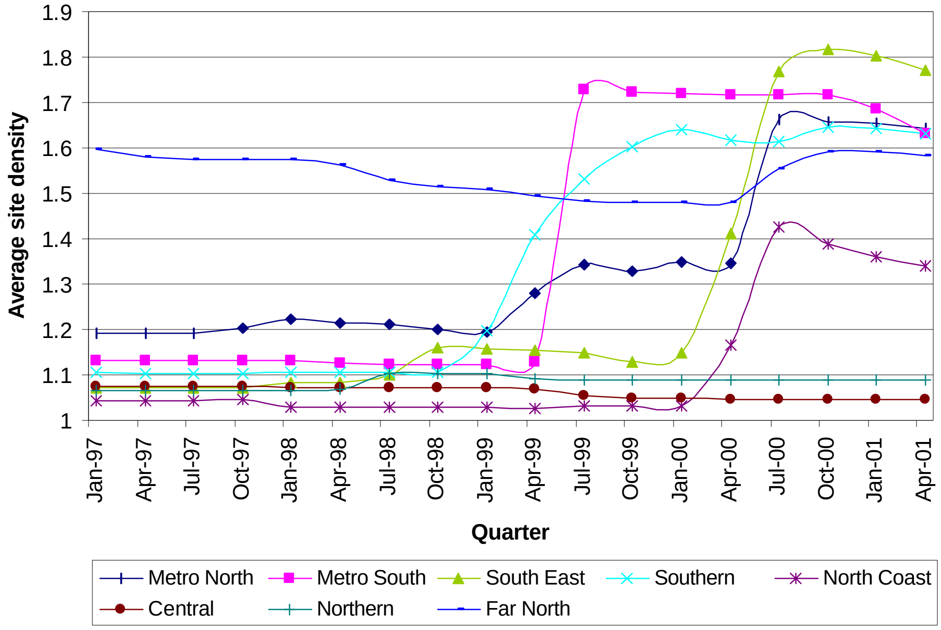
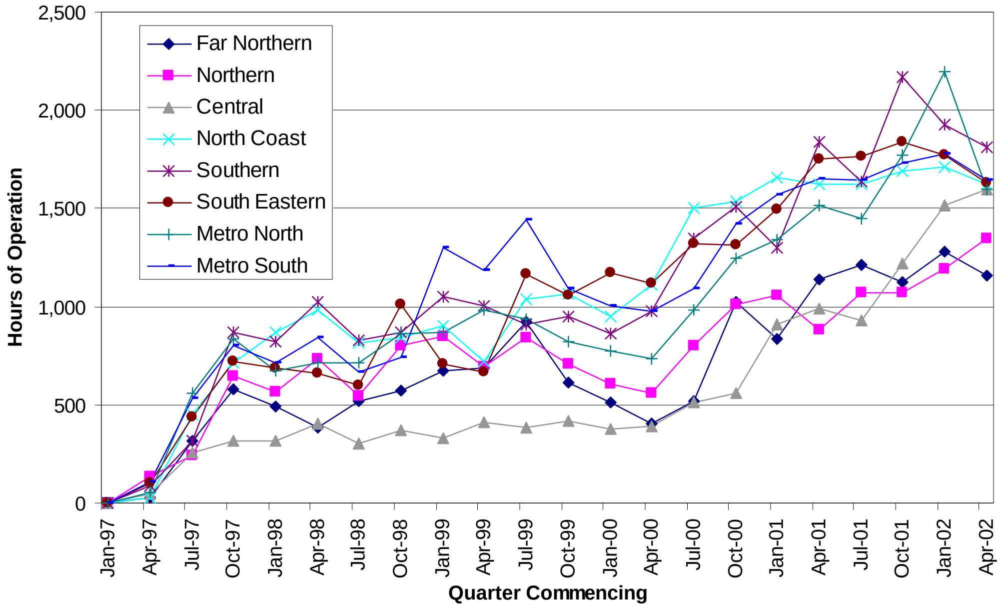


Figure 5: *Number of hours of speed camera operation in Queensland by quarter and police region*



There is significant variation in the time trends of each of the operational measures considered above by region. To obtain operational measures for Queensland as a whole, each measure was simply summed across each of the police regions, apart from the average site density per zone, which was computed directly from the total number of sites and zones. From Figures 2 and 3, it is also evident that the coverage of the speed camera program in Queensland increased dramatically in all regions during 1999. In contrast, the total number of hours worked by the speed cameras seems to have been increasing consistently over the study period.

4. METHODS

4.1 ESTIMATION OF CRASH EFFECTS

Net crash effects of the Queensland speed camera program under the quasi-experimental study design have been estimated using a Poisson log-linear statistical model. The analysis approach used here is similar to the approach used for evaluation of the Queensland Random Road Watch program (Newstead et al, 2001), as well as a number of other road safety program evaluation studies employing quasi-experimental designs. A Poisson log-linear model is felt to be appropriate for analysing the crash data for a number of reasons. Firstly, crash count data is widely considered to follow a Poisson distribution (Nicholson, 1986). It is also constrained to be non-negative as well as often being highly skewed in distribution, both factors accommodated by the log transformation in the log-linear model. Furthermore, the log-linear model structure assumes external factors, such as road safety campaigns, affect crash numbers in a proportionate way. This is in contrast to a linear model that assumes additive affects of external factors and can hence predict negative crash numbers under certain circumstances. Poisson log-linear models are also commonly used in the analysis of experimental designs in medical research (Breslow and Day, 1987).

The form of the model fitted to the monthly crash data frequencies of treatment and control data for each crash severity considered is given by equation 1.

$$\ln(y_{ijm}) = a + b_i + d_i m + g_j + f_{ij} \ldots (1)$$

where

y	is the monthly crash count
i	is an indicator for treatment annulus or control series
m	is a linear month indicator variable
j	is the speed camera program indicator
a, b, d, g, f	are parameters of the model

The indicators in the model take the following values.

m	= 1 in the first month of data
	= 2 in the second month of data etc.
i	= 0; control series (crashes 6km or greater from a speed camera site)

= 1; outer treatment annulus (crashes less than 6km but 4km or greater from a speed camera site)

= 2; middle treatment annulus (crashes less than 4km but 2km or greater from a speed camera site)

= 3; inner treatment annulus (crashes less than 2km from a speed camera site)

The speed camera program indicator, *j*, has been defined in a number of ways depending on whether effects of the speed camera program were being estimated across the total period after implementation or by year or quarter after implementation. For total program estimates, j is defined as follows;

j **= *0*** if month was before introduction of the speed camera program

= *1* if month was after introduction of the speed camera program

For annual or quarterly program estimates

j **= *0*** if month was before introduction of speed camera program

= *1* if month was in the first year (quarter) after introduction of speed camera program

= *2* if month was in the second year (quarter) after introduction of speed camera program

etc.

The net effect of the speed camera program in treatment annulus *i* in time period *j* after program implementation, measured as a net percentage reduction in crash frequency, is given by Equation 2.

$$\Delta SpeedCamera_{ij} = (1 - \exp((f_{ij} - f_{i0}) - (f_{0j} - f_{00})) \times 100\% \qquad ...(2)$$

Equation 2 is measuring the change in treatment area crash frequency from before treatment to time period j after treatment, adjusted for corresponding changes in crash frequency in the control areas over the same time period.

In practice, parameterisation of the factors in the model given by equation 1 leaves a number of parameters ‘aliased’. ‘Aliased’ parameters refer to those that are unable to be estimated because they are a linear product of other parameters in the regression design matrix. Aliased parameters are set to zero in the regression equation. With careful parameterisation and fitting of the model in equation 1, it is possible to alias the parameters f_{0j} and f_{i0} for all values of *i* and *j*. This leads to a reduction in Equation 2 to give Equation 3.

$$\Delta SpeedCamera_{ij} = (1 - \exp(f_{ij})) \times 100\% \qquad ...(3)$$

The form of Equation 3 is much more convenient in practice as statistical testing of the difference in f_{ij} from zero tests directly the significance of the change in crash frequency in speed camera annulus of influence *i* in time period *j* after program implementation. Similarly, the variance of f_{ij} can be used to compute confidence limits on the estimated change in crash frequency.

Discussion so far has centred on defining a model structure to estimate the effect of the speed camera program for all police regions in Queensland aggregated. The model structure was extended to simultaneously estimate program effects in each police region separately. The model structure for simultaneous program effect estimation in each police region is given by Equation 4.

The terms in Equation 4 are as defined above, with the addition of index *k*, which is an indicator for police region.

$$\ln(y_{ijkm}) = a + b_{ik} + d_{ik} m + g_{jk} + f_{ijk} \ldots (4)$$

Estimates of speed camera program effects by police region from the model of Equation 4 for each treatment annulus *i* and post implementation time period *j* are obtained using a logical extension to Equation 3.

All Poisson log-linear regression models were fitted using the GENMOD procedure in the SAS statistical analysis software (SAS, 1993).

4.2 COMPARISONS WITH OPERATIONAL MEASURES

Conventional linear regression techniques have been used to compare estimated crash effects with operational measures of the speed camera program. Estimates of percentage change in crash frequency were modelled as a function of the key program measures described in the Data section. Where appropriate, stepwise model selection techniques have been used to arrive at the models best describing the outcome measure. Prior to the application of the regression models, correlation analyses of the program measures were undertaken to determine the level of co-linearity between the key measures with a view to only including relatively independent explanatory variables in the regression models.

Comparison between speed camera program operational measures and estimated crash effects has been carried out in two dimensions. Variations in program effectiveness, firstly with respect to time and secondly with respect to region of operation, have been examined.

5. RESULTS

5.1 CRASH EFFECT ESTIMATES

5.1.1 Average effects over the whole post implementation period

Table 1 gives the estimates of percentage crash frequency reduction attributable to the Queensland speed camera program obtained from log-linear analysis of the data using a model of the form of Equation 1. Results are presented separately for each of the five crash severity levels coded in the Queensland crash data as well as for fatal, hospitalisation and medically treated crashes combined and all severity levels combined.

Results in Table 1 are given for each of the three annuli within the hypothesised 6km radius of speed camera influence. Also shown in Table 1 are the statistical significance probabilities of the estimated percentage crash reductions. Low significance probabilities indicate crash reduction estimates that are statistically significantly different from zero. Negative estimated percentage crash reductions indicate an estimated crash increase. None of the estimated crash increases were statistically significant meaning the apparent crash increase could have been due to chance variation in the data rather than indicating a real increase in crash risk.

Table 1: *Estimated crash reductions attributable to the Queensland speed camera program in the total post implementation period (January 1997 to June 2001).*

Crash Severity	Distance From Camera Site	Estimated Crash Reduction	Significance Probability
Fatal	0-1.99 km	15.7%	0.3549
	2-3.99 km	4.4%	0.8611
	4-5.99 km	-18.2%	0.6161
Hospital Admission	0-1.99 km	21.9%	0.0001
	2-3.99 km	14.7%	0.0647
	4-5.99 km	6.5%	0.5481
Medically Treated	0-1.99 km	8.8%	0.1946
	2-3.99 km	6.5%	0.4452
	4-5.99 km	4.1%	0.7111
Fatal to Medically Treated	0-1.99 km	15.6%	0.0002
	2-3.99 km	11.2%	0.0446
	4-5.99 km	5.1%	0.4968
Other Injury	0-1.99 km	14.7%	0.0986
	2-3.99 km	-6.6%	0.6047
	4-5.99 km	-4.0%	0.8103
No Injury	0-1.99 km	20.3%	<.0001
	2-3.99 km	16.1%	0.0045
	4-5.99 km	19.6%	0.0066
All Severity Levels	0-1.99 km	17.5%	<.0001
	2-3.99 km	11.4%	0.0027
	4-5.99 km	10.7%	0.0313

NB: Negative crash reduction estimates indicate an estimated crash increase

There are a number of notable features of the results in Table 1. In general, crash reductions associated with the speed camera program in Queensland have been greatest in the 0 to 2km annulus around operational camera sites with estimated effects clearly reducing across the outer annuli with increasing distance from the camera site. Apart from hospital admission and non-injury crashes, analysis of effects within specific crash severity levels is difficult to interpret due to a general lack of statistical significance. However, the consistency in the point estimates of program effectiveness across crash severity levels suggests the speed camera program is not associated with differential crash effects related to severity of outcome.

Aggregating the data across a range of crash severity levels for analysis gave more definitive estimates of program effectiveness. Considering crashes of all reported severity levels, statistically significant crash reductions associated with the speed camera program were found in each of the hypothesised annuli of influence. Crash reduction estimates ranged from 17% within 2km of speed camera sites to 10% in the area from 4 to 6km from the camera sites. Similar estimates were obtained for fatal, hospitalised and medically treated crashes combined although the size of the reduction in the area up to 2km from the speed camera sites was slightly smaller at 15% and the estimate of crash effect within 4 to 6km from camera sites was not statistically significant.

5.1.2 Effects by calendar year after implementation

Table 2: *Estimated percentage crash reductions attributable to the Queensland speed camera program by year after program implementation.*

		Year				
Crash Severity	**Distance From Camera Site**	**1997**	**1998**	**1999**	**2000**	**2001***
Fatal	0-1.99 km	14.6% (0.4371)	24.8% (0.2307)	34.4% (0.1147)	45.3% (0.0446)	42.6% (0.1257)
	2-3.99 km	-13.0% (0.6583)	30.5% (0.2909)	8.2% (0.8177)	-3.0% (0.9425)	8.5% (0.8578)
	4-5.99 km	-30.0% 0.4653	4.6% 0.9158	-37.7% 0.5018	37.4% 0.4228	-81.3% 0.3425
Hospital Admission	0-1.99 km	18.4% (0.0052)	28.4% (<.0001)	38.5% (<.0001)	30.5% (0.0007)	34.4% (0.0008)
	2-3.99 km	13.8% (0.1326)	12.8% (0.2148)	20.7% (0.0658)	6.7% (0.6315)	14.3% (0.3635)
	4-5.99 km	2.6% (0.8319)	21.1% (0.1000)	24.8% (0.0814)	26.7% (0.0975)	29.8% (0.1101)
Medically Treated	0-1.99 km	6.2% (0.4241)	20.4% (0.0128)	36.4% (<.0001)	39.0% (<.0001)	33.9% (0.0028)
	2-3.99 km	1.8% (0.8545)	16.1% (0.1205)	24.0% (0.032)	18.4% (0.1601)	22.8% (0.1322)
	4-5.99 km	8.5% (0.4887)	5.9% (0.6755)	26.7% (0.0608)	31.6% (0.0446)	27.0% (0.1563)
Fatal to Medically Treated	0-1.99 km	12.4% (0.0101)	25.1% (<.0001)	38.0% (<.0001)	36.3% (<.0001)	34.6% (<.0001)
	2-3.99 km	7.2% (0.2643)	16.6% (0.0172)	23.1% (0.0024)	13.4% (0.1411)	19.4% (0.0635)
	4-5.99 km	4.7% (0.5772)	13.7% (0.135)	24.0% (0.0148)	29.2% (0.0073)	25.2% (0.0559)
Other Injury	0-1.99 km	10.2% (0.3081)	9.7% (0.4046)	36.7% (0.0009)	19.3% (0.1811)	8.2% (0.6564)
	2-3.99 km	-11.8% (0.4052)	-11.5% (0.4842)	21.9% (0.1640)	5.2% (0.7965)	-21.0% (0.4313)
	4-5.99 km	3.2% (0.8570)	-22.2% (0.3262)	-6.5% (0.7871)	4.4% (0.8697)	-33.5% (0.3643)
No Injury	0-1.99 km	20.4% (<.0001)	18.1% (0.0014)	16.5% (0.0114)	21.4% (0.0030)	6.9% (0.4720)
	2-3.99 km	14.5% (0.0227)	13.1% (0.0744)	14.5% (0.0819)	16.2% (0.0834)	-5.0% (0.6938)
	4-5.99 km	18.4% (0.0225)	18.8% (0.0409)	21.9% (0.0340)	23.5% (0.0423)	9.1% (0.5496)
All Severity Levels	0-1.99 km	15.6% (<.0001)	20.4% (<.0001)	29.6% (<.0001)	28.4% (<.0001)	21.7% (<.0001)
	2-3.99 km	8.4% (0.0518)	12.3% (0.0106)	19.9% (0.0002)	14.3% (0.0211)	7.3% (0.3382)
	4-5.99 km	10.8% (0.0522)	12.7% (0.0412)	20.4% (0.0027)	24.6% (0.0012)	14.8% (0.1221)

NB: Negative crash reduction estimates indicate an estimated crash increase
**: First 6 months of 2001*

Results presented in Table 1 estimate the average crash reductions associated with introduction of the Queensland speed camera program in the total period after program implementation. Figure 2, however, shows that the program grew significantly from the time of its introduction and hence it would be expected that crash effects would change over time. This expectation is further reinforced by recalling that the hypothesised zones of speed camera influence were defined on all the speed camera sites operational up to September 2001, relatively few of which were operational at the commencement of the program. Table 2 presents estimates of crash reductions associated with the speed camera program in each calendar year after its hypothesised commencement of influence in January 1997. Interpretation of the results in Table 2 is the same as for those in Table 1.

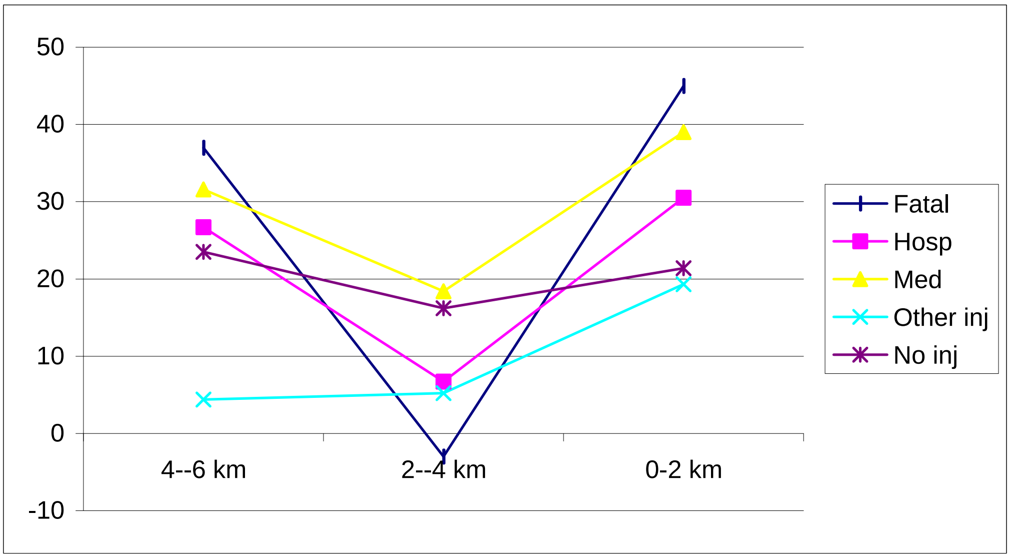
Examination of Table 2 shows that, generally, estimated crash reductions attributable to the speed camera program in Queensland have increased with time since the introduction of the program. This is particularly evident when examining results for higher severity crashes within 2km of speed camera sites. Estimated reductions in fatal to medically treated severity crashes within 2km of speed camera sites have increased from 12% in the first year of the program (1997), to around 35% in the years 2000 and 2001, with estimates in each year being statistically significant.

Unlike the results of Table 1, results in Table 2 suggest a differential effect of the speed camera program on crashes by crash severity level, particularly evident in later years after the program introduction. In these later years, estimates of fatal to medically treated crash effects within 2km of speed camera sites are in the order of 35%, with fatal effects being the highest individually at around 45%. In contrast, estimates of effects on other injury and non-injury crashes within 2km of speed camera sites in 2000 and 2001 are around 20% or less.

A further differential shown in table 2 concerns crash reduction by distance from camera site. Figure 6 shows that crash reductions are greatest nearest the camera (0-2km) as expected, but least in the next annulus out (2-4km). It is of interest that this violates the simplest deterrence hypothesis, which is that deterrence should decrease with distance from a camera site.

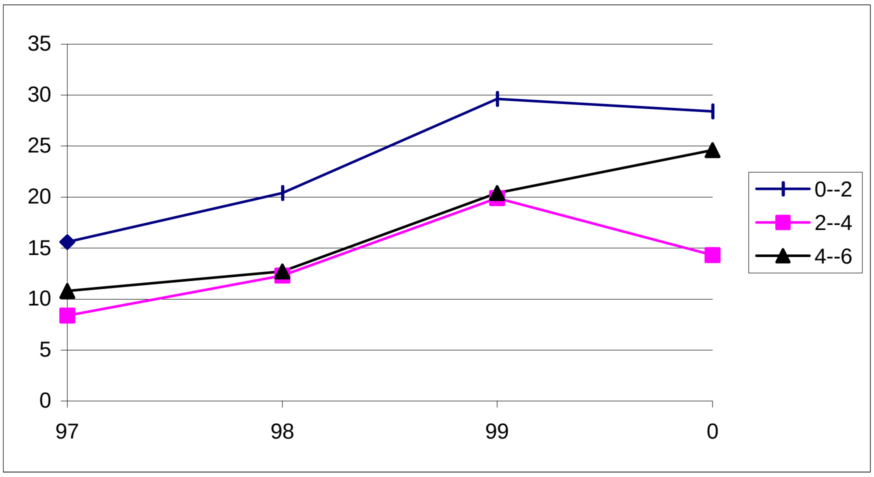
This may indicate evidence of site learning. It is proposed that this has occurred partly due to the site-specific deployment of cameras in Queensland. Consequently, some motorists may (1) learn where cameras are likely to be, (2) by subtraction, learn where they are not, and (3) speed on those sections of road where cameras are unlikely to be. The fact that generally crash reductions rise again in the third annulus (4-6km) may result from there being less certainty about camera positionings here so caution returns, albeit at a lower level than when nearest to camera sites.

Figure 6: *Year 2000 Percentage crash reduction by injury severity and distance from speed camera site*



This concept is explored further in Figure 7, which displays crash reduction by year and distance from camera for total reported crashes of all severities. Figure 7 shows that for the year 2000 both inner annuli, which may be more prone to site learning considering the general deterrence theory, indeed display a crash reduction decrease from 1999 to 2000, while the outer, theoretically less prone, annulus does not.

Figure 7: *Percentage crash reduction in total crashes of all severities by year and distance from speed camera*



Estimates of the absolute magnitude of crash savings attributable to the speed camera program, rather than just the percentage reductions shown in Table 2, are shown in Table 3. These have been derived by using the estimated annual percentage reductions in Table 2 along with the average annual pre-program crash frequency by crash severity level and annulus of influence. It should be noted that there are a number of ways of deriving actual crash savings from the percentage reduction estimates in Table 2. This is because the Poisson log-linear model used to derive the percentage reduction estimates is a multiplicative form, being a product of the change in the treatment group accounting for parallel changes in the control group as well as changes attributed to the treatment itself. The absolute magnitude of crash change attributed to the treatment will depend on whether the control effects or the treatment effects are assumed to have influenced the treatment crashes first. In the figures presented in Table 3, the effects reflected by the control group are assumed to have changed the treatment area crashes, giving the most conservative estimate of the number of absolute crashes saved by the speed camera program.

It should be noted in Table 3 that crash savings for 2001 are based on only a half year of crash data and hence should be doubled to give indicative whole year results, assuming consistent program effectiveness across the year. It should also be noted that the estimates of crashes saved for all severity levels and for fatal to medically treated crashes aggregated, were not obtained by summing the estimates from the individual crash severity levels. They were based on specific estimates of crash effectiveness from the statistical procedures applied to data from those severity levels aggregated and, as such, will be more precise than estimates gained from simply summing the savings from the individual crash severity levels.

Table 3: *Estimated total crash savings attributable to the Queensland speed camera program by year after program implementation.*

		Year				
Crash Severity	**Distance From Camera Site**	**1997**	**1998**	**1999**	**2000**	**2001***
Fatal	0-1.99 km	31	49	76	113	50
	2-3.99 km	-6	12	4	-2	2
	4-5.99 km	-5	1	-6	6	-6
Hospital Admission	0-1.99 km	480	887	1410	1097	652
	2-3.99 km	58	62	114	35	38
	4-5.99 km	5	49	67	70	41
Medically Treated	0-1.99 km	234	869	1899	2201	1012
	2-3.99 km	10	96	169	136	87
	4-5.99 km	17	13	71	88	39
Fatal to Medically Treated	0-1.99 km	827	1946	3512	3469	1740
	2-3.99 km	73	189	304	177	131
	4-5.99 km	20	65	132	162	72
Other Injury	0-1.99 km	228	223	1119	503	101
	2-3.99 km	-31	-30	73	14	-27
	4-5.99 km	3	-21	-8	4	-16
No Injury	0-1.99 km	1454	1307	1210	1599	204
	2-3.99 km	161	151	173	201	-25
	4-5.99 km	84	90	111	126	20
All Severity Levels	0-1.99 km	2500	3535	5786	5579	1985
	2-3.99 km	200	315	569	407	97
	4-5.99 km	104	134	243	294	82

NB: Negative crash saving estimates indicate an estimated crash deficit
**: Half year only*

The annual crash saving over all severity levels for areas within 2km of a speed camera site was estimated at approximately 5,500 in the years 1999 and 2000 (refer table 3). The comparable figure for fatal, hospitalisation and medically treated crashes saved in the same years was around 3,500. These figures are indicative of the full potential of the program during the study period as in these years it had expanded to its current largest coverage. Table 3 reflects the breakdown of crashes saved by distance from a speed camera site, with the majority of crash savings occurring within 2km of the speed camera site.

Whilst there is indication of crash savings in the outer annuli of hypothesised influence, they are less than in the closest annulus. Because of this, it is evident that final assessment of the measure of effectiveness of the speed camera program in Queensland should focus mainly on crash effects within the 2km annulus closest to the camera sites.

Program Benefit to Cost Ratio Estimate

Using the estimates of annual crash savings presented in Table 3 along with estimated crash costs and actual program costs, an indicative social benefit to cost ratio (BCR) of the

Queensland speed camera program over the period from program introduction to June 2001 has been computed. Crash cost figures used were those estimated by the Bureau of Transport Economics (BTE, 2000) by crash severity based on the human capital approach. In 1996 basis A$, the crash cost estimates from the BTE were $1,652,994 for a fatal crash, $407,990 for a crash resulting in hospital admission, $13,776 for a minor or other injury crash and $5,808 for a non-injury crash. In order to compare total crash cost savings from the program in any year to real program expenses in each year, the crash costs given by the BTE have been adjusted by the Consumer Price Index at June of each program year. This means, for example, that 1998 crash costs are given in 1998 dollars, whilst 2000 crash costs are given in 2000 dollars. The resulting estimates of crash cost savings associated with the Queensland speed camera program for each year after program implementation are given in Table 3a. It should be noted that crash savings from year to year are not directly comparable in Table 3a because of currency inflation differences between each year.

Table 3a: *Estimated total crash cost savings attributable to the Queensland speed camera program by year after program implementation.*

	Year					
Crash Severity	**1997**	**1998**	**1999**	**2000**	**2001***	**Total**
Fatal	$33.2M	$103.5M	$124.9M	$203.7M	$84.6M	$549.9M
Hospital	$222.3M	$411.3M	$662.7M	$516.6M	$332.0M	$2,144.8M
Medical	$3.6M	$13.6M	$30.1M	$35.1M	$17.5M	$99.9M
Other	$2.8M	$2.4M	$16.7M	$7.6M	$0.89M	$30.3M
No Injury	$9.9M	$9.1M	$8.9M	$11.8M	$1.3M	$40.9M
Total	$271.7M	$539.8M	$843.1M	$774.9M	$436.3M	$2,865.8M

*Crash cost savings for 2001 are for the 6 months from January to June only

Queensland Transport supplied information on total expenses incurred in running the speed program in each financial year from the commencement of the program. A single cost figure was supplied for each year that represented the total of both capital and operating costs of the program. Costs were converted to calendar years for comparison with the crash cost savings estimates by assuming costs were evenly distributed across the year. In calculating a BCR, capital costs should be discounted over the life of the capital investment and added to inflation adjusted operating costs to derive total program costs. As capital and operating costs were not available separately, no discounting of capital costs has been possible. Instead it has been assumed that the capital cost component of a project incurred in any one year applies only to that year. The total cost of running the Queensland speed camera program over the post implementation study period was $60.8M.

Comparing the total crash cost savings in Table 3a over the four and a half program post implementation years studied in this evaluation ($2,865.8M) with the total cost of operating the Queensland speed camera program over this period ($60.8M), the BCR of the program was estimated to be 47. That is, for every dollar invested by the Queensland Government in the speed camera program, the cost to society of road crashes reduced by 47 dollars. Although slightly less than the BCR figure estimated for the Queensland Random Road Watch program of 55 (Newstead et al, 2001), a BCR of 47 still shows the

Queensland speed camera program to be a highly cost effective means of reducing road trauma.

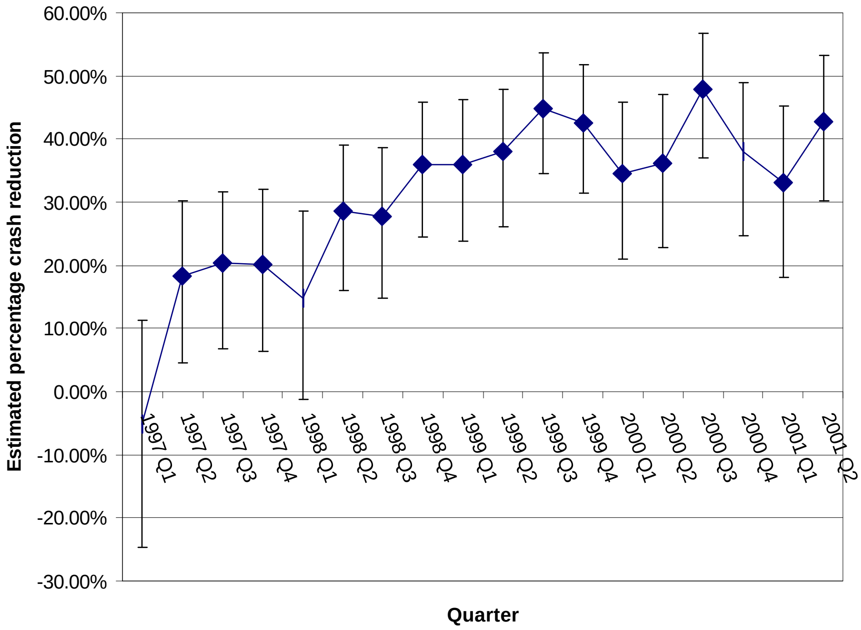
Queensland Transport also supplied information on the total revenue raised from speeding fines issued from speed camera operations. Traditionally in calculating the social BCR of a program, fine revenue is not included in the calculation, as it is generally not considered a social benefit. This assumption has also been made here and fine revenue has not been included in the BCR calculation. Furthermore, the value of fine revenue raised by the speed camera program is negligible in comparison the crash cost savings shown in Table 3a. Consequently, the inclusion of fine revenue in the BCR calculation would make very little difference to the final BCR estimated for the program. This point shows clearly that the main benefit to society from the Queensland speed camera program is the reduction in road crash costs. Any further benefit to the Queensland Government that arises through the availability of fine revenue is negligible in comparison.

5.1.3 Effects by quarter after implementation

To more closely demonstrate the varying crash effects of the Queensland speed camera program over time, estimates of program effectiveness by quarter have been made for all crash severity levels combined and fatal, hospitalisation and medically treated injury crashes combined within 2km of a speed camera site. These crash severity levels were chosen as the analysis above indicated sufficient data to give meaningfully accurate results at this level of time stratification in the post treatment period. Results for other crash severity levels and annuli of influence have not been presented due to a general lack of statistical reliability.

Figure 8 shows the estimated net reduction in fatal, hospital and medically treated crashes associated with the speed camera program by quarter after program introduction. As above, negative crash reduction estimates indicate an estimated crash increase. Each of the estimates in Figure 8 is shown with its 95% confidence limit.

Figure 8: *Estimated percentage crash reduction associated with the Queensland speed camera program by quarter after implementation: Fatal, Hospital and Medically Treated crashes within 2km of a speed camera site*

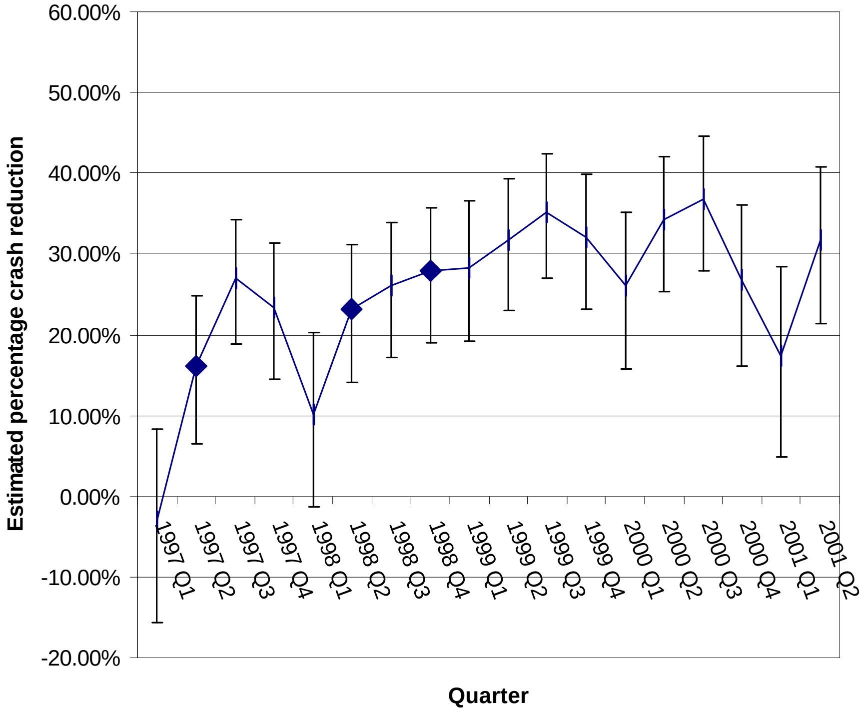


As shown in Table 2, Figure 8 further demonstrates the increasing crash effects of the Queensland speed camera program over time. The only quarter not to show significant crash reductions associated with the program was the first quarter after program introduction, namely January to March 1997. Background to the speed camera program given in the Introduction section indicated that enforcement under the program did not commence until May 1997. The period before this, from January to April 1997, was considered to be in the program post implementation period because of the significant publicity supporting the program that occurred over that time, even though no enforcement took place. Figure 6 suggests that there were no crash effects associated with the program during the period when there was publicity only, prior to the start of enforcement.

Figure 8 shows that after enforcement commenced, effects on the higher severity crashes in the area 2km from speed camera sites grew from around 15-20% in the first year of the program, to 30-45% in latter stages of the evaluation time frame. Although not statistically significant, during this growth period there seemed to be periods of high effectiveness increase along with other periods of apparent crash effect recession. The relationship between these observed crash patterns and speed camera operation patterns has been further investigated below.

Figure 9 shows analogous information to Figure 8 but for all reported crashes at all severity levels. Patterns of estimated crash effects in Figure 9 are generally similar to those shown in Figure 8 for the more severe crashes. The only difference is the generally smaller estimated crash reductions in Figure 9, particularly in the latter stages of the program. The difference in the magnitude of effect sizes between Figures 8 and 9 for the quarterly analysis is consistent with that observed for the same crash types in the annual analysis results presented in Table 2.

Figure 9: Estimated percentage crash reduction associated with the Queensland speed camera program by quarter after implementation: all reported crashes within 2km of a speed camera site



5.1.4 Total effects by police region

There are substantial differences between police regions in Queensland with respect to population and road use and environmental characteristics. In addition, because the specific operation of the speed camera program in each Queensland police district is controlled to a certain degree by the local police, it was of interest to examine the relative crash effects of the program across each police region.

Using the model given by Equation 4, net crash reductions associated with the introduction of the speed camera program have been estimated for each Police region in Queensland. Because of the relatively small quantities of data available at this level of stratification, only the average crash effects across the total post-implementation period under study have been estimated. There was also insufficient data to give reliable results for hypothesised areas of influence between 2km and 6km from a speed camera site and for individual crash severity levels. Hence, the results shown in Table 4 cover only areas within 2km of a speed camera site and for all crash severity levels combined, as well as fatal, hospital and medically treated crashes combined.

Table 4: *Estimated percentage crash reductions within 2km of a speed camera site attributable to the Queensland speed camera program by police region of crash.*

Police Region	Crash Severity	Estimated Crash Reduction	Statistical Significance
Central	**All crash severity levels**	7.8%	0.2646
	Fatal To Med. Treat.	0.2%	0.9841
Far Northern	**All crash severity levels**	32.4%	<.0001
	Fatal To Med. Treat.	22.7%	0.0713
Metro North	**All crash severity levels**	-4.7%	0.8818
	Fatal To Med. Treat.	19.5%	0.6012
Metro South	**All crash severity levels**	18.0%	0.6493
	Fatal To Med. Treat.	27.5%	0.5675
North Coast	**All crash severity levels**	4.3%	0.5526
	Fatal To Med. Treat.	10.3%	0.3124
Northern	**All crash severity levels**	30.6%	0.0003
	Fatal To Med. Treat.	37.6%	0.0009
South East	**All crash severity levels**	11.3%	0.5309
	Fatal To Med. Treat.	-0.2%	0.9943
Southern	**All crash severity levels**	11.9%	0.079
	Fatal To Med. Treat.	-3.7%	0.7392

NB: Negative crash reduction estimates indicate an estimated crash increase

Estimates of speed camera crash effects by police region in Queensland presented in Table 4 suggest significant variation in crash effects between police regions with estimates for all crash severity levels combined ranging from a 4.7% crash increase (not statistically significant) to a 32.4% crash decrease (statistically significant). Interpretation of these results should be made with care, however, as many failed to reach statistical significance. Again, due to the general lack of statistical reliability caused by small data quantities, results in Table 4 should not be taken to suggest the speed camera program has been ineffective in certain police regions. Rather the results only serve to indicate differential performance across police regions.

5.2 COMPARISON WITH OPERATIONS DATA

In the analysis above, significant variation in the estimated crash effects of the speed camera program in Queensland were observed both over time and across police region. Charts of various operational measures from the speed camera program shown in the Data section also show significant variation over time and across police region. In order to gain an understanding of the operational factors determining the success of the speed camera program in Queensland, the estimated crash effects from the program, both over time and across region, have been compared with operational measures from the program over the same dimensions.

5.2.1 Effects Over Time

Analysis of the relationship between speed camera operational measures and crash effects of the program over time were carried out on the quarterly estimates of program crash effects shown in Figures 8 and 9. For comparison, the operational measures shown in Figures 2 to 5 were aggregated across all police regions to give state wide figures. As well as the measures shown in Figures 2 to 5, a number of other measures were derived from these. A full list of the measures considered, with data used on a quarterly basis, is as follows.

- Number of active sites (sites)
- Number of active zones (zones)
- Average number of active sites per active zone (site density)
- Total hours of operation (hours)
- Average hours of enforcement per active zone (hours per zone)
- Average hours of enforcement per active site (hours per site)
- Increase in number of sites from previous quarter (site rate)
- Increase in number of zones from previous quarter (zone rate)
- Increase in site density from previous quarter (density rate)
- Increase in total hours from previous quarter (hours rate)

To avoid co-linearity problems in the regression models relating the operational measures to the estimated program crash reductions, a correlation analysis of the operational measures was undertaken to establish the level of association between each. The measures: 'sites', 'zones', 'site density' and 'hours', were all found to be highly correlated, as were 'hours per site' and 'hours per zone' as well as 'site rate', 'zone rate' and 'density rate'. The first block of correlated variables all represent program size, the second block represent enforcement density, whilst the last block represent program growth. To overcome problems of co-linearity stemming from the correlated measures, a single measure from each correlated set was chosen to be included in the regression modelling. 'Zones' was chosen as the measure of program size, 'hours per zone' as the measure of enforcement density' and 'site rate' as the measure of program growth. This left four independent measures of speed camera program operations from the original ten.

A linear regression model was fitted relating the four independent speed camera operational measures to the estimated percentage crash reductions associated with the program. A stepwise procedure was used to select only those measures that were statistically significant predictors of the estimated program crash reductions. Separate models were estimated for reductions in crashes of all severity levels combined and fatal, hospital and medically treated crashes combined. For each model, 'zones', 'hours per zone' and 'site rate' were found to be statistically significantly related to estimated crash reduction in the linear regression model. 'Hour rate' was not statistically significantly related to crash reduction in either case. Table 5 shows the standardised regression coefficients of the three significant operational measures for the two regression models along with the statistical significance of each. Standardised regression coefficients are given as they allow assessment of the relative influence of each predictor in the regression equation on the outcome variable. Also shown in Table 5 is the overall model R-squared, a measure of the amount of variation in the outcome variable explained by the regression model.

Results of the regression analysis shown in Table 5 show both regression models explain a high proportion of the variance in the estimated percentage program crash reductions. The regression model for all crash severity levels explains around 60% of the variation whilst the model for fatal to medically treated crashes explains just over 80% of the variation. Figures 10 and 11 show the level of fit of the regression model predicted values (predicted) to the original program crash reduction estimates (observed), both confirming the high level of fit as indicated by the R-squared values.

Table 5: Results of regression modelling of estimated crash reductions associated with the Queensland speed camera program against program operational measures over time.

	All crash severity levels		**Fatal, hospital and medically treated crashes**	
Operational Measure	**Standardised Regression Coefficient**	**Significance Value**	**Standardised Regression Coefficient**	**Significance Value**
Zones	0.475	0.018	0.679	<0.001
Hours per site	0.515	0.018	0.455	0.004
Site rate	0.374	0.075	0.319	0.033
Overall model R-squared	0.597		0.808	

Figure 10: *Estimated percentage crash reduction associated with the Queensland speed camera program by quarter after implementation and prediction using operational measures: All reported crashes within 2km of a speed camera site*

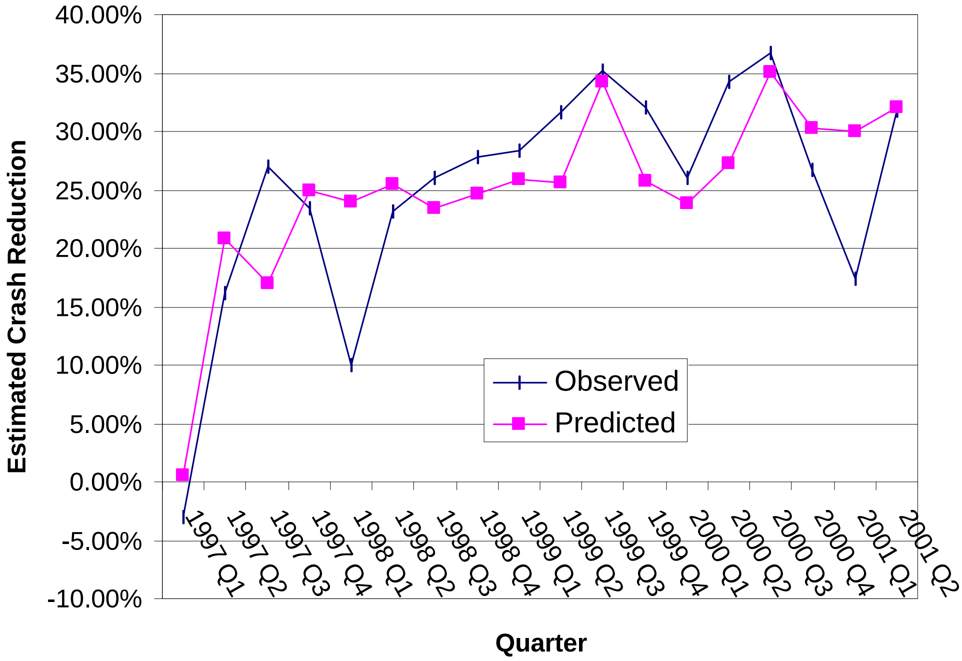
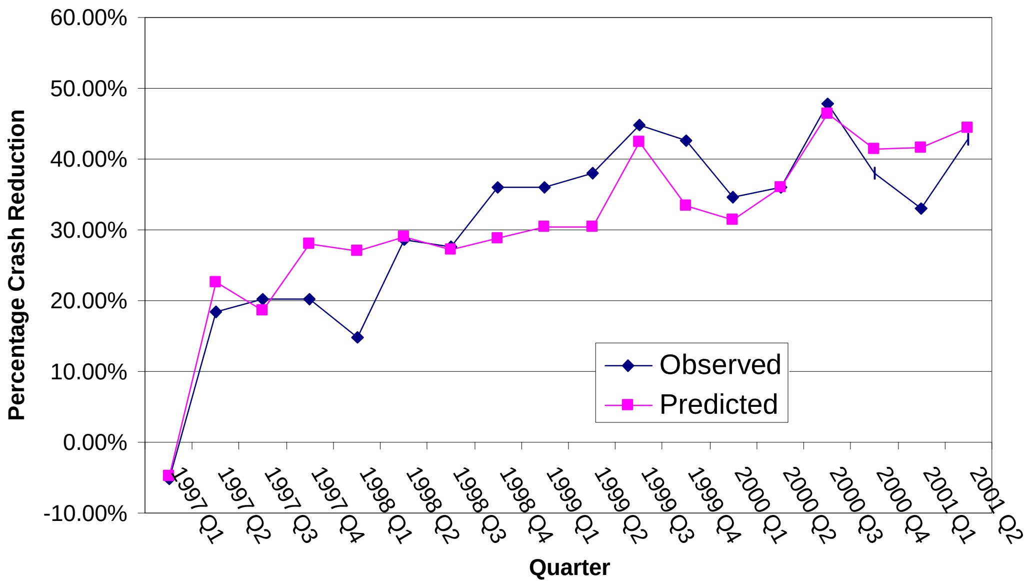


Figure 11: *Estimated percentage crash reduction associated with the Queensland speed camera program by quarter after implementation and prediction using operational measures: Fatal to medically treated crashes within 2km of a speed camera site*



Interpretation of the standardised regression coefficients in Table 5 suggests crash reduction estimates for all crash severity levels were influenced most by enforcement density (hours per site) followed by program size (zones) and to a lesser degree the rate of program growth (site rate). In contrast, reductions in the higher severity crashes were influenced most by program size followed by enforcement density and again least by the rate of program growth. It is important to note that, because of the high correlation between rate of zone creation, rate of site creation and rate of change in site density per zone, it is impossible to say what element of program growth specifically is driving crash reductions. This is important as it does not necessarily mean that increasing site density per zone in the future will lead to further crash reductions from the Queensland speed camera program.

5.2.2 Effects Across Regions

Analysis of the relationship between speed camera operational measures and estimated crash reduction outcomes across police regions was carried out using the same approach as used to examine the relationship across time. The same set of operational measures were again used here except they represented averages for each police region across the whole period of study, giving a single value for each region on each operational measure. The time-based rate measures ('zone rate', 'site rate', 'density rate' and 'hour rate') were not relevant to the region-based comparison. Ideally, comparisons would have been made by region over time, however, reliable estimates of program crash effects were not available at this level of stratification.

In addition to the speed camera operational measures defined already, two more base measures were used in the regional comparisons. The first was the average annual total crash frequency in each police region over the 5 years prior to the introduction of speed cameras (defined as 'crash'). This measure represented the size of the total crash problem in each police region. From this, the number of zones, sites and enforcement hours per crash were calculated as measures of program coverage density.

The other measure used in the regional comparison was a measure of true randomisation of camera placement achieved in operating the program in each police region. As noted in the Introduction section under the randomised operation schedule for speed cameras in Queensland, three sites are chosen randomly for speed camera operation each deployment. Police then visit one or more of these sites and undertake speed camera enforcement. Assuming police choose randomly amongst the three allocated sites issued, a profile of expected visitation to each speed camera site could be calculated. In monitoring the performance of the Queensland speed camera program, Queensland Transport computes such a profile. From this a measure is computed that represents the proportion of sites visited as expected under a truly randomised site selection process by police. This measure (denoted ‘% sites visited as expected’) has been used in comparison with regional program crash effects in the analysis here.

Again, to avoid co-linearity problems in the regression models relating the operational measures to the estimated program crash reductions, a correlation analysis of the operational measures was undertaken to establish the level of association between each. The measures, 'sites', 'zones', 'site density' and 'hours' were all found to be highly correlated, as were 'hours per site' and 'hours per zone' as well as ‘zones per crash’, ‘sites per crash’ and 'hours per crash'. The first block of correlated variables all represent program size, the second block represent enforcement density whilst the last block represent program coverage density. As before, a single measure from each correlated set was chosen to be included in the regression modelling. 'Zones' was chosen as the measure of program size, 'hours per zone' as the measure of enforcement density and 'zones per crash' as the measure of program coverage density. These, in combination with ‘% sites visited as expected’ left four independent measures of speed camera program operations for analysis.

A stepwise linear regression model was fitted relating the four independent speed camera operational measures to the estimated regional percentage crash reductions with separate models for reductions in crashes of all severity levels combined and fatal, hospital and medically treated crashes combined. For the model based on all crash severity levels, ‘zones per crash’ and ‘% sites visited as expected’ were found to be statistically significantly related to estimated crash reduction. For the model based on more severe crashes, only ‘% sites visited as expected’ was statistically significantly related to estimated crash reduction. Table 6 shows the standardised regression coefficients of the significant operational measures for the two regression models along with the statistical significance of each and the overall model R-squared.

Results of the regression analysis shown in Table 6 show the model for all crash severity levels explains around 80% of the variation whilst the model for fatal to medically treated crashes explains just under 50% of the variation. Figures 12 and 13 show the level of fit of the regression model predicted values (predicted) to the original program crash reduction estimates (observed). Figure 12 confirms the high level of fit indicated by the R-squared value for the all crash severity comparison whilst Figure 13 shows the poorer level of fit for the more severe crash levels, reflected in the much lower R-squared value for this model. This suggests there are factors, other than the percentage of site visitations as expected, that are not represented by the operation measures available but affecting crash reduction differences between police regions for these crash severity levels.

Table 6: Results of regression modelling of estimated crash reductions associated with the speed camera program against program operational measures over police regions.

	All crash severity levels		Fatal, hospital and medically treated crashes	
Operational Measure	**Standardised Regression Coefficient**	**Significance Value**	**Standardised Regression Coefficient**	**Significance Value**
Zones per crash	0.477	0.052	-	Not Sig.
% sites visited as expected	0.882	0.007	0.699	0.054
Overall model R-squared	0.825		0.488	

Figure 12: *Estimated percentage crash reduction associated with the Queensland speed camera program by police region and prediction using operational measures: All reported crashes within 2km of a speed camera site*

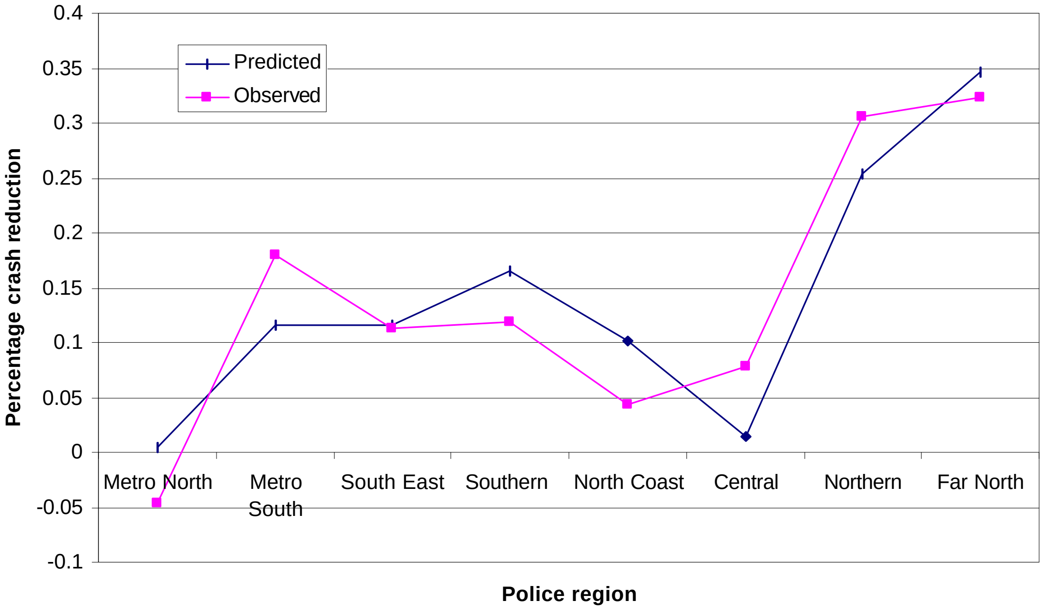
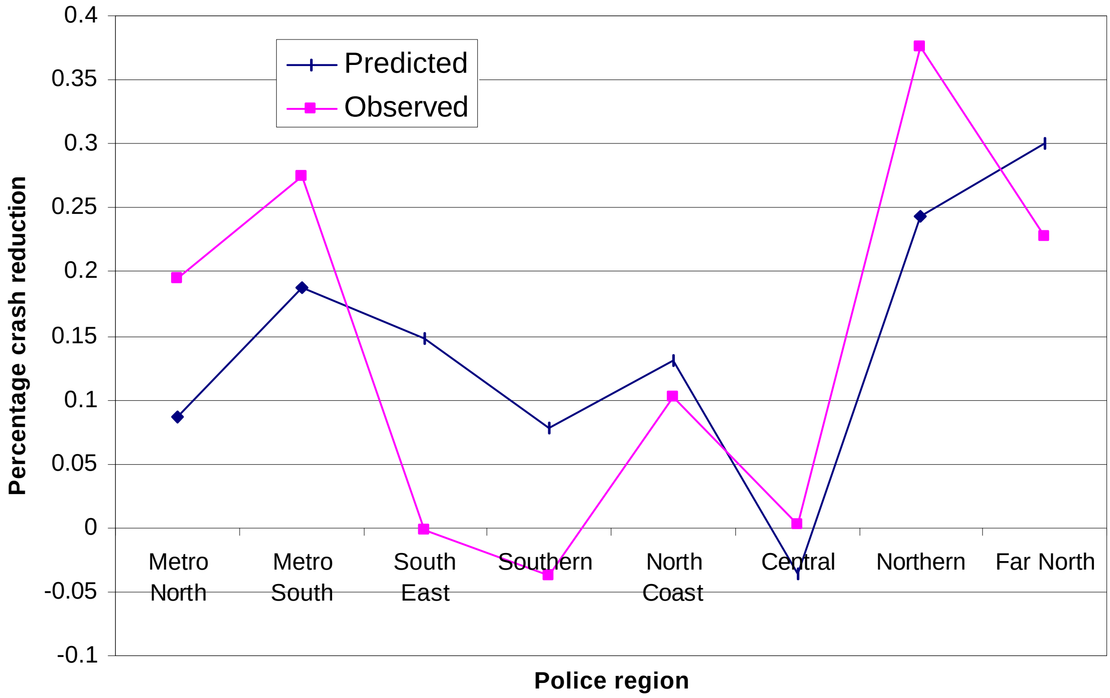


Figure 13: *Estimated percentage crash reduction associated with the Queensland speed camera program by police region and prediction using operational measures: Fatal, hospital and medically treated crashes within 2km of a speed camera site*



6. DISCUSSION

Analysis presented in this study shows clear association between the introduction of the speed camera program in Queensland and reductions in reported crashes in areas within 6km of camera sites, relative to areas outside these. Of all the estimates of program crash effects presented, the ones most indicative of the real potential of the program in reducing crashes are the annual or quarterly estimates from 2000, the last full year of data considered in the analysis. These results are considered most relevant because, as shown in Figure 2, the program coverage had reached its greatest extent to date in this year. Results for the early years of the program reflect the fact that relatively few of the speed camera sites used up to the end of September 2001, on which the spatial relationship between crashes and camera sites were defined, were in operation in those early years. Although there is some evidence of diminishing crash effects with distance from speed camera sites, Figure 1 confirms that the results in the area up to 2km from the camera sites is the most relevant, comprising around 73% of the crash population.

Considering crash reduction estimates within 2km of camera sites to be the most indicative of speed camera program performance in 2000, the program has produced a reduction in reported crashes of all severity levels of around 29%. In contrast, the higher severity crashes (fatal, hospital and medically treated) reduced by around 36%. This translated to an annual crash saving in the order of 3,500 fatal, hospital or medically treated crashes or 5,500 crashes across all severity levels. In terms of total annual road trauma in Queensland, the crash savings within 2km of speed camera sites represent a 21% reduction in all reported casualty crashes and a 26% reduction in fatal to medically treated crashes. This is based on around 73% of all crashes in Queensland being within 2km of a speed camera site.

The social benefit to cost ratio of the Queensland speed camera program over the period from its introduction to June 2001 was estimated to be 47. Because of the way in which cost data for the program were supplied, it was not possible to properly discount capital expenditure under the program over the expected useful life of the capital. Instead, it was assumed that the capital expenditure was only a cost of the program the year of expenditure. For this reason, BCR figures for individual years have not been quoted because figures for early on in the program when capital expenditure in setting up the program were greater would be underestimated whilst later figures would be overestimated. Instead, a figure for the total post implementation period has been calculated in order to dilute the problem in the way the cost have been handled and provide a more representative estimate. Even accepting a possible level of inaccuracy in the BCR estimate, it is clear the Queensland speed camera program is a highly cost effective means of road trauma reduction.

Because of the large growth in size and crash effects of the Queensland speed camera program over time, estimates of average crash effects over the total post implementation period presented in this study are not particularly meaningful in representing the true potential of the program. They are, however, presented as a record of the average performance of the program as it was implemented in Queensland. One point the average effectiveness estimates do not reflect is the differential effect of the program across crash severity levels. Annual and quarterly analysis has shown that as the program has grown, reductions in higher severity crashes have gone from being lower on average than lower severity crashes to much higher. The averaging process masks this important difference.

Comparison with speed camera program operational measures has given insight into the mechanisms of effectiveness of the Queensland speed camera program. Not surprisingly, total crash reductions are strongly related to the size of the overall program as well as to the density of enforcement. Perhaps less expected is the increased effectiveness of the program during periods of growth. This is possibly the result of added general awareness of enforcement when drivers see speed cameras operated at new sites or perhaps a response to likely heightened publicity concerning the program during times of growth. Further research would be needed to confirm the real mechanism. Conversely, lower periods of growth appear to be associated with decreased crash reduction. It is noted that QT and the QPS use an in-house performance monitoring process (see Introduction section) which provides feedback to operational police on rates of site growth and faithfulness to the scheduler. This process detected and effectively rectified periods of lack of site growth so that deteriorations in program effectiveness were short term.

Another important determinant of program effectiveness highlighted by difference in regional performance, is the level of true randomness in site selection achieved. This is supported by the established effectiveness of the Random Road Watch program also operated in Queensland that has been shown to produce significant crash savings through randomisation of relatively low levels of enforcement effort (Newstead et al 2001). Finally, the level of site coverage per crash also appears to be related to crash effects although this is not supported for higher severity crashes.

One key measure of speed camera operations that was not studied was the number of speeding infringement notices issued under the Queensland program. Study of the Victorian speed camera program found receipt of an infringement notice was a key mechanism of program effectiveness (Cameron et al 1992). It is possible infringement receipt may also have been a key driver of crash effects in the Queensland program although it should be noted that, in contrast to the Queensland program, the Victorian program is covert in operation. The first many drivers know of speed camera operations in Victoria is through receipt of an infringement notice in the mail detailing the location of offence. The overt nature of the speed camera program in Queensland may make the infringement notice less important as a deterrent mechanism. Unfortunately, complete infringement data from speed camera operations in Queensland was not available.

Speed measurement data before and after introduction of the speed camera program in Queensland is another intermediate measure that would have been useful to understand the mechanism of measured program effectiveness as well as potentially adding further validity to the crash estimates. Speed measurement data was also not available for this study.

The relationships established between crash effects and speed camera operations indicate how the effectiveness of the Queensland program may be optimised. Increased coverage should be sought, whilst increasing the density of enforced areas per crash may also be beneficial (eg the RRW program has 12,000 sites, 4 times the current number of speed camera sites). Increased hours of operation per site should lead to increased crash effects although the research here is not able to identify the point of diminishing returns for enforcement input. Further research would be needed to determine this for the Queensland program. Police regions should also aim to maximise the randomness of enforcement scheduling within the options given to them under the standard site selection regime.

Because of the overt nature of speed camera operations in Queensland, analysis in this study has focussed on the localised effects of the program. It is possible that the program has also produced more generalised effects on crashes in Queensland with respect to the area of influence. Generalised effects from speed camera programs have certainly been measured for the speed camera program in Victoria (Cameron et al, 1992). The high coverage of crash locations achieved by the Queensland program may mean that the localised effects measured in this study are close to what might be considered as general state wide effects. Indications of diminishing crash reduction effects with distance from speed camera sites indicated in the crash analysis also suggests the effects of the Queensland program are localised to a large degree. There may be evidence that part of the reason for this is site learning arising from the fact that speed cameras are deployed to a specific point.

The existence of large crash effects outside the areas of influence hypothesised in this study would produce under estimates of program crash effects in the study design used here. However, the large crash effects measured in this study further suggest the effects of the Queensland program are largely localised to the areas considered.

Given the quite different approaches used in the Queensland and Victorian speed camera programs in terms of visibility of operations and program coverage, it is interesting to compare the relative crash reduction performance of the two programs. Cameron et al (1992) estimated crash reductions from the Victorian program from 14% to 30% depending on the time after program implementation and type of road examined. Although Rogerson et al (1994) and Newstead et al (1995) found some evidence of localised crash effects associated with the Victorian program, the principal mechanism of crash effectiveness of the Victorian program is still believed to be through generalised deterrence associated with the covert nature of camera operations. In the context of a broader examination of road trauma reductions in Victoria during the early 1990's, Newstead et al (1995) estimate the reduction in serious casualty crashes associated with the Victorian speed camera program and associated publicity to be around 19%. This is fairly comparable to the estimated 26% state wide reduction in fatal to medically treated crashes for the Queensland program. It suggests the two programs have been similar in total effectiveness despite fundamental difference in their modes of operation.

An issue that is often associated with quasi-experimental designs, as used in this study, is regression-to-the-mean (RTM). A number of factors markedly minimise the likelihood of RTM in this study either temporally or spatially. Temporally, RTM may occur if a short-term crash increase causes a measure to be implemented soon after. The process of introducing a speed camera program in Queensland happened over a long period of time with extensive parliamentary and community consideration (Queensland Parliament, 1994). In fact, some three years passed between first consideration of a program and initial implementation. Consequently, it is clear that implementation of the Queensland program was based on many factors and not any instantaneous peak in road trauma in Queensland. Spatially, RTM can occur if a measure is implemented only at high crash areas in a region. As seen in Figure 1, 85% of crashes in Queensland are within 4km of a speed camera site, meaning the program must extend well beyond only the highest crash frequency locations. Furthermore, analysis has also taken into account long term (5 year) crash trends in the hypothesised areas of program influence, with the statistical model explicitly measuring long-term trends rather than relying on a single measurement of average before-treatment crash rate. Finally, the strong relationships observed between program operational measures and estimated crash reductions further discount the possibility that observed crash reductions are largely influenced by RTM effects.

7. CONCLUSIONS

This study has investigated the crash effects of the speed camera program in Queensland across the period from its introduction in May 1997 to the end of June 2001. Due to the overt nature of the Queensland program, analysis has examined crash reductions associated with the program in areas within 6km of speed camera sites that had been used up to September 2001. As 73% of reported crashes in Queensland occurred within 2km of a speed camera site, estimated crash effects within this area were considered to be most indicative of program performance.

Analysis results showed evidence of diminishing crash reductions with increasing distance from speed camera sites. Significant increases in crash reductions associated with the program were also observed over time, reflecting the substantial growth of the program over the study period. When operating at maximum coverage, the Queensland speed camera program was estimated to have produced a reduction in fatal crashes of around 45% in areas within 2km of speed camera sites. Corresponding reductions of 31%, 39% 19% and 21% were estimated for hospitalisation, medically treated, other injury and non-injury crashes respectively. This translates to an annual crash saving in the order of 110 fatal, 1100 hospitalisation, 2200 medically treated, 500 other injury and 1600 non-injury crashes. In terms of total annual road trauma in Queensland, these savings represent a 32% reduction in fatal crashes, a 26% reduction in fatal to medically treated crashes combined and a 21% reduction in all reported casualty crashes. The benefit cost ratio estimated for the program over the period from its introduction to June 2001 was 47.

Comparison of the estimated crash reductions associated with the Queensland speed camera program and program operational measures gave insight into the mechanisms of program effectiveness. Variations in estimated crash reduction over time were strongly related to the size of the overall program as well as the density of enforcement. Periods of program growth were also associated with larger crash reductions beyond that expected from the increasing size of the program alone. Higher levels of true randomness in selection of speed camera sites for operation were also associated with higher levels of crash reduction when comparing differential performance of the program across police regions in Queensland. Finally, higher levels of site coverage per crash were also related to larger crash reductions although this is not reflected in higher severity crashes.

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