A resource allocation model for traffic enforcement

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Abstract

A method has been developed to estimate the crash reduction benefits of increases in each type of traffic enforcement applied to an appropriate road environment. This method has been based on numerous studies linking enforcement levels with road crashes and/or injury severity in the Australian States and internationally. Economic analysis of the crash savings and costs from investment in each type of traffic enforcement has shown that mobile speed cameras and random drug tests provide the highest benefit-cost ratios.

Introduction and approach

A review of strategic approaches to choosing packages of road safety initiatives, including enforcement programs, concluded that greatest economic value is obtained from packages in which the components have marginal benefits (from reductions in road trauma) greater than marginal costs (Diamantopoulou, Clark and Cameron 2009). Traffic enforcement initiatives with variable levels of intensity should be analysed to decide the appropriate types and levels of operation for inclusion in an overall program.

A Traffic Enforcement Resource Allocation Model (TERAM) was developed to guide allocation of Police resources regarding the enforcement of speeding, drink-driving and drug-driving in Victoria. The first step was to document the research and relationships connecting levels of traffic enforcement of each type with reductions in road trauma measured by crash frequency and/or the injury severity of crash outcomes. Evaluations of each enforcement type were summarised by meta-analysis (Christensen 2003) to provide an overall estimate of the key parameter of the relationship connecting the enforcement with road trauma reductions.

The intensity of some enforcement types, usually mobile operations, can be measured by operational hours, vehicles or drivers assessed, or number of infringements detected and prosecuted. In contrast, the intensity of fixed operations, usually camera-based, is principally measured by the number of sites covered (within an enforcement halo) as well as the other measures. The effect of fixed camera-based operations on road trauma is related to the number of sites and the crash reductions at each individual site.

The next step was to estimate the costs per unit of intensity of each traffic enforcement type, covering equipment capital cost and maintenance, person operating costs, and costs of offence processing. The final step was to compare the social cost value of the reduction in road trauma at each level of intensity of each enforcement type with the total cost of offence detection and processing at that intensity level. The economic value of each enforcement type and intensity level was assessed by its benefit-cost ratio, both for the full increase from its current level and at the marginal level for the next unit increase in intensity.

Relationships between traffic enforcement intensity and road trauma

Background

Elvik (2001) has developed a general framework for the cost-benefit analysis of police enforcement. A key part of this framework is the relationship between changes in the level of police enforcement and changes in crashes, measured by the percentage reduction in crashes or relative risk, relative to a base level.

After reviewing a large number of studies of the effects of varied levels of traffic enforcement on casualty crashes, Elvik (2001) concluded that the relationship is of the form shown in Figure 1. Even for the most effective forms of enforcement, the relationship with crash reductions is not linear. Diminishing returns apply as the level of enforcement increases. However, within the range of increases observed in the studies (up to 10-12 fold), it appears that at least some crash reductions occur for each increase in enforcement effort.

Elvik (2001) proposed a number of potential functional forms for the relationship shown in Figure 1. Perhaps the most suitable is the power function:

$$Y = A \cdot X^B$$

where Y is the number of casualty crashes, X is the level of enforcement, and A and B are parameters related to the

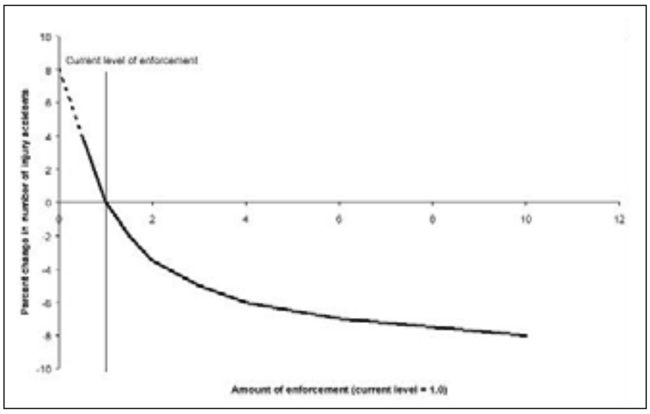

Figure 1: General relationship between traffic enforcement and crashes (Elvik 2001)

shape and level of the relationship. Figure 1 indicates that B is negative, i.e., a given increase in enforcement from its current level leads to a lower level of crashes. The magnitude of B depends on the strength of the relationship between the specific type of enforcement and crashes. For the power function, B is often referred to as the "elasticity", i.e., the percentage change (reduction) in crashes for 1% increase in enforcement.

The following sections summarise research providing estimates of the relationships with crashes in the cases of speeding, drink-driving and drug-driving enforcement. From each study reviewed, an estimate has been made of the parameter B (elasticity) in a power function connecting the level of enforcement with risk of crashes or the injury severity of the crash outcomes. The statistical standard error of each estimate of elasticity was used in the subsequent meta-analysis of similar estimates as a weighting factor to provide a more reliable overall estimate.

Speed enforcement

Manual speed enforcement

The relationship shown in Figure 1 developed by Elvik (2001) was based on 11 studies of manual speed enforcement (involving police officers measuring speed and intercepting drivers) during 1966 to 1998. A later source indicated an elasticity of -0.04525 for this relationship (UK Department for Transport 2014).

Cameron and Delaney (2006) estimated a negative exponential relationship between casualty crash reductions and the annual offences detected by moving-mode radar units in Victoria, based on effects during 1995/96 and 1996/97 estimated by Diamantopoulou, Cameron and Shtifelman (1998); and Diamantopoulou and Cameron (2002). This data was revisited and a power function fitted, producing an estimated elasticity of -0.0581.

Mixed manual and camera-based speed enforcement

Povey, Frith and Keall (2003) estimated a logarithmic relationship between mean free speed and speeding tickets issued from mixed speed enforcement on New Zealand rural roads during 1996-2002. They also estimated a logarithmic relationship between "low alcohol hour" casualty crashes and mean speeds over the same years. These relationships were combined to produce a negative exponential relationship between relative crash risk and the increase in speeding tickets. A power function fitted to this relationship had an elasticity of -0.385.

Elvik (2011) extended the analysis of Elvik (2001) by adding four studies of speed camera effects related to camera hours or speeding tickets issued for detected offences. Effect estimates were related to the levels of increased speed enforcement (either manual or camera-based) from a base level in each case. Functional relationships between them were analysed, either weighting or not weighting each effect estimate by a measure of statistical reliability (reciprocal of the standard error squared). Elvik (2011) preferred the resulting logarithmic

Table 1: Estimated elasticities of manual and mixed speed enforcement levels

Manual and mixed (manual and camera) speed enforcement	Non- camera enforcement	Mixed with Elvik (2011) weighted	Mixed with Elvik (2011) un-weighted
Global estimate	**-0.0461**	**-0.2994**	**-0.1908**
Standard error	0.0019	0.0020	0.0020

and inverse functions, respectively, but also provided results for fitted power functions. The estimated elasticities were -0.299 (weighted estimates) and -0.190 (unweighted).

Meta-analysis of manual and mixed speed enforcement

A meta-analysis of the elasticity estimates from the studies involving manual speed enforcement was conducted to provide global estimates of the elasticity for manual (only) enforcement and mixed (manual or camera-based) enforcement. The method followed the meta-analysis approach of Christensen (2003). The individual effect estimates are weighted by the reciprocal of their standard error squared and a weighted average calculated to provide the global estimate. This method is more appropriate than a simple arithmetic average because the weights reflect the reliability of each elasticity estimate. The standard error of the global estimate is also provided (Table 1). Further details of the meta-analyses summarised in this paper are given in Cameron, Diamantopoulou and Newstead (2015).

Covert mobile speed cameras

Since the covert operation of mobile speed cameras was first introduced in Victoria in December 1989, there have been a series of evaluations of their general effect on crashes as the program expanded during 1990 and 1991 and then later years. Each of these evaluations used models in which monthly crashes were expressed as multiplicative functions of mobile camera activity (camera hours or speeding tickets issued from camera detections) and other influential factors (random breath tests, Transport Accident Commission television publicity, economic conditions measured by unemployment rates, long-term trend and seasonal variation in crashes). In these multiplicative functions, the relationship between mobile camera activity and crashes was a power function and the elasticity was estimated as part of the analysis. This assumed that the coefficients were fixed effects over the period analysed.

The first evaluation analysed monthly casualty crashes during "low alcohol hours" (LAH) in Melbourne during 1983 to 1991 (Cameron et al 1992). A statistically significant elasticity of -0.0132 was found between monthly tickets issued from mobile camera detections and casualty crashes on arterial roads (where most camera operations took place). The analysis also found a significant elasticity of -0.0233 between mobile camera tickets and the severity of casualty crashes, measured by the proportion of crashes with serious outcomes (resulting in a fatality or hospitalisation).

Subsequent studies focused on the elasticity with serious casualty crashes. Analysing LAH serious crashes during 1983 to 1992, Newstead et al (1995) found a significant elasticity of -0.0243 with mobile camera tickets in Melbourne and -0.0098 with mobile camera tickets in the rest of Victoria.

Similar analysis of serious casualty crashes in Melbourne during 1983 to 1996 found a significant elasticity of -0.0209 between mobile camera tickets and LAH crashes (Newstead et al 1998). The analysis also found a significant elasticity of -0.0109 with "high alcohol hour" (HAH) serious casualty crashes, but no significant elasticities were found between tickets and crashes outside Melbourne.

As part of a cost-benefit analysis of mobile speed cameras, Gelb et al (2000) analysed monthly LAH casualty crashes in Melbourne during 1987 to 1998. They found significant elasticities of -0.0179 with mobile camera hours and -0.0122 with mobile camera tickets.

During 1999, Victoria Police varied the levels of speed camera activity substantially in four Melbourne Police districts according to a systematic plan (Cameron et al 2003). Analysis of casualty crashes during 1996 to 2000 found they were inversely related to changes in the levels of speeding tickets issued following detection in the same district during the previous month. When a power function was fitted, the elasticity was estimated to be -0.1115 (Cameron and Delaney 2006). A similar relationship was found for the risk of fatal outcome in a casualty crash, with an estimated elasticity of -0.8516 in this case.

An evaluation of speed-related initiatives in Victoria during 2000-2002 (including 50% increased mobile speed camera hours and reduced offence tolerance) analysed monthly casualty crashes and their fatal outcomes from 1998 to 2003 (Bobevski et al 2007). The elasticity between mobile camera hours and casualty crashes was estimated to be -0.092, whereas the elasticity with the risk of fatal outcome in these crashes was estimated to be -2.03. Elasticities with camera tickets could not be estimated due to the reduced tolerance.

Meta-analysis of covert mobile speed cameras

A meta-analysis of the elasticity estimates from the evaluations of covert mobile speed cameras was conducted to provide global estimates and their standard errors (Table 2). The estimates relevant to studies of the effects on casualty crashes, serious casualty crashes, and the risk of fatal outcome in casualty crashes have been meta-analysed separately because the elasticities relate to fundamentally different risks.

Table 2: Estimated elasticities of covert mobile speed camera levels

Covert mobile speed cameras in Victoria	Casualty crashes	Serious casualty crashes	Fatal outcome in casualty crashes
Global estimate	**-0.1054**	**-0.0225**	**-0.9838**
Standard error	0.0038	0.0034	0.1939

Overt mobile speed cameras

The tripling of speeding tickets issued from detections by overtly-operated mobile speed cameras in Ireland between 1997 and 2000 was associated with a significant decrease in casualty crashes compared with all reported crashes (Smith et al 2001). The elasticity between annual tickets issued and the casualty crash rate was estimated to be -0.1428.

A series of evaluations of the crash effects of Queensland's mobile speed cameras was conducted as the program grew from 852 hours per month in 1997 to about 6,000 hours per month during 2003-2006 (Newstead and Cameron, 2003; Newstead, 2004, 2005, 2006). Crash reductions were generally limited to an area within 2 km of the camera sites. The strongest effects were on casualty crashes, with no differential effect on crashes of different severity (fatal, hospital admission, or medical treatment crashes). The elasticity between monthly camera hours and casualty crashes within 2 km was estimated to be -0.2416.

A characteristic of the Queensland program is the randomised scheduling of camera sessions to sites, thus contributing to their unpredictability across the broader road system. As the program grew, the 2 km areas around camera sites covered a greater proportion of the total casualty crashes in Queensland, rising from about 50% to 83% over the evaluation period. The localised crash reductions around camera sites can be interpreted as a general effect on crashes, even assuming that the program had no effect beyond the 2 km areas. A logarithmic relationship between the increased monthly hours and the general casualty crash reductions in Queensland was calibrated by Cameron (2008). A power function explains this relationship equally as well, with an estimated elasticity of -0.2202. The relationship between fatal crashes and camera hours was also estimated. There was no evidence that the magnitude of the reduction on fatal crashes was any greater than that achieved on casualty crashes.

Newstead et al (2014) updated the evaluations of the Queensland program, estimating crash effects each year from 1997 to 2011 (all casualty crashes) and to 2012 (serious casualty crashes). During 2010 to 2012, the percentage of mobile camera hours operated covertly rose from 7.2% to 23% and then fell to 20%. In contrast with earlier research, crash effects were estimated within 1 km of urban camera sites and within 4 km of rural sites. These areas covered about 78% of total casualty crashes in Queensland during the latter years.

The elasticity between monthly camera hours and casualty crashes within 1 or 4 km of camera sites was estimated after taking into account the separate effects of the reduced enforcement tolerance in 2008 (11% crash reduction) and partial covert operations from 2010 (not statistically significant). The estimated elasticity between hours and the local casualty crash risk was -0.0794. When the local crash

Table 3: Estimated elasticities of overt mobile speed camera levels

Overt mobile speed cameras in Queensland (& Ireland)	Casualty crashes (general effect)	Serious casualty crashes (general effect)	Local effect on casualty crashes
Global estimate	**-0.1277**	**-0.0345**	**-0.0982**
Standard error	0.0104	0.0132	0.0121

effect was interpreted as a general casualty crash effect across Queensland, the estimated elasticity with camera hours was -0.0618.

Elasticities between camera hours and serious casualty crashes were also estimated, including 2012 data and again taking into account the reduced enforcement tolerance (13% crash reduction) and partial covert operations (not statistically significant). The estimated elasticity between hours and the local serious casualty crash risk was -0.0469. When interpreted as a general effect on serious casualty crashes, the estimated elasticity with hours was -0.0345. As found in previous research, there appeared to be no greater effect of the Queensland mobile cameras on the more severe crashes than on casualty crashes in general.

Meta-analysis of overt mobile speed cameras

A meta-analysis of the elasticity estimates from the evaluations of overt mobile speed cameras was conducted to provide global estimates and their standard errors (Table 3). The estimates relevant to studies of the effects on all casualty crashes and serious casualty crashes (general effects), and local effects on casualty crashes (within a few kilometres of camera sites), have been meta-analysed separately because the elasticities relate to different effects.

Random breath testing

Since the introduction in 1990 of high-profile bus stations ("booze buses") that substantially increased the number of random breath tests in Victoria, a series of studies have estimated the relationship between the monthly number of tests and crash reductions. Each of these studies used models in which monthly HAH crashes were expressed as multiplicative functions of the number of tests and other influential factors (speed camera tickets, TAC television publicity, economic conditions measured by unemployment rates, and trend and seasonality).

In an evaluation of alcohol-related Transport Accident Commission publicity, Cameron et al (1993) modelled monthly HAH serious casualty crashes in Melbourne during 1983 to 1992 and found an elasticity of -0.0176 with the monthly tests (from either car- or bus-based testing stations). They also modelled the non-serious casualty crashes in Melbourne and found an elasticity of -0.0167. These findings led to models of all casualty crashes during HAH, in which elasticities between monthly random breath tests and crashes were estimated as -0.0115 in Melbourne and -0.0118 in the rest of Victoria.

Newstead et al (1995) also modelled monthly HAH serious casualty crashes in Melbourne during 1983 to 1993 and estimated an elasticity of -0.0186 between crashes and tests. Further modelling of these crashes during 1983 to 1996 (Newstead et al 1998) estimated elasticities of -0.0204 in Melbourne and -0.0155 in the rest of Victoria.

In modelling monthly casualty crashes in (then) five Police Regions in Victoria during 1989 to 1997, Diamantopoulou et al (2000) used a structural time series analysis method which potentially provided more reliable estimates of the coefficients of the multiplicative models. Estimated elasticities between monthly random breath tests (from either car- or bus-based testing stations) and HAH casualty crashes ranged from -0.1496 to -0.1013. Statistically significant elasticities between tests and LAH casualty crashes were also found, ranging from -0.1910 to -0.0958.

Henstridge et al (1997) examined the association between daily levels of random breath tests and serious casualty crashes in New South Wales. Crashes during the period 1976 to 1992 were analysed, including the high-profile introduction of RBT in December 1982 that needed to be modelled as a specific short-term effect. The analysis confirmed that diminishing returns-type relationships apply to levels of RBT. A 10% increase in the current testing levels (6,300 per day) was associated with a 3.5% reduction in serious casualty crashes, suggesting an elasticity of -0.35.

In Western Australia from the year 2000 to 2011, the number of roadside preliminary breath tests (90% random) per licensed driver was reduced by 49%. The percentage of killed drivers found to have BAC greater than 0.05g/100ml increased substantially during the period. Analysing the annual tests and annual percentage of killed drivers, Cameron (2013a) estimated an elasticity of -0.236 between them. However, change in the percentage of drivers killed with illegal BAC gives an exaggerated view of the change in the relative risk of a driver being killed. When this was taken into account, an elasticity of -0.115 was estimated between the annual preliminary breath tests per licensed driver and the relative risk of driver fatalities.

Meta-analysis of random breath testing

A meta-analysis of the elasticity estimates from the evaluations of random breath testing was conducted to provide global estimates and their standard errors (Table 4). The estimates relevant to studies of the effects on casualty crashes, serious casualty crashes, and killed drivers have been meta-analysed separately because the elasticities relate to different effects.

Roadside drug testing

Roadside oral fluid tests (ROFTs) of drivers for three proscribed drugs were introduced in Victoria in December 2004. Not all tests were conducted on a random selection of drivers, but up to 2009 most of the tests were considered to be "random drug tests" (RDT) aimed at general deterrence of drug driving. The number of drivers screened by ROFTs in Victoria increased each year from 13,158 in 2005 to 27,883 in 2009. The detection rate of proscribed drugs fell

Table 4: Estimated elasticities of random breath testing

Random breath testing in Victoria, NSW and Western Australia	Casualty crashes	Serious casualty crashes	Killed drivers relative risk
Global estimate	**-0.0132**	**-0.0184**	**-0.115**
Standard error	0.0027	0.0024	0.096

from 2.3% to 1.0% during the same years (Boorman 2010). The percentage of killed drivers found to have an impairing drug in their blood fell during the same period.

The relationship between the annual number of ROFTs and the annual percentage of killed drivers with at least one of the proscribed drugs is shown in Figure 2. An even stronger relationship is apparent between the number of ROFTs and the percentage of killed drivers with any impairing drug (including the three proscribed drugs).

The estimated elasticity between the annual ROFTs and the percentage of killed drivers with a drug present was found to be -0.260 in the case of any impairing drug, or -0.288 in the case of one or more proscribed drugs (Cameron 2013b). However, change in the percentage of drivers killed with drugs present gives an exaggerated view of the change in the relative risk of a driver being killed. When this was taken into account, it was estimated that the elasticity between annual ROFTs and the relative risk of driver fatalities was between -0.145 (based on the deterrence of combining any impairing drug with driving) and -0.069 (based on the deterrence of proscribed drug driving). A global estimate of this elasticity is given in Table 5.

Fixed camera systems

The intensity of fixed operations, usually camera-based, is principally measured by the number of sites covered (within an enforcement halo). The effect of fixed camera-based operations on road trauma is related to the number of sites and the road trauma reduction at each individual site. The following sections summarise research that has evaluated the effect of each type of fixed camera system on crashes at various levels of injury severity.

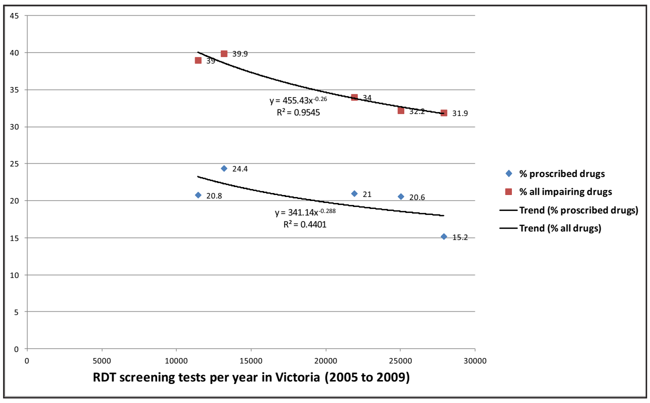

Figure 2: Relationships between percentage of killed drivers with proscribed drugs, or any impairing drug, versus number of drivers screened by ROFTs in Victoria

Fixed spot-speed cameras

The most comprehensive experience with fixed spot-speed cameras comes from the UK, where the program has also been carefully evaluated at each stage during its expansion. Results at each stage of the expansion indicate that the fixed cameras have achieved 5% to 42% reductions in casualty crashes and 47% to 65% reductions in serious casualties (fatalities and serious injuries) at camera sites (Cameron and Delaney 2006). Similar experience has been seen with the initial 28 overt fixed speed cameras in New South Wales. At camera sites, casualty crashes were reduced by 23% and fatal crashes by 90% (ARRB 2005).

The UK speed camera program had expanded to 4,000 sites by the time of the most recent evaluation study (Gains et al 2005). The estimated benefit-cost ratio of 2.7 during its fourth year was typical or marginally lower than what had been achieved in earlier years (BCRs of 2.75 to 3.4). The benefit-cost ratio of the first 28 overt fixed speed cameras in New South Wales was also no more than 3.6. These findings suggest that the overall effects of fixed speed cameras is essentially the sum of their individual localised effects, and that the program benefit-cost ratio is essentially the same as individual fixed camera installations.

In this study, it was envisaged that fixed spot-speed cameras in Victoria would continue to be placed on urban and rural

Table 5: Estimated elasticities of roadside drug testing

Roadside drug testing in Victoria	Period	Estimated elasticity (Power B)	Stand-ard error	Killed drivers relative risk	Elasticity based on relationship between annual ROFTs and killed drivers:
Cameron (2013b)	2005-2009	-0.260	0.0328		% with impairing drug
	2005-2009	-0.288	0.1872		% with proscribed drug
	2005-2009	-0.145	0.0193	1*	deterrence of impairing drugs
	2005-2009	-0.069	0.0441	1	deterrence of proscribed drugs
Global estimate				-0.1328	
Standard error				0.0177	

*** The index (1) indicates the specific elasticity estimate contributing to the global estimate.**

freeways, following current practice. It was estimated that fixed speed cameras inhibit speeding for up to about 5 km from the camera site (ICF 2003).

The average reduction in casualty crashes at fixed camera sites across all studies was 26.2%, whereas the average reduction in serious casualty crashes was 53.3%, about twice the magnitude. In the UK studies, the crash reductions had been measured over one kilometre road lengths centred on the fixed camera site. The evaluation of fixed speed cameras in NSW also considered road sections adjacent to and upstream and downstream from the camera site section (each about 1-2 kilometres), so that effect on crashes on the total section of about 5 km could be assessed. Over the combined 5 km lengths there was only 7.76% reduction in casualty crashes (ARRB 2005). Because of the known greater effect of fixed cameras on more serious injury crashes, it was assumed in the analysis here that serious casualty crashes would be reduced by twice this amount, i.e. 15.52%.

Point-to-point average-speed camera systems

A comprehensive review of P2P systems internationally has been carried out by Soole et al (2012, 2013), including a summary of estimated effects on crashes at various injury severity levels. Many of the early applications of P2P were on short road sections and mainly at roadwork sites. Table 6 extracts the crash reductions measured for P2P systems covering relatively long road sections (usually involving multiple links each at least 2 km in length). The measured reductions for fatal, serious injury or minor injury crashes specifically have been averaged in the last row of Table 6. Crash reductions of this magnitude were assumed if a point-to-point camera system was installed on each of the freeway links in Victoria.

Speed/red-light cameras

The assumed effect of each speed/red-light (SRL) camera on casualty crashes was the 26% reduction found in a study of installations at 77 signalised intersections (Budd, Scully and Newstead 2011). The same reduction was used for crashes of each injury severity because the study found no statistically significant evidence of differential crash reduction effects. This is apparently the most comprehensive evaluation of SRLs internationally.

Costs of traffic enforcement

As well as estimating the reductions in road trauma from increases in the intensity of each type of traffic enforcement in Victoria, it was necessary to compare this with the cost of each increase. To do this, it was necessary to estimate the costs per unit of intensity of each traffic enforcement type, covering equipment capital cost and maintenance, person operating costs, and costs of offence processing. The process relied on information obtained from many sources, including other States, internationally, and non-government sources. In each case, the estimated unit costs have been updated to year 2014 prices using the CPI (and after conversion to Australian dollars, where necessary). Details are given in Cameron et al (2015).

Economies of scale are expected to be associated with each of the unit costs of offence detection. Except for random breath testing, this effect could not be represented in the unit costs. From information obtained in Western Australia (Cameron 2012), it was possible to estimate the cost per test (including officer time cost) as a function of the total number of RBT tests per year. In contrast, the unit cost of a random drug test (RDT) was considered fixed and included the preliminary oral fluid test (POFT) device and, where applicable (estimated 3.2% of POFTs), the secondary OFT and laboratory test cost.

The unit cost of each fixed camera system was estimated differently. Because each of these systems operates continuously, the cost per hour is small. The purchase price was amortised over the useful life, discounted at 7% per annum, and then added to the annual maintenance cost to provide an estimate of the total annual cost of each fixed camera system in Victoria.

No information was available on the unit cost of processing a drink- or drug-driving offence detected by random breath or drug testing operations. These unit costs could be substantial, involving officer time to prepare a brief and attend court, if the offence is so severe that it is not eligible to be processed by a traffic infringement notice.

Options for traffic enforcement in Victoria

Crashes in Victoria during 2012 to 2014 were classified by the different road environments that were considered to represent the principal targets for the application of each type of traffic enforcement. For each targeted road environment, one or more enforcement types that could be applied were defined (Table 7).

Table 6: Estimated reductions in fatal, serious injury and minor injury crashes due to major P2P systems (Soole et al 2012, 2013). Average crash reduction across enforced sections.

Jurisdiction	Location	Highway	Length (km)	Fatal crashes	Serious injury crashes	Minor injury crashes
England	Cambridgeshire	A14	22.4	65.4%*		20.2%
Scotland	Strathclyde	A77	51.5	50.0%	40.6%	19.3%
Italy	All	ASPI motorways	2900	50.8%	34.8%	
Austria	Vienna	A22 tunnel	2.3	48.8%*		32.2%
Average				50.4%	37.7%	23.9%

*** Available information covered reduction in fatal and serious injury crashes combined. Not included in average.**

Table 7: Enforcement types considered in each road environment

TARGET ROAD ENVIRONMENT	Enforcement type
RURAL VICTORIA	
Freeway (518 km* 2 directions)	Fixed spot-speed camera (uni-directional)
	P2P camera system (uni-directional, covering up to 3 lanes)
Divided Highway (418 km)	Semi-covert Mobile Speed Camera (MSC) (unmarked/unsigned)
	Overt Mobile Speed Camera (with random scheduling)
Undivided Roads (134,030 km)	Semi-covert Mobile Speed Camera (MSC) (unmarked/unsigned)
	Overt Mobile Speed Camera (with random scheduling)
	Moving Mode Radar (MMR)
Town Street	Hand Held laser/radar
	Bus-based Random Breath Test (RBT)
	Bus-based Random Drug Test (RDT)
All rural road environments	Car- & Bus-based RBT
	Car-based Preliminary Breath Test (PBT) (not random)
	Car- & Bus-based RDT
	Car-based Roadside Oral Fluid Test (ROFT) (targeted)
URBAN (Melbourne)	
Freeway (273 km* 2 directions)	Fixed spot-speed camera (uni-directional)
Arterial Road (2,927 km)	Covert Mobile Speed Camera (MSC)
Signalised Intersection (2,908)	Speed/Red-Light camera (SRL)
Street (21,300 km)	Hand Held laser/radar
All urban road environments	Bus-based RBT
	Car-based RBT
	Car-based PBT (not random)
	Car- & Bus-based RDT
	Car-based ROFT (targeted)

In part, this assignment to each road environment reflected uncertainty about the likely general effect of the enforcement type, or whether only a local effect in the vicinity of operation is assumed. RBT was considered to have a potential general effect across rural and urban Victoria. However, rural RBT carried out at bus-based testing stations may have only a general effect across the rural towns in which they operate. (Similarly, in Melbourne, bus-based RBT may have only a local effect on the arterial roads to which buses are constrained in general).

Rural bus-based random drug testing (RDT), because it is generally carried out in conjunction with RBT at buses, was considered in the same way.

Current levels of traffic enforcement in Victoria

Victoria Police provided information on the hours of operation, numbers of roadside tests, and/or numbers of prosecutions for each enforcement type during a recent year (Table 8). Hours and traffic infringement notices (TINs) from mobile speed cameras were not separately available for each type of rural road. The totals were split in proportion to total vehicle-kilometres on divided and undivided highways (25%: 75%).

Covert mobile speed cameras are operated from unmarked cars at unsigned locations on rural highways, but are not considered to be as covert as operations on urban arterial roads. For this reason, they were labelled as "semi-covert" on rural roads. Overt mobile speed cameras (with random scheduling to sites, as operated in Queensland) are not currently operated in Victoria. It was assumed for analysis that overt mobile speed cameras could be an alternative to the "semi-covert" mobile cameras on rural highways, and hence their base level of hours operated would be the same as the current level of the semi-covert cameras.

Bus-based random tests for alcohol (RBT) and drugs (RDT) in rural Victoria were considered to have occurred mainly in towns and the analysis initially used the bus-based tests as the base in that road environment. There are plans to expand the rural RDT operations to include random ROFTs from highway patrol cars to cover rural roads more broadly.

In Table 8, numbers of prosecutions resulting from alcohol and drug testing operations were not available and ultimately their costs of offence processing were ignored.

Effects of increased enforcement of each type

Elasticities and crash reductions

The appropriate elasticities in Tables 1-5 were extracted for each type of enforcement with variable levels of operation. The estimated crash reductions associated with each type of fixed camera system, outlined in Section 2.5, were also extracted (Cameron et al 2015).

The operation of "semi-covert" mobile speed cameras on rural roads was not considered to be as effective as covert operation on urban arterial roads. For these operations, the elasticity associated with fatal outcome risk of casualty crashes (Table 2) was halved.

The estimated elasticity between RDT and driver fatalities was similar to that found for RBT (Table 4 and 5). For this reason it was considered that RDT would have elasticities with lower severity crashes similar to that found for RBT. In particular, it was estimated that the elasticity between RDT and serious casualty crashes is the same as that for RBT (Table 4).

Table 8: Annual levels of traffic enforcement in Victoria during 2012/13 or 2013, where available. Estimates italicised (explanation in text).

		BASE YEAR LEVELS			
TARGET ROAD ENVIRONMENT	Enforcement type	Units - devices or P2P sections	Hours (if variable)	Assessments (tests)	Prosecutions (TINs)
RURAL VICTORIA					
Freeway	Fixed speed camera	8			81,860
	P2P camera system	8			44,307
Divided Highway	Semi-covert MSC		*11,930*		*25,277*
	Overt MSC		*11,930*		*25,277*
Undivided Road	Semi-covert MSC		*35,789*		*75,830*
	Overt MSC		*35,789*		*75,830*
	MMR		71,631		86,543
Town Streets	HH laser/radar	Included in urban street operations below			
	Bus RBT			*54,563*	NK
	Bus RDT			*2,352*	NK
All rural roads	Car & Bus RBT			*575,061*	NK
	Car PBT (not random)			*319,433*	NK
	Car ROFT (targeted)			13,062	NK
URBAN (Melbourne)					
Freeway	Fixed speed camera	18			252,033
Arterial	Covert MSC		63,018		394,297
Signalised Intersection	SRL camera	175			405,466
Street	HH laser/radar	841	29,792		96,967
All urban roads	Bus RBT			*1,039,941*	NK
	Car RBT			*780,747*	NK
	Car PBT (not random)			*479,150*	NK
	Car & Bus RDT			19,789	NK
	Car ROFT (targeted)			4,081	NK
ALL VICTORIA					
All Victorian roads	All Alcohol Screening Tests			3,194,332	NK
	All RDT (bus & car)			22,141	NK

No elasticities were available for non-random car-based preliminary breath testing (PBT) for alcohol nor car-based roadside oral fluid testing (ROFT) of drugs in targeted operations. While these impaired driver tests have occurred in substantial numbers in Victoria, it has not yet been possible to link these tests with the deterrence of drink- and drug-driving. Further research is required to determine if relationships exist and to estimate their elasticities.

The elasticities for an increase in total alcohol screening tests (random and non-random) were assumed to be the same as for RBT (from Table 4). An increase in total roadside tests for alcohol was considered in order to include the effect of non-random car-based PBTs.

A 50% increase in enforcement levels

For the initial analysis, a 50% increase in each type of enforcement applied to the specific road environments shown in Tables 7 and 8 was considered. The 50% increase was applied to the number of enforcement units, hours of operation, or roadside tests per year. The number of prosecutions resulting from detected offences was similarly increased by 50% although it could be expected that offence rates and hence detections would not increase to the same extent. Adjustment for reduced offence rates was beyond scope of the analysis in this paper.

Each type of enforcement is expected to have a general effect on the crashes in the road environment on which it is focused. The magnitude of the crash reduction is related to the elasticity, in conjunction with the enforcement increase, or to the percentage crash reduction applied to the annual

Table 9: Crash focus of each fixed camera system and hand-held laser/radar device

Road environment	Enforcement type with limited focus in the road environment	Halo or coverage assumed	Total of road environ-ment	Crash ranking selection factor	Focus on total crashes in the road environment
Rural freeway	Fixed speed camera	5 km	2 x 518 km	4.53	2.19%
Rural freeway	P2P camera system	av. 10 km	2 x 518 km	2 (est.)	1.93%
Melbourne freeway	Fixed speed camera	5 km	2 x273 km	4.53	4.15%
Signalised intersection	SRL camera	All legs	2,908 int's	2.3	0.079%
Urban street	Hand-held laser/radar	2 km	20% of 21,300 km	2.72	0.128%

number of crashes. The exception to this general effect is in the case of those enforcement types that have a limited halo or coverage across the road environment in which the enforcement operates, e.g. fixed camera systems.

Crash focus of traffic enforcement types with limited halo or coverage

The effects of the fixed camera systems and hand-held laser/radar speed detection devices were considered to be limited to crashes within the halo of influence or the length of road covered by the enforcement. There is no evidence of a general effect of the UK fixed speed cameras beyond the strong local effects identified. Point-to-point speed camera systems are assumed to affect crashes only on the road section. Speed/red-light intersection cameras appear to affect crashes on all road legs (26% casualty crash reduction), notwithstanding an even stronger effect on the approach road on which the camera is located (Budd et al 2011).

The proportion of the total size (e.g. length) of the road environment represented by the halo or coverage of the enforcement was considered to be the proportion of crashes

Table 10: Estimated percentage crash reductions from 50% increase in each enforcement type. Italicised estimates: see further explanation in text.

		CRASH REDUCTION (% of target crashes/severity)					
TARGET ROAD ENVIRONMENT	Enforcement type	Fatal crashes per casualty crash	Fatal crashes	Hospital admission crashes	Total serious casualty crashes	Medical treatment crashes	Total casualty crashes
RURAL VICTORIA							
Freeway	Fixed speed camera				-1.36%		-0.68%
	P2P camera system		-3.89%	-2.91%		-1.85%	
Divided Highway	Semi-covert MSC	*-18.1%*	*-21.5%*				*-4.18%*
	Overt MSC						-5.05%
Undivided Roads	Semi-covert MSC	*-18.1%*	*-21.5%*				*-4.18%*
	Overt MSC						-5.05%
	MMR						-1.85%
Town Streets	Bus RBT		-4.56%		-0.74%		-0.53%
	Bus RDT		-5.24%		*-0.74%*		
All rural roads	Car & Bus RBT		-4.56%		-0.74%		-0.53%
URBAN (Melbourne)							
Freeway	Fixed speed camera				-5.79%		-2.90%
Arterial	Covert MSC	-32.9%	-35.7%				-4.18%
Signalised Intersection	SRL camera						-1.80%
Street	HH laser/radar				-2.39%		-2.02%
All urban roads	Bus RBT		-4.56%		-0.74%		-0.53%
	Car RBT		-4.56%		-0.74%		-0.53%
	Car & Bus RDT		-5.24%		*-0.74%*		
ALL VICTORIA							
All Victorian roads	All AST (R & not R)		-4.56%		-0.74%		-0.53%
	All RDT (bus & car)		-5.24%		*-0.74%*		

Table 11: Estimated crashes saved by 50% increase in enforcement & total social benefit. Italicised estimates derived from bold estimates by addition and interpolation.

		CRASHES SAVED (p.a.)					BENEFIT
TARGET ROAD ENVIRONMENT	Enforcement type	Fatal crashes	Hospital admission crashes	Total serious casualty crashes	Medical treatment crashes	Total casualty crashes	Total value of crash saving per year ($m)
RURAL VICTORIA							
Freeway	Fixed speed camera	*0.16*	*1.02*	1.19	*0.08*	1.27	1.76
	P2P camera system	0.47	2.19	*2.66*	1.84	*4.50*	4.95
Divided Highway	Semi-covert MSC	1.00	2.32	3.32	*5.51*	8.83	9.90
	Overt MSC	*0.24*	*4.00*	*4.24*	*6.41*	10.65	4.19
Undivided Roads	Semi-covert MSC	31.04	*14.68*	*45.73*	*44.81*	90.53	270.99
	Overt MSC	*7.28*	*55.15*	*62.43*	*46.76*	109.20	87.05
	MMR	*2.67*	*20.24*	*22.91*	*17.16*	40.07	31.94
Town Streets	Bus RBT	1.03	*4.15*	5.18	*8.67*	13.85	11.18
	Bus RDT	1.19	*3.99*	5.18	NK	*5.18*	11.48
All rural roads	Car & Bus RBT	8.37	*6.18*	14.55	*12.98*	27.53	73.98
URBAN (Melbourne)							
Freeway	Fixed speed camera	*0.73*	*11.38*	12.11	*6.27*	18.38	11.14
Arterial	Covert MSC	38.91	57.41	96.32	*234.71*	331.03	374.04
Signalised Intersection	SRL camera	*0.48*	*18.91*	*19.39*	*52.23*	71.62	16.90
Street	HH laser/radar	*0.47*	*22.28*	22.75	*45.25*	68.00	17.33
All urban roads	Bus RBT	7.65	*25.89*	33.54	*51.31*	84.85	79.63
	Car RBT	7.65	*25.89*	33.54	*51.31*	84.85	79.63
	Car & Bus RDT	8.81	*24.73*	33.54	NK	*33.54*	83.22
ALL VICTORIA							
All Victorian roads	All AST (R & not R)	16.02	*32.06*	48.09	*64.29*	112.37	153.61
	All RDT (bus & car)	18.43	29.65	48.09	NK	*48.09*	165.87

that are its focus. To this must be added that all of the fixed camera systems are typically located in places that have been ranked with high numbers of serious crashes per unit length or per intersection. Experience in Queensland and Western Australia (Cameron 2008, 2009, 2010) has found that this crash ranking typically results in fixed camera systems being placed at locations with crash rates typically 2 to 4.5 times higher than the average crash rate in the road environment (Table 9). These considerations allowed the focus of each fixed camera system on the percentage of total crashes in the road environment to be estimated.

Benefits of 50% increase in enforcement

The estimated percentage reduction in crashes, or injury outcome at each severity level, due to the 50% increase in enforcement of each type is shown in Table 10. Apart from the fixed camera systems and hand-held laser/radar, the percentage reduction was estimated by applying a power function (e.g. Figure 1), with the appropriate elasticity, to the 50% increase in the base enforcement level shown in Table 8. In addition, for the covert and semi-covert mobile speed cameras (MSCs), the reduction in fatal crashes was estimated by combining the reduction in casualty crashes with the reduction in fatal crashes per casualty crash.

The percentage reductions due to the fixed camera systems and hand-held laser/radar devices were estimated by applying the increased number of systems/devices (50% increase) to the percentage of total crashes in the road environment considered to be the focus of each system/device (Table 9) and then to the estimated crash reduction within its halo or coverage (given in Section 2.5).

The percentage reductions shown in Table 10 were then used to estimate the annual crash savings for each type of enforcement considered in each road environment (Table 11).

The total social benefit of the savings in fatal, hospital admission and medical treatment crashes was estimated by weighting each crash saving by the "willingness to pay" (WTP) value of preventing each crash (PricewaterhouseCoopers 2008, Hensher et al 2009). Each fatal crash was valued at $8,391,870 in 2014. The hospital admission and non-admitted medical treatment crashes were valued at $376,734 and $110,115, respectively.

Table 12: Estimated costs of 50% increase in enforcement of each type

		COST OF INCREASED ENFORCEMENT ($m p.a.)			
TARGET ROAD ENVIRONMENT	Enforcement type	Capital cost of fixed cameras ($m amortised)	Offence detection	Offence processing	Total additional cost ($m p.a.)
RURAL VICTORIA					
Freeway	Fixed speed camera	0.100		0.761	0.861
	P2P camera system	0.606		0.412	1.018
Divided Highway	Semi-covert MSC		0.930	0.235	1.165
	Overt MSC		0.695	0.114	0.809
Undivided Roads	Semi-covert MSC		2.790	0.705	3.496
	Overt MSC		2.086	0.342	2.428
	MMR		2.000	0.928	2.928
Town Streets	Bus RBT		1.473	NK	1.473
	Bus RDT		0.177	NK	0.177
All rural roads	Car & Bus RBT		15.527	NK	15.527
URBAN (Melbourne)					
Freeway	Fixed speed camera	0.225		2.343	2.568
Arterial	Covert MSC		4.914	3.666	8.580
Signalised Intersection	SRL camera	1.714		3.770	5.484
Street	HH laser/radar		0.832	1.039	1.871
All urban roads	Bus RBT		9.939	NK	9.939
	Car RBT		9.172	NK	9.172
	Car & Bus RDT		1.486	NK	1.486
ALL VICTORIA					
All Victorian roads	All AST (R & not R)		18.665	NK	18.665
	All RDT (bus & car)		1.662	NK	1.662

Economic analysis of increased enforcement

Costs of increased enforcement

The annual cost of 50% increase in enforcement of each type was derived from the unit cost of equipment (amortised over its useful life), offence detection cost and offence processing cost (where known). The absence of information on the unit cost of processing drink- and drug-driving offenders meant these costs could not be included (Table 12). The only costs that reflect economies of scale are those estimated for the roadside alcohol testing (where more than 1 million tests p.a.), based on estimates made by WA Police (Cameron 2012).

Benefit-cost analysis of 50% increase in enforcement

The benefits of the increased enforcement, measured by the WTP value of the annual crash savings (Table 11), were compared with the additional costs in Table 13. The benefit-cost ratio (BCR) reflects the value of the increased savings compared with the increased cost, not the BCR of the total enforcement (150%). The marginal BCR is the benefit divided by cost of the next 1% increase in enforcement (to 51%). The BCR and marginal BCR of each fixed camera system are the same because no diminishing returns were assumed. The net present value (NPV) is the difference between the annual savings and the annual costs.

It is important to note that each of the estimated benefits are independent (applicable to an increase in the specific enforcement type alone) and are not necessarily additive. Some enforcement types are aimed at the same illegal behaviour in the same road environment. Even when the enforcement types differ in their target behaviour, it does not necessarily follow that their combined benefit is the sum of their individual effects. Methods to estimate the crash reductions from a combination of enforcement types are given by Elvik (2009) and have been applied as an illustrative example in the current context by Cameron et al (2015).

Benefit-costs of 100% to 300% increases in enforcement

Apart from the fixed camera systems, it could be expected that the analysis will reflect diminishing returns (crash savings) because the marginal crash reductions will decrease with increased enforcement and costs generally increase. The estimated BCR of 100% increase in enforcement of each type is generally lower than that of 50% increase (Table 14). The increase in the BCR for rural

Table 13: Benefit-cost ratio (BCR), marginal BCR, and Net Present Value (NPV) of 50% increase in enforcement of each type

		BENEFITS & COSTS OF INCREASED ENFORCEMENT ($m p.a.)				
TARGET ROAD ENVIRONMENT	Enforcement type	Total value of crash saving per year ($m)	Total additional cost of enforcement ($m)	**BCR:** Increase benefits/ increase costs	Marginal BCR(for next 1% increase in enforcement)	**NPV:** (Increase) benefits minus costs ($m)
RURAL VICTORIA						
Freeway	Fixed speed camera	1.76	0.861	**2.05**	2.05	**0.900**
	P2P camera system	4.95	1.018	**4.86**	4.86	**3.930**
Divided Highway	Semi-covert MSC	9.90	1.165	**8.50**	6.27	**8.737**
	Overt MSC	4.19	0.809	**5.18**	4.13	**3.380**
Undivided Roads	Semi-covert MSC	270.99	3.496	**77.52**	56.53	**267.490**
	Overt MSC	87.05	2.428	**35.85**	28.61	**84.617**
	MMR	31.94	2.928	**10.91**	8.85	**29.017**
Town Streets	Bus RBT	11.18	1.473	**7.59**	6.11	**9.711**
	Bus RDT	11.48	0.177	**64.99**	52.02	**11.300**
All rural roads	Car & Bus RBT	73.98	15.527	**4.76**	3.82	**58.449**
URBAN (Melbourne)						
Freeway	Fixed speed camera	11.14	2.568	**4.34**	4.34	**8.567**
Arterial	Covert MSC	374.04	8.580	**43.60**	29.41	**365.458**
Signalised Intersection	SRL camera	16.90	5.484	**3.08**	3.08	**11.419**
Street	HH laser/radar	17.33	1.871	**9.26**	9.26	**15.458**
All urban roads	Bus RBT	79.63	9.939	**8.01**	8.07	**69.692**
	Car RBT	79.63	9.172	**8.68**	9.97	**70.459**
	Car & Bus RDT	83.22	1.486	**56.01**	44.81	**81.738**
ALL VICTORIA						
All Victorian roads	All AST (R & not R)	153.61	18.665	**8.23**	7.52	**134.942**
	All RDT (bus & car)	165.87	1.662	**99.78**	79.75	**164.212**

car- and bus-based RBT with 100% increase compared with 50% is an artefact of the fixed cost per test ($54) used for total RBTs less than 1 million per year.

The influence of diminishing returns for further increases in those types of enforcement with variable levels of operation can be seen in Table 14. When the enforcement level is increased by 300%, the operation of either semi-covert or overt mobile speed cameras (MSC) on rural divided highways is approaching a break-even investment (marginal BCR less than 1.5).

The BCRs of each fixed camera system have not been included in Table 14 because they were considered fixed in the absence of assumptions about diminishing returns.

Summary of the economic analysis

It can be seen from Tables 13 and 14 that mobile speed cameras (operated covertly or semi-covertly) and random drug tests have the highest BCRs for a 50% increase and the highest marginal BCRs for further increases. In part this is due to these two enforcement types achieving relatively large reductions in fatal crashes. While many other methods of traffic enforcement have BCRs well above one, and should be included in a comprehensive road safety program, these two enforcement types currently represent the best return on investment in traffic enforcement in Victoria. At the other extreme, further investment in fixed types of camera-based enforcement appears to provide more modest returns, principally due to the limited halo effect or coverage of these enforcement methods.

Conclusion

A method has been developed to estimate the crash reduction benefits of increases in each type of traffic enforcement applied to an appropriate road environment in Victoria. This method has been based on numerous studies linking enforcement levels with road crashes and/or injury severity in the Australian States and internationally. Economic analysis of the crash savings and costs from investment in each type of traffic enforcement has shown that mobile speed cameras and random drug tests provide the highest benefit-cost ratios. The results may be different in other jurisdictions with different crash profiles and different base levels of each type of traffic enforcement.

Table 14: BCRs and marginal BCRs of 100% to 300% increases in enforcement types with varying levels of operation

		100% increase		200% increase		300% increase	
TARGET ROAD ENVIRONMENT	Enforcement type	**BCR**	Marginal BCR	**BCR**	Marginal BCR	**BCR**	Marginal BCR
RURAL VICTORIA							
Divided Highway	Semi-covert MSC	**6.78**	4.09	**4.90**	2.25	**3.88**	1.48
	Overt MSC	**4.34**	2.99	**3.36**	1.89	**2.77**	1.37
Undivided Roads	Semi-covert MSC	**61.44**	36.24	**43.95**	19.41	**34.49**	12.50
	Overt MSC	**30.09**	20.70	**23.25**	13.12	**19.21**	9.49
	MMR	**9.26**	6.56	**7.27**	4.30	**6.08**	3.18
Town Streets	Bus RBT	**6.41**	4.47	**4.99**	2.88	**4.14**	2.11
	Bus RDT	**54.66**	37.80	**42.36**	24.11	**35.08**	17.52
All rural roads	Car & Bus RBT	**9.07**	11.71	**9.32**	8.39	**8.91**	6.78
URBAN (Melbourne)							
Arterial	Covert MSC	**33.08**	17.19	**22.50**	8.27	**17.14**	5.02
All urban roads	Bus RBT	**7.88**	7.24	**7.31**	5.75	**6.79**	4.76
	Car RBT	**9.01**	8.97	**8.63**	7.11	**8.09**	5.87
	Car & Bus RDT	**47.10**	32.55	**36.48**	20.74	**30.20**	15.06
ALL VICTORIA							
All Victorian roads	All AST (R & not R)	**7.67**	6.44	**6.83**	5.02	**6.22**	4.13
	All RDT (bus & car)	**83.84**	57.84	**64.88**	36.77	**53.67**	26.66

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