Economic Development Committee

<u>Inquiry into the road safety benefits of fixed speed cameras</u>

Submission 43

Inquiry into the Road Safety Benefits of Fixed Speed Cameras

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EXECUTIVE SUMMARY

Trauma resulting from traffic crashes is a significant problem worldwide and is associated with substantial economic and social costs (Peden et al., 2004; Richter, Berman, Friedman, & Ben-David, 2006). Speed is regularly cited as being a major contributing factor in traffic crashes and commonplace on Australian roads and there is a growing evidence of the positive relationship between increased vehicle speeds and increased crash risk and severity (Aarts & van Schagen, 2006). Given this relationship a number of speed reduction countermeasures (including fixed and mobile speed cameras, hand-held and moving-mode radars, routine traffic patrol and more innovative approaches such as point-to-point speed cameras and intelligent speed adaptation) have been developed and evaluated in terms of their ability to reduce speed-related fatalities and injuries. These approaches has been adopted at a widespread rate in Australia, however there exist a number of differences regarding the extent of implementation and characteristics of operation (e.g., mobility and visibility).

Despite the widespread global use of speed cameras as a police law enforcement tool for speed management, there is still much debate regarding the perceived effectiveness of such methods. Overall, the available literature provides evidence to suggest speed cameras are an effective tool for reducing vehicle speeds and related crashes in close proximity to camera locations (Harrison, 2001; Pilkington & Sanjay, 2005). A range of evaluations have suggested evidence of effectiveness associated with the implementation of automated and stationary approaches, such as fixed and mobile speed cameras, albeit often producing localised effects only. In addition, positive impacts have also been found for less automated, moving approaches (e.g., hand-held and moving-mode radars, routine traffic patrols) and more innovative approaches (e.g., point-to-point speed cameras, vehicle-activated signs and intelligent speed adaptation). Moreover, based on the available evidence it appears that a mixture of overt and covert approaches is typically most effective. However, the methodological quality of much of the literature is often questioned and there is a definite need for more scientifically rigorous research in the area.

Best practice in speed enforcement

There are numerous challenges to reducing vehicle speeds and related crashes, including the transient, frequent and evasive nature of the behaviour and the reinforcing effect of punishment avoidance. From the available research, a number of recommendations regarding best practice principles for the implementation of speed enforcement operations, and particularly speed cameras, can be made.

Speed enforcement programs need to utilise a variety of enforcement strategies which are tailored to specific situations.

A one-size-fits-all approach to speed enforcement is unlikely to be as effective as one which incorporate a range of enforcement methods, tailored to the variety of roads and situations across the road network (Cameron, 2008). As a result, a mixture of covert and overt, as well as stationary and moving, operations is argued to produce the greatest road safety benefits, however the precise optimal combination of approaches is not yet known (McInerney, Cairney, Toomath, Evans, & Swadling, 2001; Zaal, 1994). Automated and stationary methods appear to be most effective in crash black-spots, given the limited distance and time halo effects commonly associated with such approaches and the fact that observed effects are generally localised to the camera site only (Champness, Sheehan, & Folkman, 2005). On the contrary, less automated, moving approaches appear most beneficial in instances where more network-wide approaches are desired. Overt operations serve a primarily general deterrent effect however covert operations increase the unpredictability of enforcement operations and minimise the impact of punishment avoidance strategies and halo effects. Moving, covert enforcement methods are likely to represent an effective approach to the detection and apprehension of more deviant offenders.

Fixed speed cameras are most effective at locations with localised speed-related problems and where other speed enforcement approaches are not practical or safe.

Fixed speed cameras are most likely to be beneficial in the management of vehicle speeds and related crashes at locations with high levels of speed-related problems. That is, fixed speed cameras are likely to produce the greatest benefits at crash black spots or at locations with high speeding offence rates. While the automated, stationary nature of fixed cameras often results in localised effects of vehicle speeds and crash rates, this still represents an effective approach when speed-related problems are also localised. In addition, fixed cameras also provide an appropriate enforcement method at locations where other speed enforcement approaches are not safe or practical, such as on limited access roads, freeways and in tunnels. Finally, fixed cameras provide the optimal approach at locations requiring consistent enforcement.

Operations should be sufficiently intensive so as to produce an "atmosphere" of enforcement presence and be randomly scheduled to increase unpredictability of enforcement activities.

Operations must be implemented with a sufficient level of intensity such that the driving population perceives their likelihood of exposure to enforcement activities as being high, thus increasing the risk and reducing the benefits associated with exceeding the speed limit (Delaney, Diamantopoulou, & Cameron, 2003; McInerney et al., 2001; Newstead, Cameron, & Leggett, 1999; Zaal, 1994). In addition, there is evidence to suggest that optimal levels of effectiveness are achieved when enforcement operations are randomly scheduled, such that unpredictability of enforcement activity is increased (Delaney et al., 2003; Leggett, 1997; Newstead et al., 1999).

More wide-spread implementation of innovative approaches, particularly point-to-point systems, will likely produce more network-wide effects on vehicle speed and crashes.

Point-to-point speed enforcement has been found to be extremely effective in reducing vehicles speeds and increasing compliance with speed limits (Soole & Watson, 2009). More widespread use of this approach would likely result in more network-wide impacts on both vehicle speeds and crash rates. In addition, the evidence that such an approach is perceived as being more fair and legitimate by drivers, as well as the ancillary benefits such as reduced traffic congestion, suggests that such an approach has the potential to result in substantial changes to underlying attitudes regarding speed choices if drivers are able to regularly associate driving at the posted speed limit with smoother traffic flows and reduced congestion. However, the relatively high cost of the approach calls for careful consideration in regard to locations where such systems are used.

The use of ISA should be considered as a punishment for recidivist and high-range speeders.

The use of ISA in general to reduce the incidence of speeding among the general public should be fully explored, however such provisions are likely to be met with stiff opposition from vehicle manufacturers and drivers alike. This will be particularly true for more intervening systems which have been found to be associated with the greatest behavioural effects. One particular application of the technology which warrants further attention is the use of intervening ISA systems as a punishment option (or mandated response) for recidivist and high-range speeding offenders (Watson, Watson, Siskind, & Fleiter, 2009).

Policy and practice regarding the operation of speed cameras should be highly transparent and public education of the role of speed cameras to improve road safety must be clearly conveyed.

Accompanying speed enforcement operations with publicity campaigns specifically related to the method of speed enforcement can bolster the effectiveness of operations (Cameron, Newstead, Diamantopoulou, & Oxley, 2003; Delaney et al., 2003; McInerney et al., 2001; Rogerson et al., 1994; Zaal, 1994). Moreover, publicity campaigns present a unique channel of communication between traffic authorities, the police and the general driving public. As such, the communication of messages to debunk stereotypes and misconceptions regarding speed enforcement policy and practices may increase the perceived legitimacy and transparency of enforcement efforts, and in turn encourage greater levels of compliance.

The feasibility of reducing enforcement tolerance levels should be examined.

Enforcement tolerance levels should be set at the lowest acceptable level to increase the perceived certainty of punishment associated with speeding behaviour. That is, drivers must be encouraged, through threat of punishment, to drive at or below the posted speed limit rather than at a *de facto* speed limit based on perceived enforcement tolerances. While the enforcement tolerances used in Queensland are not made public, a recent survey of preferred driving speeds among Queensland drivers revealed a general preference for speeds approximately 10% above posted speed limits, with perceptions of enforcement tolerance levels one of the leading reasons why respondents reported driving above posted speed limits (Fleiter & Watson, 2006; Fleiter, Watson, Lennon, King, & Shi, 2009).

The aim of any speed management program should be to deter, rather than catch, speeding drivers.

Speed management programs must be geared such that they are designed to deter drivers from exceeding the speed limit, rather than identifying the most effective way to apprehend speeding drivers (Zaal, 1994). This is not to suggest that the apprehension of speeding drivers should not be an aim of speed enforcement; simply that it should be secondary to deterrence. Ideally, enforcement activities that are intensive, randomly scheduled and involve a mixture of approaches should create an atmosphere such that the general public is deterred from exceeding the speed limit. This will largely be achieved through increased perceptions of enforcement presence, unpredictability of operations and perceived risk of detection, apprehension and punishment.

Speed management programs must be multifaceted.

Speed enforcement represents but one element of an effective speed management program. Indeed, speed management must involve a multifaceted approach incorporating not only enforcement but also community initiatives, public education, media campaigns, offender rehabilitation programs and traffic engineering initiatives (e.g., reviewing speed limits). In addition, innovative approaches such as Intelligent Speed Adaptation (ISA) provide a promising new line of approaches to speed management. Finding the precise optimal mix of various components, while also balancing issues such as driver acceptability and perceived legitimacy and transparency of policies and practices, is an arduous task. Future empirical research should seek to rectify the methodological shortcomings of prior evaluations and identify the unique contribution of various approaches to road safety.

1. INTRODUCTION

1.1. Background

This submission has been prepared in response to the Economic Development Committee's *Inquiry into the Road Safety Benefits of Fixed Speed Cameras*. This submission will outline the contributory role of speed in crashes; give an overview of the current policies and practices relating to speed management in Queensland; review the evidence regarding the effectiveness of current approaches, paying particular attention to fixed speed camera use; and, highlight the potential road safety benefits associated with a number of innovative approaches. The primary aim of the submission is to analyse the road safety impact of fixed speed camera use relative to other enforcement methods.

1.2. Scope of the submission

While it is acknowledged that speed management strategies in many jurisdictions, including Queensland, involve multifaceted approaches incorporating enforcement, community initiatives, public education, media campaigns and offender rehabilitation programs, this submission will largely focus on the road safety implications of enforcement approaches; in particular fixed speed cameras. This focus is in keeping with the research interests and expertise of the authors. Nonetheless, it is important to continue to view the speed management task as a multifaceted approach, such that different aspects work in unison to complement each other and produce optimal road safety benefits.

Thus, brief mention will be given to innovative approaches, such as Intelligent Speed Adaptation (ISA), point-to-point speed cameras and adaptive cruise control (ACC). Specifically, their role in reducing speed-related problems and how they can be incorporated with current enforcement efforts (e.g., compulsory fitting of ISA for high-range and recidivist speeders), will be discussed. Furthermore, in addition to understanding the impact of enforcement approaches on rates of traffic crashes and speeding violations, it is important to consider driver perceptions toward, knowledge of, and acceptability of enforcement efforts, such that policies and practices are transparent and perceived to be legitimate, and in turn encourage compliance.

2. THE SCOPE OF THE SPEEDING PROBLEM

Trauma resulting from traffic crashes is a significant problem worldwide and is associated with substantial economic and social costs. Each year more than a million people are killed, and an additional 50 million are seriously injured, on roads throughout the world (Peden et al., 2004; Richter, Berman, Friedman, & Ben-David, 2006). It has been estimated that traffic crashes cost nations throughout the world approximately $518 billion each year (Richter et al., 2006), with costs in Australia estimated to be approximately $17 billion a year[1], predominately in human costs, such as medical treatment, hospitalisation and loss of productivity (Connelly & Supangan, 2006). In the United States, speed-related crashes

[1] Costs associated with serious injury crashes represent 61% of all costs associated with traffic crashes, compared to less than 18% associated with fatal crashes.

alone cost an estimated $40 billion each year, or 20% of the total cost of traffic crashes in the country (Liu, Chen, Subramanian, & Utter, 2005).

In 2008, a total of 1,463 persons were killed on Australian roads, at a rate of 6.8 fatalities per 100,000 of the population, while in Queensland, 328 fatalities were recorded at a rate of 7.7 per 100,000 of the population (Australian Transport Safety Bureau, 2008). Numerous high-risk behaviours are associated with increased risk of traffic crash involvement, including speeding, driving while substance-impaired, fatigue and monotony, inattention and failing to wear a restraint (Petridou & Moustaki, 2000). Speed is regularly cited as being a major contributing factor in traffic crashes. There is a growing body of evidence suggesting a positive relationship between increased vehicle speeds and increased crash risk and severity (Aarts & van Schagen, 2006; Fildes, Rumbold, & Leening, 1991; Kloeden, McLean, & Glonek, 2002; Kloeden, McLean, Moore, & Ponte, 1997a; Lynam & Hummel, 2002).

Given this relationship a number of speed reduction countermeasures have been developed and evaluated in terms of their ability to reduce speed-related fatalities and injuries. These countermeasures include speed cameras, road engineering and speed calming devices, lower speed limits and intelligent transportation systems (Richter et al., 2006). Speed cameras have received considerable attention, both in terms of implementation and evaluation; particularly in Australia. In order to continue the growth and development of effective countermeasures it is imperative that the relationship between vehicle speed and crash risk and severity be properly understood and the prevalence of speed-related crashes be accurately estimated.

2.1 Speed as a contributing factor in traffic crashes

Typically, speed is judged to be a contributing factor if a crash involves one or more vehicles deemed to be exceeding the posted speed limit or travelling too fast for the prevailing weather and road conditions (Robinson & Singh, 2006). Attempting to precisely quantify the impact of speed as a contributing factor in traffic crashes is methodologically problematic for a number of reasons. For instance, it is often difficult to assess the influence of speed after the fact due to insufficient evidence (Robinson & Singh, 2006). Moreover, categorisation of crash causality is not mutually exclusive and multiple contributing factors may be attributed to a single crash. Thus, *contributing factors* should not be confused with *causal factors*. In addition, available data from which many statistics are typically generated (e.g., police and hospital records) are subject to human error and poor reliability; under-reporting of traffic casualties in police records is commonplace; and, there is substantial variation between hospital data and formal police records (Broughton, Markey, & Rowe, 1998; Elvik & Mysen, 1999; Farmer, 2003; Hvoslef, 1994; Jeffrey et al., 2009; Ward, Lyons, & Thoreau, 2006). Nonetheless, a number of estimates, which are more than likely to represent underestimates, have been calculated.

In Queensland in 2006, speed was reported to be a contributing factor in 27.2% of fatalities (Queensland Transport, 2007), while in 2003 speed was a contributing factor in 16% of fatal crashes, 5% of hospitalisation crashes, 7% of other injury crashes and 5% of all crashes (Queensland Government, 2005). In New South Wales, speeding was reported as a contributing factor in 37% of fatal crashes and 16% of injury crashes between 2004 and 2008 (Walker, Bryant, Barnes, Johnson, & Murdoch, 2009). These findings show no reduction in the contributory role of speed in fatal crashes from figures reported between 1995 and 1999 (Roads and Traffic Authority, 2000). Moreover, the relationship between speed and crash severity was highlighted, with speeding reported to be a contributing factor in 37% of crashes where one person was killed, 44% of crashes where two people were killed and 59% of crashes where three or more people were killed.

Speeding has also been recognised as one of the leading contributing factors in road fatalities and injuries in other countries. These include: the United Kingdom (Robinson & Singh, 2006); United States (Liu et al., 2005); China (Wang et al., 2003); South Korea (Yang & Kim, 2003); Kenya (Odero, Khayesi, & Heda, 2003); Ghana (Afukaar, 2003); and, South Africa (Ministry of Transport, 2001). Moreover, there is a strong association between speed and alcohol impairment in fatal crashes (Liu et al., 2005) and speeding-related crashes have been found to be particularly prevalent among young novice drivers (Braitman, Kirley, McCartt, & Chaudhary, 2008; Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005) and on rural roads (up to 4.7 times greater risk) compared to urban roads (Kloeden, Ponte, & McLean, 2001; Tziotis, Mabbott, Edmonston, Sheehan, & Dwyer, 2005).

2.2 Prevalence of speeding

A number of studies have used self-report or observational methods in an attempt to estimate the proportion of drivers who exceed the speed limit. The evidence suggests that speeding is commonplace and that many drivers choose speeds within 10km/h over the speed limit. Indeed, in Queensland, 40.3% of speeding infringements are for offences up to 12km/h over[2] (Queensland Transport, 2008). Observational studies conducted in Australia have shown that, across the different speed zones, as many as 44.6% of drivers exceed the posted speed limit (Glendon, 2007; Glendon & Sutton, 2005). In New South Wales, speeding was reported by 72% of respondents in 50km/h zones, 39% in 60km/h zones and 41% in 100km/h zones (Walker et al., 2009). These studies all reported that most drivers typically travel at less than 10km/h over the limit. Also in New South Wales, free speed measurements of over 34 million vehicles at 87 locations revealed 19% exceeded the speed limit by more than 10km/h in 60km/h zones and 12% in 100km/h zones (Roads and Traffic Authority, 2000). Finally, speeding has been found to be particularly prevalent among young novice drivers, with as many as 27% receiving a speeding infringement within the first year of licensure (Palamara & Stevenson, 2000).

Numerous studies have explored whether demographic, person-related and social factors can be used to predict the propensity for an individual to engage in speeding and be involved in speed-related crashes (Harrison, Fitzgerald, Pronk, & Fildes, 1998; Machin & Sankey, 2008; Stradling, Meadows, & Beatty, 2000; Williams, Kyrychenko, & Retting, 2006). Numerous factors have been highlighted (see Table 1), with relationships typically strongest in relation to individuals

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[2] Taking into account the undisclosed enforcement tolerance associated with Queensland speed enforcement practices, it is likely a much greater proportion of speeding drivers are travelling at speeds within 12km/h of the posted limit (than the 40.3% reported here).

Table 1. Characteristics associated with increased propensity to speed and speed-related crash involvement.

Characteristic	Evidence	Sources
Demographic		
Gender	Males more likely to choose greater speeds; report more positive attitudes toward speeding; be high-range/recidivist offenders; be involved in fatal speed-related crashes	Fuller et al. (2008); Liu et al (2005); McColl (2001); Parker et al (1995); RTA (2000); Shinar et al (2001); Stradling et al. (2003); Walker et al. (2009); Watson, et al. (2009)
Age	Younger drivers more likely to choose greater speeds; report more positive attitudes toward speeding; state that driving faster is enjoyable; have lower perceptions of risk; report deliberate speeding; be high-range/recidivist offenders; be involved in speed-related crashes	Brown & Cotton (2003); Harrison et al. (1998); Liu et al (2005); McColl (2001); Palamara & Stevenson (2000); Parker et al. (1992); RTA (2000); Stradling et al. (2000); Walker et al. (2009); Williams et al. (2006); Watson, et al. (2009)
Person-related		
Infringement & crash histories	Increased likelihood of speeding behaviour among individuals with past infringement and crash histories	Cooper (1997); Fildes et al. (1991); Harrison et al. (1998); Iversen & Rundmo (2002); Maycock et al. (1998); Read et al. (2002); Stradling et al. (2000); Williams et al. (2006); Watson, et al. (2009)
Risky driving behaviours	Increased likelihood of speeding behaviour and more positive attitudes toward speeding among individuals with tendencies to engage in other risky driving behaviours; particularly true the case for young drivers	Gabany et al. (1997); Harrison et al. (1998); Machin & Sankey (2008); Palamara & Stevenson (2000); Stradling et al. (2000)
Perceptions of own driving ability	Increased likelihood of speeding behaviour among individuals who display overconfidence, have an inflated perception of their own driving ability	Harrison et al. (1998); Palamara & Stevenson (2000); Read et al. (2002); Walker et al. (2009)
Perception of risk	Increased likelihood of speeding behaviour among individuals who perceive their risk of detection as being lower	Harrison et al. (1998); Homel (1986)
Personality traits	A number of traits found to be positively associated with speeding: sensation-seeking; normlessness; perceived invulnerability; heightened internal locus-of-control; and, authority-rebellion	Corbett (2001); Fernandes et al. (2007); Iversen & Rundmo (2002); Jonah (1997); Machin & Sankey (2008); Stradling et al. (2000)
Protective factors	A number of traits found to be positively associated with speeding: aversion to risk-taking; and, alturism	Brown & Cotton (2003); Machin & Sankey (2008)
Situational		
Socio-economic status	Increased likelihood of speeding behaviour associated with lower socio-economic status drivers	Lipscombe & Wilkinson (1996); Maycock et al. (1998); Stradling et al. (2000)
Annual mileage	Increased likelihood of speeding behaviour associated with greater exposure to road (greater mileage)	Fildes et al. (1991); Harrison et al. (1998); Maycock et al. (1998); Stradling et al. (2000)
Time-pressures	Increased likelihood of speeding behaviour among drivers in a rush	Fuller et al. (2008); Gabany et al. (1997); Read et al. (2002); Stradling et al. (2003)
Occupational driving	Increased likelihood of speeding behaviour among individuals driving for work purposes; anticipated regret and perceived social norms serve protective function	Fildes et al. (1991); Harrison et al. (1998); Maycock et al. (1998); Newman et al. (2004)
Passengers	Mixed evidence: effect of passengers likely to be moderated by other factors (e.g., age, gender, experience); family members found to be a protective factor	Baxter et al. (1990); Fildes et al. (1991); Glendon (2007); Glendon & Sutton (2005); Walker et al. (2009)
Vehicle characteristics	Motorcyclists overrepresented in speeding related crashes; some evidence of greater speeding among vehicles with larger engine capacities; increased likelihood of speeding among drivers of newer vehicles	Fildes et al. (1991); Fuller et al. (2008); Glendon (2007); Glendon & Sutton (2005); Lipscombe & Wilkinson (1996); Liu et al (2005); Stradling et al. (2000); Williams et al. (2006)
Road environment	Speed-related crashes occur more frequently when negotiating bends and on rural roads; speeding more frequent in clear, daytime conditions;	Lipscombe & Wilkinson (1996); Liu et al (2005); RTA (2000)

who speed excessively. Nonetheless, speeding appears to be a relatively ubiquitous behaviour engaged in by the majority of drivers at least some of the time. Obviously, the prevalence of speeding has substantial implications for the development of effective countermeasures which must consider the wide cross-section of drivers who engage in this behaviour.

Despite the abundant literature highlighting the negative health and safety impacts of increased vehicle speeds on public health and safety (see Section 2.1.1 below) there remains, arguably, a general 'social acceptance' of speeding behaviour in Australia by many. A number of reasons have been purported to explain this positive social attitude toward speeding, including: perceptions that speeding is 'safe' as long as it not excessive; perceptions of an enforcement tolerance in most jurisdictions; a lack of personal and social motivators to inhibit speeding; dissatisfaction with speed limits; perception that speeding does not constitute a 'real' offence; and a perception that the risks associated with speeding are low, particularly compared to other risky driving behaviours (Corbett, 2001; Elliott, 1999; Fleiter, Lennon, & Watson, 2010; Forward, 2006; Fuller et al., 2008; Read et al., 2002; Roads and Traffic Authority, 2000; Tyler, 1990). However, other studies have highlighted paradoxical attitudes, suggesting that drivers are not completely ignorant to the risks associated with speeding, such that many report speed preferences in excess of the speed limit despite the risks associated with speeding being well understood (Fleiter & Watson, 2006).

Moreover, absolute crash risk does not precisely highlight the dangers associated with various risky driving behaviours. Instead it is necessary to analyse relative crash risks. Indeed, in a study conducted in Australia, Kloeden and colleagues (1997) found that travelling 5km/h over the posted limit in a 60km/h zone almost doubled the risk of being involved in a crash compared to a vehicle travelling at the speed limit. Moreover, they found evidence that the relationship between vehicle speed and crash risk is exponential with relative risk ratios doubling for every additional 5km/h over the speed limit vehicles travelled. The results cited above relating to attitudes towards speeding and the risks associated with speeding highlight one of the fundamental challenges for road safety practitioners; convincing road users that speeding is risky and will not be tolerated by society at large. However, the transient nature of speeding compared to other risky driving behaviours, such as drink driving, and the sense that drivers perceive themselves to have control over consequences when speeding, complicates this task.

2.1.1 The relationship between vehicle speed and crash risk

An extensive body of literature highlights the relationship between vehicle speed and crash risk and severity. Overall, there is consistent evidence to suggest that increased vehicle speed is associated not only with increased risk of crash involvement but also increased severity of injury and damage in the event of a crash (Aarts & van Schagen, 2006; Elvik, Christensen, & Amundsen, 2004; European Transport Safety Council, 1995; Kloeden, McLean, & Glonek, 2002; Kloeden et al., 1997; Lynam & Hummel, 2002; Peden et al., 2004; Taylor, Lynam, & Baruya, 2000). Indeed, some researchers contend that "speed is an aggravating factor in all crashes" (Global Road Safety Partnership, 2008; p.6). Over the years, this relationship has been the focal point of numerous government media campaigns aimed at reducing speeds. The key to a successful speed management program is creating a balance between public safety and individual mobility needs (Fildes, Langford, Andrea, & Scully, 2005).

Evidence regarding the relationship between vehicle speed and crash severity is relatively compelling, largely as a function of the undisputable laws of physics and kinetic energy (Aarts & van Schagen, 2006). Comparatively, the relationship between speed and crash risk is more complicated due to the fact that most crashes involve a multitude of driver, vehicle and environmental contributing factors (Baruya, 1998). The relative risks associated with increased vehicle speeds were highlighted in a case-control, crash reconstruction study conducted in Australia by Kloeden and colleagues (Kloeden et al., 2002; Kloeden et al., 1997). Results revealed that, compared to a vehicle travelling at the speed limit in a 60km/h zone, a vehicle travelling 65km/h was estimated to be at almost twice the risk of being involved in a crash (RR=1.82). The relationship was cited as being exponential with relative risk ratios doubling for every additional 5km/h over the speed limit travelled. Specifically, the relative risks of being involved in a crash were 3.57 (70km/h), 7.63 (75km/h), 17.66 (80km/h), 44.36 (85km/h) and 120.82 (95km/h).

Overall, the empirical evidence highlights a number of consistent trends regarding the relationship between vehicle speed and crash risk (Aarts & van Schagen, 2006). Specifically, the literature has revealed: (a) there is a positive exponential relationship between vehicle speed and crash risk at an individual vehicle level (Fildes et al., 1991; Kloeden et al., 2002; Kloeden et al., 1997); (b) a power function best explains the relationship between vehicle speed and crash risk at a road section level (Elvik, 2005; Elvik et al., 2004; Nilsson, 2004); (c) the relationship between vehicle speed and crash risk is more pronounced on urban roads compared to open roads (Kloeden et al., 2002; Kloeden et al., 1997); and, (d) speed variation between vehicles has been found to be a critical factor in the prediction of increased crash risk[3] (Cirillo, 1968; Hauer, 1971; Munden, 1967; Research Triangle Institute, 1970; Solomon, 1964).

However, the literature investigating the relationship between vehicle speed and crash risk is not free from methodological limitations. Criticisms include the relatively small number of locations from which data is generally collected; the "snapshot" approach to operationalising preferred driving speed; and, the lack of accounting for fatal crashes and confounding factors such as traffic flow and density, junction density, lane width, road length as well as many other driver, vehicle and environmental factors (Aarts & van Schagen, 2006; Fildes & Lee, 1993). To summarise, there is consistent evidence to suggest a positive relationship between vehicle speed and crash risk and severity. Moreover, this relationship is exponential in nature and more pronounced on urban roads and speed variation between vehicles is particularly associated with increased crash risk. While there are obvious limitations to the data, it is unlikely that any degree of error in the estimates negates the consistent positive relationship observed across the multitude of studies conducted (Lynam & Hummel, 2002).

[3] While early research suggested a U-shaped relationship, suggesting that crash involvement was also higher among vehicles driving significantly slower than the traffic flow, more recent evidence has failed to produce similar results. Thus, while the true nature of the relationship remains inconclusive, it may be better explained as representing a J-curve.

3. A BRIEF HISTORY OF SPEED ENFORCEMENT IN AUSTRALIA

Speed enforcement has become a key component in road safety strategies throughout the world. Traditionally, police traffic patrols were largely responsible for this function. However with advances in technology came a new era of speed enforcement. Australia, like many other highly motorised countries, has embraced this technology in a widespread manner. There are numerous types of speed enforcement technology, including: speed cameras (both mobile and fixed); lasers and radars (both hand-held and moving-mode/vehicle-attached[4]); and more recently, point-to-point speed enforcement. Each of these approaches has been implemented in Australia to differing degrees. Automated, camera-based speed enforcement technology is undoubtedly the most common approach now adopted in Australian jurisdictions (Delaney, Ward, & Cameron, 2005).

The manner in which speed enforcement is conducted differs between jurisdictions on two continuums: visibility and mobility (Soole, Lennon, & Watson, 2008). Visibility refers to whether the method is overt (visible) or covert (hidden) in nature, while mobility refers to whether the method is stationary or moving in its operation (see Figure 1 for examples). Mobility somewhat overlaps with the issues of immediacy of punishment and contact with authority, such that mobile methods are typically associated with immediate issue of an infringement notice at the time and site of the offence and direct contact with police officers. Conversely, stationary methods are typically associated with a delay between the time of the offence and issuing of the infringement notice (e.g., 1-2 weeks via the mail) and no direct contact with authorities. In addition, the automated nature of speed cameras allows such methods to detect much larger numbers of offending vehicles per working hour than manually operated devices.

In Australia, there is a tendency to rely on stationary approaches; however moving approaches still remain a critical component of speed management programs. In addition, there is substantial between-jurisdiction variation in the level of visibility of enforcement efforts, ranging from the highly overt operations typical in Queensland and New South Wales to the more covert approaches adopted in Victoria (Delaney et al., 2005), although this is now beginning to change. Mobile speed cameras are arguably the most common method of enforcing speed limits, however fixed cameras are becoming increasingly popular. A number of jurisdictions are beginning to trial

Figure 1. Classification of various enforcement methods by visibility and mobility.

Visibility		Mobility: *Stationary*	Mobility: *Moving*
	Visible	Fixed/permanent speed cameras. Overt mobile speed camera vans.	Marked patrol vehicle in the traffic flow. Marked patrol car on the side of the road. Overt operation of a hand-held radar.
	Hidden	Covert mobile speed camera vans	Unmarked patrol vehicle in traffic flow. Covert operation of a hand-held radar.

Source: Soole et al. (2008)

[4] Moving-mode radars are radar devices attached to a police vehicle; typically the roof strut above the driver-side door.

or implement point-to-point speed cameras involving a series of camera banks that measure average vehicle speeds over a specific distance of the road network (e.g., Victoria, Queensland, New South Wales). In addition, more traditional methods of speed enforcement such as routine patrols and held-held and moving-mode radar use also remain an integral part of the speed management program of each jurisdiction.

The first implementation of mobile speed cameras in Australia occurred in Victoria in 1985 (Delaney et al., 2005). This initial trial involved overt operation and was found to have little effect on vehicle speeds and crash rates. As a result, in 1989 a more covert program of speed camera use was implemented. Since then the total number of operational speed cameras has increased, the enforcement tolerance has gradually been reduced and camera operation has become outsourced and privatised (Delaney et al., 2005; Sullivan, Cavallo, & Drummond, 1992). In 1988, Western Australia became the second Australian jurisdiction to implement a speed camera program, involving a mixture of overt and covert techniques. New South Wales followed soon after in 1991, with a program predominately focused on overt operation of cameras.

Interestingly, Queensland was relatively late in its introduction of speed cameras (in May 1997), with all states having implemented mobile speed cameras to some extent by this time. Nonetheless, mobile speed cameras are now an integral part of the speed management program in the state. Traditionally, operation has been almost completely overt due to the strong focus on general deterrence (Queensland Police Service Traffic Camera Office, 2007). However, in early 2010, covert mobile speed camera operations begun operation on Queensland roads in an attempt to increase both the general and specific deterrence impacts associated with speed camera operations.

More recently, fixed speed cameras have begun to experience wider implementation in a number of Australian jurisdictions. As the name suggests, fixed cameras involve cameras permanently located at a single location, typically mounted to existing gantries or other roadside infrastructure (e.g., bridges, poles). Fixed cameras are generally operated in an extremely overt fashion and camera sites represent crash black-spots or areas where speed-related problems have been identified and other speed enforcement approaches are difficult or unsafe (Delaney et al., 2005). In 1997, New South Wales introduced a fixed speed camera in the Sydney Harbour tunnel, with a full camera program rolled out in 1999 at numerous black spots throughout the state (ARRB Group Project Team, 2005; Delaney et al., 2005; Roads and Traffic Authority, 2010). In late 2007, Queensland introduced two fixed speed cameras at a number of crash black-spot locations. More recently this number has increased to nine sites all located in the south-east region (Queensland Transport, 2010). Fixed speed cameras are also extensively used in Victoria and are growing in popularity in the Australian Capital Territory and Tasmania. Moreover, use of fixed speed cameras is more widespread throughout Europe and particularly in the United Kingdom (Gains, Nordstrom, Heydecker, & Shrewsbury, 2005).

However, the implementation of speed enforcement technology has not been without criticism and controversy. Indeed, Goldenbeld (2002) outlined four common sources of criticism of speed enforcement technology: credibility, legitimacy, implementation and social dilemmas. The credibility and legitimacy of speed enforcement technology is often questioned in regards to the underlying purpose of speed cameras (revenue-raising versus road safety). The fact that, in some Australian jurisdictions at least, revenue generated from speed cameras is channelled to consolidate revenue rather than to fund road safety programs has fuelled this controversy (Delaney et al., 2005). However, this is not the case in Queensland in relation to the speed cameras. In addition, speed cameras have been criticised in regard to the appropriateness of camera site locations, covert operations and the lack of acknowledging extenuating circumstances (Delaney et al., 2005). Implementation issues include scepticism regarding the accuracy and reliability of speed cameras and it has been argued that enforcement tolerances should allow an acceptable leeway for inconsistencies in speedometer calibrations (Delaney et al., 2005). Finally, social dilemmas typically refer to the social acceptability of speeding behaviour (Fleiter & Watson, 2006; Pennay, 2006) and a driving culture where many drivers feel they can safely exceed the speed limit (Fleiter et al., 2010; Svenson, 1981; Walton & Bathurst, 1998).

2.1.2 Speed Enforcement Policy & Practice in Queensland

The Queensland Speed Management Strategy is based on the theoretical underpinnings of deterrence theory, particularly general deterrence, and as a consequence is inherently overt in nature (Queensland Police Service Traffic Camera Office, 2007). However, a balance is struck between general and specific deterrence to ensure that those offenders who refuse to obey speed limits are appropriately penalised. Indeed, the traditionally overt operation of speed cameras is complemented by graduated penalty structures and the recent introduction of covert speed cameras.

Fixed speed cameras were first introduced in Queensland in late 2007 with additional sites introduced in 2009 and 2010 (Department of Transport and Main Roads, 2009). Currently, fixed cameras are only located in the south-east region. Specifically, fixed speed cameras are currently implemented at the following locations: Bruce Highway at Burpengary; Main Street at Kangaroo Point on the approach to the Story Bridge; Pacific Motorway at Tarragindi; Nicklin Way at Warana; Sunshine Motorway at Mooloolaba; Warrego Highway at Muirlea and Redwood; and, Gold Coast Highway at Labrador and Broadbeach. Fixed speed enforcement is also used throughout the Clem Jones Tunnel. Available mobile speed camera units are randomly scheduled to a selection of over 4000 camera sites. The criteria for selecting both fixed and mobile camera sites[5] is predominately based on locations with a history of road traffic crashes, however public complaints and other factors may also influence decisions. In addition, the cameras are operated during the day and night, with mobile cameras accompanied by uniformed police officers.

Penalties associated with speeding offences include demerit point loss, fines and licence suspension and typically escalate with the seriousness of the infringement (Queensland Police

[5] *Speed camera zones*, which are 1km in diameter in urban areas and 5kms in diameter in rural areas, are selected by a committee of representatives made up of members of the Queensland Police Service, Queensland Transport, Main Roads, relevant Local Government Authority and RACQ. *Speed camera sites*, which refer to the specific locations within a zone where a speed camera will operate, are located within these selected zones (Queensland Police Service Traffic Camera Office, 2007).

Service Traffic Camera Office, 2007). Licence suspension is applied to drivers caught in excess of 40km/h over the speed limit and for recidivist offenders. Given the life-threatening nature of speeding behaviour, there are no provisions from speed legislation on the basis of good driving history or extenuating circumstances. Despite some misconceptions that exist in the driver population, there is no legislation prohibiting the use of speed cameras on downhill grades. In addition, in regard to mobile speed cameras, while it is a Queensland Police Service requirement for the '*Speed Camera in Use'* sign to be in place there is no legislative requirement regarding the use of the sign. Moreover, provisions exist under the Traffic Act that allow police officers to breach sections of the Act whilst performing a function of their duties, such as operating a mobile camera on footpaths or no parking areas. Finally, in Queensland, all speed cameras are operated with an unspecified enforcement tolerance (Queensland Police Service Traffic Camera Office, 2007).

2.1.3 The Theoretical Basis of Speed Enforcement in Queensland: Extended Deterrence Theory

Shinar and McKnight (1985) have argued that the most fundamental influence on speeding behaviour is the perceived risk of detection and apprehension, and thus it has been argued that the most critical goal of speed management should be to increase this perceived risk (Zaal, 1994). One popular theory used to explain the processes in which police can increase the perceived risk of detection and punishment is deterrence theory. This theory proposes that enforcement and punishment must be sufficient enough to deter offenders, as well as the general public (e.g., potential offenders), from engaging in the behaviour (Akers & Sellers, 2009). According to the theory, deterrence is achieved when compliance is the direct consequence of a fear or threat of negative consequences (Beyleveld, 1979; Elliott, 2003). Such consequences may be legal, such as a monetary fine or loss of licence, or non-legal, such as social stigma. That is, for deterrence to occur the potential gains associated with the behaviour must be outweighed by the potential risks (Elliott, 2003). Compliance achieved through any other mechanism other than the fear or threat of negative consequences is not deemed to be evidence of deterrence.

Two forms of deterrence have been described: general deterrence and specific deterrence. General deterrence operates under the premise that the general public can be discouraged from engaging in prohibited behaviours by increasing the perceived threat of detection and punishment (Akers & Sellers, 2009). General deterrence can be achieved in a number of ways, including making a public example of offenders, educating the public about enforcement efforts and by engaging in highly overt enforcement practices (Fildes & Lee, 1993). In contrast, specific deterrence focuses on detecting and punishing offenders in an attempt to prevent a reoccurrence of the prohibited behaviour (Akers & Sellers, 2009; Zaal, 1994). However, general and specific deterrence are not mutually exclusive. Specific deterrence can promote general deterrence through the process of vicarious learning, such that an individual may be dissuaded from engaging in a prohibited behaviour through indirect experience of punishment of others (Fildes & Lee, 1993).

According to classical deterrence theory, the effectiveness of any punishment is a function of the perceived severity, certainty and swiftness of the penalty (Ross, 1982). Specifically, severity refers to the perceived harshness of the punishment; certainty to the perceived probability of detection and punishment[6]; and, swiftness to the time elapsed between commission of an offence and administration of the punishment (Ross, 1982). While it may appear intuitive to assume that the deterrent effectiveness of a punishment might be positively associated with severity, research has revealed a critical threshold at which any further increase in severity results in diminished returns and indeed may be counterproductive (Elliott, 2003; Legge & Park, 1994; Ross, 1985). Research suggests a greater impact for policies and practices designed to increase the certainty and swiftness of punishment (Elliott, 2003; Legge & Park, 1994; Ross, 1985).

Using police speed enforcement as an example, speed cameras are effective in the sense that the punishment is relatively certain and many would argue the penalties are sufficiently severe. However, speed enforcement practices vary in regards to the swiftness of punishment. For example, infringement notices from speed cameras may take weeks to reach an offending driver. Thus, this form of punishment is not as swift as other police speed enforcement methods such as radar or laser use or routine traffic patrol where offending drivers are typically pulled over at the site of the offence. However, the punishment associated with these latter approaches may not be as certain because police are afforded discretion in the use of punishments and fewer motorists are exposed to such methods.

More recently, the classical approach to deterrence theory has been extended to include the concepts of punishment avoidance and vicarious learning (Stafford & Warr, 1993). While it is widely accepted that experiences with punishment affect future behaviour, extended deterrence theory proposes that the experience of punishment avoidance, or the absence of negative consequences associated with the commission of an offence, can also affect subsequent behaviour. As Stafford and Warr (1993; p.125) suggest: "offenders whose experiences are limited largely to avoiding punishment may come to believe that they are immune from punishment, even in the face of occasional evidence to the contrary". Moreover, the experience of punishment or punishment avoidance need not necessarily be experienced directly (Stafford & Warr, 1993). Indeed, the behaviour of an individual may be influenced by indirect experiences of peers or family members, through a process of vicarious learning. Indeed, research in the area of unlicensed driving and speeding has shown that experiences of punishment avoidance is a strong predictor of offending behaviour (Fleiter, 2004; Watson, 2004).

4. EVIDENCE OF THE EFFECTIVENESS OF SPEED CAMERAS

Despite the widespread global use of speed cameras as a police law enforcement tool for speed management, there is still much debate regarding the perceived effectiveness of such methods. According to Willis (2006; p.6), the logic behind speed cameras as an effective tool for reducing crash rates is simple: "if illegal speeds increase the risk of crashing and crash severity and if speed cameras reduce illegal speeds … then, all other things being equal, speed cameras should reduce speeding-related crashes and crash severity". Typically, studies review enforcement efforts at a

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[6] While the automated nature of speed cameras ensures that *punishment* is relatively certain, the overt nature and relatively low level of use produces a situation where, for many drivers, speeding behaviour more often than not goes undetected. Thus, the overall low perceived risk of *detection* may negatively influence the deterrent properties of approaches with certain punishments (Elliott, 2008). If a driver regularly speeds without detection than the perceived risk of punishment may become a far less important factor influencing their behaviour.

macro level. Thus the ability to precisely quantify the effects of speed cameras is problematic given that it is inherently difficult to partial out the impact of confounding factors, such as other enforcement operations and initiatives, changes to the road environment and general shifts in driver behaviour and attitudes. Thus, the task of providing recommendations regarding what works, or does not work, in police speed enforcement is inherently problematic (Harrison, 2001).

Nonetheless, a number of systematic reviews of the available literature have revealed evidence that speed cameras are an effective tool for reducing vehicle speeds in close proximity to camera locations and reducing road crash fatalities and casualties, particularly those that are speed-related (Harrison, 2001; Pilkington & Sanjay, 2005). Pilkington and Kinra (2005) systematically reviewed 14 observational studies, of which most employed a before-after methodology. Of these, six analysed the impact of fixed cameras, four the impact of mobile cameras and four the impact of both fixed and mobile cameras. The outcome variables of interest were road traffic collisions, deaths and injuries. All the reviewed studies suggested positive effects for speed cameras, however to varying degrees. Results revealed reductions in collisions between 5 and 69%, reductions in injuries between 12 and 65% and reductions in fatalities (in close proximity to camera sites) between 17 to 71%. In addition, reductions in fatalities over the entire road network were also reported in a number of studies. The authors, however, note the relatively poor methodological quality of a lot of the literature.

In a Cochrane Collaboration review, 26 studies evaluating the effectiveness of speed enforcement detection devices on speed and crash outcomes were reviewed (Wilson, Willis, Hendrikz, & Bellamy, 2006). Twenty-two of the reviewed studies employed controlled before-after studies, while four used interrupted time-series designs. Thirteen studies evaluated fixed cameras, eleven evaluated mobile cameras and two evaluated a combination of both. All but one study reported a reduction in mean vehicle speeds associated with speed enforcement. Reductions ranged from 1 to 15% for all vehicles and 14 to 65% for excessive speeders (greater than 15km/h over the speed limit), when compared to control locations. Those studies with crash outcomes all reported reductions associated with speed enforcement efforts. Injury crashes were reduced by 8 to 46%, fatal crashes by 40 to 50%, and all crashes by 14 to 72%. Diffusion of benefits across the entire road network was also noted in a number of studies.

Harrison (2001) also reviewed the evidence and made a number of interesting conclusions and recommendations. Firstly, he highlighted that speed cameras are typically associated with site-specific effects, particularly at fixed speed camera locations, and that time (less than 3 days) and distance (less than 5km downstream) halo effects are not uncommon. Specifically, halo effects occur when the impact of a speed camera on vehicle speeds extends beyond the site of the camera (distance halo effect) or speeds are impacted at the site even after removal of the camera (temporal halo effect). Secondly, a number of operational characteristics were argued to increase the effectiveness of speed camera programs including ensuring the program is highly intensive and operated in a random fashion, such that the locations and timing of enforcement operations are unpredictable. Thirdly, covert speed camera operations were argued to have few immediate impacts on vehicle speeds, however are associated with long-term reductions. Finally, the need for evaluations using more rigorous research designs was emphasised.

This section continues, reviewing the available evidence regarding the effectiveness of fixed and mobile cameras. The majority of evaluative studies reviewed here have been conducted in highly motorised countries using observational, before-and-after methodologies. In addition, it has been reported that methodological shortcomings are common in the literature, including such issues as inadequate comparison groups, a lack of control for confounding variables and regression-to-the-mean effects[7]. Moreover, in the sections that follow, alternative, non-automated approaches (e.g., hand-held and moving-mode radars and lasers, routine traffic patrol) to speed management will also be reviewed, as well as more innovative approaches (e.g., point-to-point camera systems and ISA) regarding their potential role in reducing speeds and crash rates.

4.1 Fixed cameras

As stated in Section 3, the implementation of fixed speed cameras in Australia is a relatively recent event. Thus, evaluation data analysing the impact of fixed speed cameras on vehicle speeds and crash rates is somewhat scarce. In a study conducted in New South Wales, the effectiveness of the fixed digital speed camera program was evaluated (ARRB Group Project Team, 2005). The study analysed 28 of the then 81 sites in the state where fixed cameras were operational. Results suggested significant reductions in vehicle speeds at the camera site at 24-month follow-up. Specifically, average vehicle speeds were reduced by 5.8km/h; the number of vehicles exceeding the speed limit by 71.8%; the proportion of vehicles travelling in excess of 10km/h over the speed limit by 87.9%; 85th percentile speeds by up to 20%; and, speed standard deviations by up to 40%. Distance halo effects were observed with much of the positive effect on vehicle speeds diminishing within two kilometres of the camera site.

The study also revealed significant reductions in crash rates associated with fixed cameras (ARRB Group Project Team, 2005). An analysis, controlling for regression-to-the-mean and the influence of confounding factors, revealed a number of positive crash effects at 24-month follow-up. Specifically, the following reductions in crash-related variables were observed at the camera sites: 89.8% reduction in fatal crashes; 22.8% reduction in fatal and serious injury crashes; 20.1% reduction in injury crashes; 16.9% reduction in property damage crashes; and, 19.7% reduction in all crashes;. While distance halo effects were observed, a 56.7% reduction in fatal crashes within a four-kilometre radius of the camera sites was observed. A number of diffusion of benefits were observed for both crash rates and vehicle speeds. Finally, the fixed camera program was found to be highly cost-effective, with a cost-benefit ratio of 3.4:1.

Fixed cameras have also been found to significantly reduce vehicle speeds in Victoria (Diamantopoulou & Corben, 2001). The cameras were located in a metropolitan tunnel, where deployment of alternative approaches to speed enforcement was not practical. Results found a reduction in average vehicle speeds of 2.6km/h; a 66% reduction in the proportion of vehicles exceeding the speed limit; and, a 79% reduction in the proportion of vehicles exceeding the speed limit by more than 10km/h. It has been argued that reductions in risk of crash involvement, particularly in the tunnel, should be expected as a consequence of these positive

[7] Regression-to-the-mean occurs when reductions in an outcome variable are attributed to an intervention but more accurately represent a regression of abnormally high levels to prior, more ‘normal’, levels.

effects on vehicle speeds (Delaney, Diamantopoulou, & Cameron, 2003). While fixed speed cameras are also used in Queensland, the program is yet to be formally evaluated.

To date, the majority of the research evaluating fixed speed cameras has originated from the United Kingdom, largely as a function of the more extensive use of the approach in the country[8]. A number of studies have also specifically compared the road safety impacts of mobile and fixed speed cameras. The generalisabilty of findings generated from studies conducted in the United Kingdom to the Australian context is somewhat questionable given the differences in criteria used to choose fixed camera locations. That is, Australian criteria are typically more stringent, with camera deployment generally restricted to crash black-spots. Nonetheless, the study raises relevant issues relating to the deployment of speed cameras in Australia and highlights the potential road safety benefits associated with fixed speed camera implementation.

In a national study, the use of both fixed (502 sites) and mobile (1,448 sites) speed cameras was evaluated for the period 2000 to 2004 (Gains et al., 2005). The analysis revealed significant reductions in both vehicle speeds and crash rates associated with both types of cameras, however larger effects were observed in relation to fixed cameras. Specifically, results showed an overall 6% reduction (2.2mph) in average vehicle speeds at camera sites (15% at fixed sites and 3% at mobile sites); a 7% reduction in 85th percentile speeds (18% at fixed sites and 3% at mobile sites); a 31% reduction in the number of vehicles exceeding the speed limit (70% at fixed sites and 18% at mobile sites); and, a 51% reduction in the proportion of vehicles travelling more than 15mph over the speed limit (91% at fixed sites and 36% at mobile sites). The findings are consistent with previous reviews highlighting the localised effects of speed cameras.

Positive impacts on crash rates were also reported in association with the use of both types of speed cameras (Gains et al., 2005). Overall, there was a reduction of 42.1% in the number of fatality and serious injury crashes at camera sites (49.5% at fixed sites and 34.6% at mobile sites); 22.3% for other injury crashes (23.6% at fixed sites and 20.9% at mobile sites); and 32% for fatalities (29% at fixed sites and 35% at mobile sites). The authors argue that these effects, while undoubtedly influenced by regression-to-the-mean, remain substantial even when accounting for this bias. Furthermore, reductions in both vehicle speeds and crash rates appeared to be sustained over time. Finally, the use of speed cameras was found to be cost-effective, with a cost-benefit ratio of 2.7:1. In a similar study comparing the impact of fixed versus mobile speed cameras from evaluations conducted throughout the world, both approaches were again found to result in injury crash reductions (Decina, Thomas, Srinivasan, & Staplin, 2007). However, fixed cameras were found to result in smaller reductions (20-25%) compared to mobile cameras (21-51%).

Also in the United Kingdom, a series of studies evaluating the impact of 62 fixed speed camera sites found positive effects on vehicle speed and crash rates (Mountain, Hirst, & Maher, 2004a, 2004b). Reductions in all measures of vehicle speeds were found, including a 4.4mph reduction in mean speeds; 5.9mph reduction in 85th percentile speeds; and, 35% reduction in the proportion of vehicles exceeding the speed limit. Reductions in vehicle speeds were evident up to one kilometre before and after the camera location. Controlling for regression-to-the-mean

[8] Mobile speed cameras still represent close to three-quarters of the operational cameras in the United Kingdom (Gains, Nordstrom, Heydecker, & Shrewsbury, 2005).

effects the authors found a non-significant 11% reduction in fatal and serious injury crashes and a significant 25% reduction in injury crashes associated with the fixed cameras[9].

However, in another study conducted in the United Kingdom, three sites with speed limits ranging from 40 to 60 mph where fixed cameras operate were evaluated (Keenan, 2004). Results revealed significant distance halo effects, with the cameras having only localised effects. Specifically, the proportion of vehicles exceeding the speed limit 500 metres prior to the camera ranged from 38% to 79%, decreasing to between 9% and 22% adjacent to the camera, before increasing to between 45% and 81% 500 metres after the camera. A similar pattern of results was found for mean vehicle speeds, 85th percentile speeds and the standard deviation of traffic speeds. In addition, no discernable changes in rates of overall collisions or fatal and serious injury crashes were observed at the camera sites. While the study reported that drivers manipulated their speeding behaviour in close proximity to the camera site and engaged in potentially risky behaviours (e.g., suddenly applying brakes a short distance before the camera and accelerating sharply after passing the camera), other studies have failed to observe such effects (Mountain et al., 2004a, 2004b).

In another study conducted in the United Kingdom, the impact of 49 fixed speed camera sites on the frequency of injury crashes, independent of trends and seasonality, other time-dependent factors and regression-to-the-mean, was evaluated (Hess & Polak, 2004). The study analysed data between 1990 and 2002 and produced estimates at varying distances from the camera sites. The greatest significant estimated reductions were recorded in the immediate vicinity of the camera sites, with injury crashes reduced by 45.7% within 250 metres and 41.3% within 500 metres. Lower, but still significant, estimated reductions were also reported further from cameras, with 31.6% fewer injury crashes within 1000 metres and 20.9% fewer within 2000 metres.

Fixed speed cameras have also been evaluated elsewhere. In the United States, the effectiveness of the implementation of a fixed speed camera on a freeway in Arizona was evaluated in regard to the impact on vehicle speeds and crash rates (Shin, Washington, & van Schalkwyk, 2009). Results revealed localised reductions in average vehicle speeds of 9mph and an associated reduction in speed dispersion. In addition, overall crash rates were reduced by up to 54%, injury crashes by up to 48% and property damage crashes by up to 56%. Earlier results from a pilot evaluation of fixed speed cameras along the same stretch of highway also revealed positive effects on vehicle speeds, with an 88% reduction in vehicles travelling in excess of 11mph over the speed limit (Retting, Kyrychenko, & McCartt, 2008). In both studies, time and distance halo effects were observed, with traffic speeds increasing again after cessation of enforcement activities and effects localised at the camera site. Finally, in Spain, the impact of fixed speed camera use on traffic crashes in Barcelona was analysed (Pérez, Marí-Dell'Olmo, Tobias, & Borrell, 2007). A time-series analysis revealed the relative risk (RR) of a traffic crash upon implementation of the cameras was 0.73 (95% CI =0.63, 0.85) compared to before the cameras were implemented. This equated to the prevention of 364 crashes and 507 fewer injuries over a two-year period.

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[9] In regard to fatal and serious injury crashes, 6% was attributed to reductions in vehicle speed associated with the cameras and 5% with drivers choosing alternate routes to avoid roads with fixed speed cameras. In regard to injury crashes, 20% was attributed to the reductions in vehicle speed associated with the cameras and 5% with drivers choosing alternate routes to avoid roads with fixed speed cameras.

In summary, there is growing evidence of the effectiveness of fixed speed cameras in reducing vehicle speeds and crash rates; however effects tend to be highly localised to the camera site. Nonetheless, fixed cameras located at crash black-spots and locations with speed-related problems have the potential to provide significant road safety benefits. Moreover, there is evidence to suggest a greater magnitude of effects on key road safety outcomes associated with the use of fixed cameras compared to mobile speed cameras. That said, the methodological quality of the majority of the research is poor and there is a fundamental need for more rigorously designed studies to bolster the evidence regarding the impact of fixed speed cameras. The following section reviews the available literature regarding the impact of mobile speed cameras.

4.2 Mobile speed cameras

Considerably more research has been conducted evaluating the impact of mobile speed cameras on vehicle speeds and crash rates. Similar to the research investigating the effect of fixed cameras, there are numerous methodological issues that have reduced the reliability of findings. Nonetheless, the overall consistency of the findings is promising. While direct comparisons between studies conducted in various jurisdictions are difficult, due to a number of important operational differences (e.g., mobility and visibility of operations), the evidence provides a meaningful starting point. As noted above, there is a critical need for more scientifically rigorous research in the area.

A number of studies have evaluated the introduction of overtly operated mobile speed cameras in Queensland (Newstead, 2009; Newstead & Cameron, 2003). Most recent data suggests that mobile speed cameras operated in the state have been associated with reductions in crash rates within close proximity of the camera location. Specifically, reductions of 40.4% in fatal crashes and crashes requiring hospital admissions, 25% in injury crashes, 50.7% in crashes requiring medical treatment, 4.8% in non-injury crashes and 31.2% in crashes of any level of severity, have been reported (Newstead, 2009). These reductions represent 8746 fewer crashes of any level of severity and a saving in social costs of $1.8 billion. Similar results were reported in an earlier study evaluating the first four years of the program (Newstead & Cameron, 2003). A number of operational variables were reported to strongly influence the effectiveness of mobile speed cameras, including more intensive use of the cameras and full randomness of camera deployment. Finally, the use of mobile speed cameras was found to be cost-effective, with a cost-benefit ratio of 47:1 (Newstead & Cameron, 2003).

In Victoria, covert operation of mobile speed cameras, including an increase in operational hours and a decrease in enforcement tolerance, has been reported to be an effective tool in reducing crash frequency and severity on urban and open roads (D'Elia, Newstead, & Cameron, 2007; Delaney et al., 2003). Specifically, the use of the cameras was reported as being associated with a 3.8% reduction in casualty crashes across Victoria, 4.8% reduction in metropolitan Melbourne and a reduction in risk of fatal crashes. The current speed enforcement program in Victoria has also been found to be highly cost-effective. A series of earlier studies also found evidence of positive impacts. Specifically, operations of low enforcement intensity were found to significantly reduce low-alcohol casualty crashes on arterial roads by 15% (Cameron, Cavallo, & Gilbert, 1992). Moreover, increasing the publicity associated with operations led to reductions in low-alcohol times of 32%, as well as reductions in crash severity and the proportion of vehicles travelling in excess of 15km/h over the speed limit (Rogerson, Newstead, & Cameron, 1994). However it should be noted that early trials of overt speed camera operation in Victoria revealed limited effects on crash rates and produced only localised effects on vehicle speeds (Delaney et al., 2003).

In a controlled, before-and-after study conducted in the United Kingdom, the impact of mobile speed cameras on traffic crash injuries was analysed (Christie, Lyons, Dunstan, & Jones, 2003). Two methods[10] were used to evaluate the impact of the use of mobile cameras at 101 sites on crash rates, using matched sites from a neighbouring police district with minimal speed camera use as a comparison area. Using a circular zone method, a significant crash reduction of 73% in comparison to expected rates was reported within 100 metres of the camera, as well as 24% between 100-300 metres. This equated to 85 fewer injurious crashes within 100 metres and 61 fewer within 100-300 metres. No effect was found outside of 300 metres. Using the route method, significant crash reductions were found up to 500 metres from the camera location, with all crashes reduced by 51%. For both methods the greatest impact was found within 100 metres of the camera site suggesting distance halo effects.

In a series of studies conducted in British Columbia, Canada (Chen, Meckle, & Wilson, 2002; Chen, Wilson, Meckle, & Cooper, 2000), visible speed camera operations were evaluated using traffic speed data collected from induction loops in the road and using multiple analytical approaches including before-and-after, time-series and cross-sectional analyses. The first-year evaluation revealed a reduction in the number of speeding vehicles at camera sites from 66% to 33%, and an even larger reduction in excessive speeding[11] from 10.5 to 2.6%, at one-year follow-up. At camera sites there were significant reductions in mean vehicle speeds of 2.4km/h. Furthermore, there was a 25% reduction in daytime speed-related collisions and a 17% reduction in daytime traffic fatalities. Finally, diffusion of benefits effects were reported, with a reduction in the number of speeding vehicles across the entire road network, from 69 to 61% for all vehicles and 24 to 14% for excessive speeders.

Jones, Sauerzapf and Haynes (2008) analysed the impact of mobile speed camera operations on crash rates in a rural English county. The before-after study analysed crash data at 29 camera sites two years prior to, and following implementation, controlling for regression-to-the-mean effects. In addition, crash rates from the remainder of the county were used as a comparison. Results showed significant reductions in total crashes (19%) and fatal and serious injury crashes (44%), equating to an estimated 23 fewer crashes and 12 fewer killed or seriously injured road users. In a similar study conducted in the Netherlands, the impact of mobile speed cameras on vehicle speeds and crashes was assessed (Goldenbeld & van Schagen, 2005). Over a five-year period

[10] Crash rates were analysed using two approaches: circular zones and a route method: "Circles of radius 100, 300, 500, and 1000 metres were drawn around each site, along with similar route lengths. Routes were extended in both directions to the set distance (100, 300, 500, or 1000 metres), but terminated 60 metres short of any roundabout, T-junction, or other major junction that would cause traffic to slow or stop. Any portions of either the circles or routes polygons that overlapped any other polygon with an earlier camera deployment date were excluded to avoid double counting or misclassification of before-after status of crashes" (Christie et al., 2003; p.303).

[11] Travelling 16km/h or more over the posted limit.

following the introduction of the enforcement efforts there was a significant gradual decline in mean speeds and an estimated 21% reduction in traffic crash injuries. A diffusion of benefits effects across the entire road network was also found.

Finally, in Norway, increased use of mobile speed cameras and speed radars implemented in a randomised fashion across a 35 kilometre section of road was evaluated, using a nearby similar stretch of road as a comparison site (Vaa, 1997). Results showed reductions in mean vehicle speed of between 0.9 and 4.8km/h and a reduction in the proportion of speeding drivers. Moreover, a diffusion of benefits was reported in a number of locations that lasted as long as eight weeks.

4.2.1 Comparison of overt versus covert approaches

A number of studies have attempted to compare the effects associated with speed enforcement operations of varying degrees of visibility. Typically, this operational characteristic has been evaluated in association to mobile speed camera use, and thus warrants discussion here. In Victoria, a study directly compared the effect of overt and covert speed camera operations (Diamantopoulou & Cameron, 2002). While evidence suggests casualty crash reductions in relation to either approach, optimal benefits were reported where either covert, or a mixture of covert and overt operations, were used. The most significant crash reductions (71.3%)[12] were observed when a combination of approaches was used and accompanied by highly visible public education. Similarly, a series of studies conducted in New Zealand (Keall, Povey, & Frith, 2001, 2002) suggested that covert operations combined with public education campaigns produced net falls in vehicle speeds and casualty crashes larger than those associated with highly visible enforcement operations. However, a number of methodological shortcomings were highlighted by the authors including inappropriate comparisons, a lack of control for confounding variables and regression-to-the-mean.

Similarly, in North Carolina, the impact of mobile speed cameras, operated with varying degrees of visibility, were evaluated (Dowling & Holloman, 2008). Operation differed in regards to the use of marked versus unmarked vehicles as well as the level of conspicuousness in speed camera vehicle placement (e.g., hidden behind existing infrastructure or in plain sight)[13]. Vehicle speeds were measured in terms of absolute reductions one mile after passing the camera compared to one mile before, somewhat controlling for distance halos effects. Results revealed reductions associated with speed enforcement efforts regardless of the nature of visibility. Vehicle speed reductions were greatest when speed camera vehicles were positioned inconspicuously (-6.1mph for marked vehicles and -5.0mph for unmarked vehicles). Moderate effects were found for somewhat inconspicuous placement of both marked and unmarked vehicles (-3.4mph and –2.5mph, respectively). Finally, conspicuous positioning of marked and unmarked vehicles were associated with the lowest reductions in vehicle speeds (-0.7mph and –1.5mph, respectively).

[12] Failing to control for confounding factors.

[13] Regardless of the level of visibility and conspicuousness, the speed camera vehicle was intended to be clearly visible when drivers were adjacent to the camera.

In summary, while there are numerous methodological shortcomings evident in the current literature, the general consistency in the direction of results is promising. Overall, there is growing evidence suggesting that mobile speed camera operations are effective in reducing vehicle speeds and crash rates. Moreover, like other automated stationary approaches, distance halo effects are common and effects largely localised. Recent evidence has suggested that increasing the covert nature with which operations are conducted can produce additional benefits, and there is some evidence to suggest inconspicuous placement of marked speed camera vehicles (e.g., semi-covert) may produce optimal benefits. In addition, operations that are intensive and scheduled to random locations across the road network, so to increase unpredictability, have also been found to be more effective. Finally, there is some evidence to suggest that high levels of publicity associated with mobile speed camera operations can help to increase the effects of operations. There is a fundamental need for more rigorously designed studies examining the impact of mobile speed cameras. The following section reviews evidence regarding the effectiveness of alternative approaches to speed enforcement, including both more traditional and innovative approaches.

5. ALTERNATIVE APPROACHES TO SPEED ENFORCEMENT

A number of alternative approaches are available to police when conducting speed enforcement operations. Indeed, the more traditional use of routine traffic patrols and the use of less automated technologies, such as hand-held and moving-mode radars, form a critical element of the overall speed management program in all jurisdictions. Moreover, advances in technology have also resulted in more innovative approaches to speed management such as point-to-point speed cameras, intelligent speed adaptation (ISA) and vehicle-activated signs (VAS). The following section will review the evidence regarding these approaches.

5.1 Traffic patrol and radar/laser use

Few evaluation studies have been conducted specifically evaluating the impact of traffic patrols on speed-related outcomes. In addition, there is a paucity of research evaluating less automated technologies such as hand-held and moving-mode radars. In Victoria, an evaluation of hand-held radar operation was found to produce reductions in crash frequency, but not severity, on urban roads (Diamantopoulou, Cameron, & Shtifelman, 1998). It was reported that the overt nature of this type of enforcement was found to be associated with relatively localised effects on vehicle speeds. In addition, the use of moving-mode radar devices, whether used covertly or as a mixture of covert and overt operations, were found to be effective in reducing casualty crashes on open roads in rural areas; however their effect in more metropolitan areas was reported to be negligible (Diamantopoulou et al., 1998).

In Queensland, the Random Road Watch Program, developed from an American model of police patrols, was evaluated (Newstead, Cameron, & Leggett, 1999). The program involved the deployment of highly visible police patrols according to a random schedule. While not solely restricted to speed enforcement (e.g., targeted other risky driving behaviours also), the program produced a number of positive effects on crash outcomes. By the third year of the program, reductions in fatal crashes (33%), injury crashes (25%) and non-injury crashes (22%) were reported. This equated to 2749 fewer traffic crashes in the third year of implementation and a saving of $163 million in crash-related costs. It was suggested that widespread use of such a program at low to medium intensity, compared to more intense efforts in fewer areas would increase the positive crash effects of the program.

The Queensland Road Safety Initiatives Package (RSIP) developed by Queensland Transport, in conjunction with the Queensland Police Service, has also been evaluated (Newstead, Bobevski, Hosking, & Cameron, 2004). The RSIP incorporated enforcement, including increased speed camera operation and routine traffic patrols targeting high-risk behaviours such as speeding, drink driving, fatigue, and restraint use, as well as public education campaigns. Results suggested significant reductions in fatal and hospital admission crashes (13.1%), crashes requiring medical treatment (14.2%) and overall crashes (8.8%). These reductions equated to significant estimated monthly crash savings for fatal and hospital admission crashes (-45), medically treated crashes (-60) and all crashes (-147). The speed camera program was reported as providing the greatest road safety benefits of all components of the RSIP, with social costs estimated as being reduced by over $235 million.

5.1.1. Comparison of stationary versus moving approaches

A number of studies have attempted to analyse the differential impact of automated versus non-automated approaches to speed enforcement. In a recent study conducted in Queensland, Tay (2009) examined the impact of automated and non-automated speed enforcement efforts on all crashes and serious injury crashes, based on infringement issuing data. Results suggested that non-automated approaches resulted in significant reductions in both total and serious crashes, while automated approaches affected only total crashes. Tay suggested that the differential impact was a result of non-automated approaches being responsible for the detection of significantly more young, male offenders who are likely to exceed the speed limit by greater amounts and whose crashes typically result in more severe consequences. Thus, non-automated approaches appear to have stronger specific deterrent impacts, targeted at high-risk offenders. Conversely, automated approaches typically exert a more general deterrent impact.

A number of studies have provided evidence of halo effects associated with highly visible speed camera operations (Champness, Sheehan, & Folkman, 2005; Delaney et al., 2003). In Queensland, analysis of the halo effects associated with deployment of a mobile speed camera on a section of highway with a 100km/h speed limit revealed that, while significant reductions in the number of speeding vehicles (53 to 16%) and mean speeds (6%) were observed, these effects were limited to the immediate vicinity of the operational camera. Indeed, the impact of the camera on vehicle speeds had completely dissipated within 1,500 metres of the camera location. In addition, there was no evidence of a time halo effect. Similarly, in Victoria, early trials of overt speed camera and hand-held laser operation revealed only limited effects on crash frequency and localised effects on vehicle speeds in the immediate vicinity of the enforcement location (Delaney et al., 2003; Diamantopoulou et al., 1998).

5.2 Innovative approaches to speed management

5.2.1 Point-to-point speed cameras

Point-to-point speed enforcement involve a series of cameras installed at multiple locations along a section of the road network enabling the measurement of average vehicle speeds over that distance. Typically, the cameras are fixed to existing gantries or roadside structures and distances between camera banks can be up to 50 kilometres and beyond (Cameron, 2008; Cameron & Delaney, 2006; Harris, 2005). An image and data are recorded for each vehicle as it enters the system and then again at subsequent cameras in the system and matched using Automatic Number Plate Recognition (ANPR) and Global Positioning System (GPS) technologies. The data from at least two points are then used to calculate the average speed of the vehicle by dividing the time taken to travel through the two points by the specific distance between the two points. If the average speed of the vehicle exceeds the posted speed limit for that section of road[14] the offending vehicle is issued an infringement notice by the relevant authorities (Cameron, 2008; Cameron & Delaney, 2006; Kursius, King, & Russo, 2003).

The premise of point-to-point speed enforcement as a deterrent to speeding is that it encourages drivers to reduce speed and comply with the speed limit over a longer section of the road network (Barker, 2005). Thus, this approach may be a more effective option for producing network-wide effects in reducing speeds and related crashes than fixed or mobile speed cameras. Camera locations are typically chosen based on crash and speed criteria and sections of roads with limited opportunities or incentives for access or egress and are operated in an inherently overt manner. The approach has been found to be highly technologically reliable (Aspect Traffic, 2006; Ellis, 2002; Parliamentary Travelsafe Committee, 2008). While point-to-point speed enforcement has been reported as a comparatively expensive approach to speed management (Cameron, 2008), there is evidence suggesting that this approach can be cost-effectivene (Cameron, 2008; Dalbert, 2001; Palmer, 1999; Stefan, 2006).

A number of countries are currently using, have trialled, or have intentions to implement point-to-point enforcement systems. The technology was first implemented in the Netherlands in 1997, however the use of the technology is most extensive in the United Kingdom. The systems are also widely used throughout other European nations (Soole & Watson, 2009). In Australia, the approach is currently only used in a formal manner in Victoria; however Queensland is currently in the stages of implementing a system located on a 13km stretch of the Bruce Highway on the Sunshine Coast. Use of the technology began in April 2007 on a stretch of the Hume Highway outside of Melbourne at a site chosen due to the high fatal crash rate. The system involves five camera banks that monitor speeds along four contiguous sections over a 54 kilometre length of the highway (Cameron, 2008). In addition, point-to-point cameras are also currently being trialled in New South Wales and there are plans to implement the technology in South Australia, the Australian Capital Territory and Western Australia.

There is consistent evidence suggesting the positive impact of point-to-point speed enforcement on vehicle speeds, crash rates and a number of other key road safety outcomes. However, the

[14] Typically, point-to-point systems are operated with an enforcement tolerance, however this varies by jurisdiction.

findings should be considered in light of the poor standard of methodological quality evidenced in the majority of studies. Nonetheless, the consistency of the evidence is promising. Specifically, the approach has been found to be associated with reductions in average and 85th percentile vehicle speeds, as well as attaining exceptional rates of compliance (in excess of 90%) with speed limits (A77 Safety Group, 2008; Autostrade per l'Italia, 2009; Collins & McConnell, 2008; Gains et al., 2005; Galata, 2007; Malenstein, 1997; Speed Check Services, 2009; Stefan, 2005, 2006; Stevens, 2007; Transport Scotland, 2009).

Moreover, point-to-point speed enforcement has been found to have a positive impact on crash rates. Specifically, reductions in fatal and serious injury crashes between 30% and 85% have been reported, while other injury crashes have been shown to be reduced by 15% to 60% (A77 Safety Group, 2008; Autostrade per l'Italia, 2009; Barker, 2005; Collins & McConnell, 2008; Galata, 2007; Keenan, 2002; Speed Check Services, 2009; Stefan, 2006). In addition, average speed enforcement has been shown to improve traffic flow (Collins, 2007; Collins & McConnell, 2008; Schwab, 2006), reduce traffic noise and vehicle emissions (Collins, 2007; Collins & McConnell, 2008; Stefan, 2005; Stoelhorst, 2008), and is associated with high levels of public acceptance (Malenstein, 1997; Stefan, 2005; van Schagen, Wegman, & Roszbach, 2004). For a comprehensive review of point-to-point speed cameras, the reader is directed to see Soole and Watson (2009).

5.2.2 Vehicle Activated Signs (VAS)

Vehicle-activated signs (VAS) are a specific variation of variable message signs (VMS)[15]; electronic signs used to display dynamic, changeable messages (Soole, Smith, Lewis, & Rakotonirainy, 2009). Typically, such signs cover issues more pertinent to the immediate driving environment than static road signs. The signs can be either stationary or portable, with stationary systems typically fitted to overhead gantries or existing fixtures and mobile systems mounted on trailers or similar portable structures. Information displayed may be represented by text characters or pictograms (e.g., symbols) and sequential messages of numerous frames or phases can be presented[16]. VAS involves message presentation triggered by vehicles, typically via loops and detectors placed below the driving surface[17].

More recently, this type of technology has been implemented to measure vehicle speeds, for the purpose of presenting speed-related safety messages to offending drivers. The distinguishing feature of VAS compared to traditional VMS is the enhanced ability to target road safety related messages at particular vehicles. This can be achieved through appropriate timing of displayed messages or through the accompanied use of ANPR technology to directly identify specific vehicles. Typically, messages have employed "you" statements to target offending drivers and rule sets are used to ensure that messages are only presented to offending drivers when there are no non-offending vehicles within the legibility distance of the VAS.

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[15] Variable message signs are also commonly referred to as changeable, dynamic or electronic message signs; matrix signs; electronic traffic signs; electronic information sign; or dynamic traffic control.

[16] Full a comprehensive review of best practice in the implementation of VMS and VAS, see Soole et al. (2009).

[17] Radar devices can also be used.

A number of studies have evaluated the impact of VAS on vehicle speeds. A Queensland trial of a VAS system using loop detectors and displaying infringement penalty information revealed reductions in average vehicle speeds and the proportion of vehicles exceeding the speed limit, however effects gradually decreased over the course of the trial and shifted to pre-trial levels following the cessation of the trial (Peters & Troutbeck, 2009). A number of evaluations conducted elsewhere throughout the world have also shown evidence of reductions in average and 85th percentile speeds, and the proportion of speeding vehicles. These findings have been found for a variety of message presentation formats, as well as for systems using loop detectors and radar devices (Garber & Patel, 1994; Mattox, Sarasua, Ogle, Eckenrode, & Dunning, 2007; Tribbett, McGowen, & Mounce, 2000; Wang, Dixon, & Jared, 2003; Winnett & Wheeler, 2002).

A number of studies have highlighted the ancillary benefits associated with identifying specific vehicles, generally through the use of ANPR technology to present messages in conjunction with number plate details (Casey & Lund, 1993; Comte & Jamson, 2000; Fremont & Lacrampe, 2004; Garber & Patel, 1995; Helliar-Symons, Wheeler, & Scott, 1984; Olsen, 1998; Tropic, 1996). In addition, a number of evaluations have shown that systems presenting actual vehicle speeds to drivers can also produce vehicle speed reductions (Fontaine & Carlson, 2001; McCoy, Bonneson, & Kollbaum, 1995; Pesti & McCoy, 2001a, 2001b; Rose & Ullman, 2003; Ullman & Rose, 2005), although others have highlighted the potential for drivers to abuse this feature (Mattox et al., 2007). The presentation of positive messages (e.g., the proportion of drivers *not* speeding) has also been found to produce reductions in vehicle speeds (Groeger & Chapman, 1997; Ragnarsson & Bjorgvinsson, 1991). Overall, VAS have also been found to have a positive influence on driver attention (Luoma, Rämä, Penttinen, & Anttila, 2000; Nygardhs & Helmers, 2007; Rämä, 2001; Rämä & Kulmala, 2000).

5.2.3 Intelligent Speed Adaptation (ISA)

Police speed enforcement is only one aspect of the speed management program in most jurisdictions. Other elements are also important, including community initiatives, media and public education campaigns and intelligent transportation systems (ITS). The premise of ITS in relation to speed management is to effectively modify driver behaviour and manage vehicle speeds, rather than enforce speed limits through deterrence and threats of punishment. Intelligent Speed Adaptation (ISA) technology is one such ITS approach that has shown the potential to result in positive changes in driver speed choice through increased driver awareness of speed limits. Such a shift in behaviour can subsequently be expected to result in reductions in the incidence and severity of speed-related traffic crashes.

There are a number of approaches to ISA systems. The use of global positioning system (GPS) technology and databases of digital road maps and speed zone data are common to all types of ISA systems. This information is processed and an in-vehicle interface continuously displays the current speed limit and prompts the driver in instances where the speed limit is violated. However, ISA systems differ regarding the extent to which they intervene when a driver intentionally or inadvertently drives at a speed above the posted limit. Typically, there are three approaches adopted by the Australasian Intelligent Speed Assist Initiative (AISAI). Advisory systems remind drivers of the prevailing speed limit, typically through visual and auditory prompts, however the system exerts no control over the vehicle. Supportive systems provide some degree of vehicle-initiated limiting of speed however allows the driver to override the system. Finally, limiting systems involve vehicle-initiated speed limiting devices that cannot be overridden by the driver. The potential application of the technology for recidivist speeding offenders has been suggested (Watson et al., 2009). Systems can be equipped with an on-board computer that records data regarding violations, including speed, time and location.

Trials of ISA technology have been conducted in various countries across the world, including Australia, numerous European nations, Spain and Japan. In Australia, trials of ISA technology have been undertaken in Victoria (TAC SafeCar Project). Implementation of ISA technology has been found to be cost-effective (Carsten & Tate, 2005; Marchaua, van der Heijden, & Molin, 2005) and highly reliable and also well accepted by drivers (Katteler, 2005; Paatalo, Peltola, & Kallio, 2002; van Loon & Duynstee, 2001). However, vehicle manufacturers have been reluctant to seriously consider the implementation of the technology in vehicles (Goodwin, Achterberg, & Beckmann, 2006), most likely because of the low public acceptability of intervening systems which are most effective (Carsten & Tate, 2005). A number of studies have shown that ISA technology (both advisory and more intervening systems) is associated with reductions in average and 85th percentile speeds, speed variation, and proportion of time spent speeding, with greater reductions generally associated with limiting systems compared to advisory systems (Agerholm, Tradisauskas, & Lahrmann, 2009; Almqvist & Nygard, 1997; Biding & Lind, 2002; Duynstee, Katteler, & Martens, 2001; Harms et al., 2008; Lahrmann, Madsen, & Boroch, 2001; Lind, 2000; Paatalo et al., 2002; Sundberg, 2001).

Reductions in traffic crashes have also been found to be associated with ISA implementation. A number of studies have suggested that extensive market penetration of ISA can result in significant crash reductions. Specifically, widespread implementation of advisory systems in the United Kingdom is estimated to reduce injury crashes by up to 13%, fatal and serious crashes by up to 18% and fatal crashes by up to 24% (Carsten & Tate, 2005). Moreover, estimated reductions are even more encouraging for the supportive (up to 18%, 26% and 32%, respectively) and limiting variants of ISA (up to 36%, 48% and 59%, respectively) systems. Specific evaluations have reported reductions in injury and fatal crashes of up to 40% and 59%, respectively (Carsten & Fowkes, 2000; Marchau & van der Heijden, 2003; Oei & Polak, 2002; Varhelyi & Makinen, 2001). In addition, ISA has also been shown to produce reductions in fuel consumption and subsequently harmful traffic emissions (Carsten & Tate, 2005; Lui & Tate, 2004; Servin, Boriboonsomsin, & Barth, 2006) and increase driver awareness of speed limits (Agerholm et al., 2009; Biding & Lind, 2002).

Finally, other ITS approaches, such as Adaptive Cruise Control (ACC), are also becoming more popular. The first ACC systems became available in the mid 1990s as a supplement to existing standard cruise control devices. The technology extends on standard systems by adapting the selected vehicle speed to adjust for the speed of the vehicle in front, such as to maintain safe following distances. Evidence of the effectiveness of ACC on vehicle speeds is not yet fully established, however, the systems have the potential to increase the homogenisation of traffic speeds and promote safer following distances, and if used in conjunction with collision-avoidance systems, represent a promising approach to crash-reduction in-vehicle technology (Kallberg et al., 2008).

5.3 Limitations

Numerous methodological shortcomings have been highlighted in the study of the impact of speed cameras and other approaches to speed enforcement. One of the most important factors regularly cited as reducing the reliability of speed camera evaluations is regression-to-the-mean (Willis, 2006). This factor is particularly pertinent to speed cameras, which are routinely implemented at sites with increased crash histories. In addition, confounding variables such as the influence of other concurrent road safety interventions, media campaigns and overall changes in driver attitudes are difficult to control. Thus, quantifying the precise contribution of speed enforcement efforts to observed changes in outcome variables is inherently problematic. While researchers acknowledge a number of significant methodological shortcomings present in many evaluative studies, the consistent positive findings suggest that any methodological errors are unlikely to negate the direction of the observed effects.

6. DRIVER PERCEPTIONS OF SPEED ENFORCEMENT

Undoubtedly, the fundamental outcomes from which to assess the effectiveness of speed enforcement operations are the impact on vehicle speeds and traffic crashes. However, it has been suggested that driver perceptions regarding enforcement practices also represent an important source of information, such that enforcement operations deemed to be transparent and legitimate will encourage greater compliance (McKenna, 2005; Soole et al., 2008). Moreover, the specific characteristics of speed camera implementation are critical to ensuring public support. Indeed, according to Willis (2006; p.7), inappropriate implementation of speed cameras can “offend drivers to such an extent that public opposition leads to the program’s demise”.

A number of studies have directly assessed driver attitudes toward fixed speed cameras. In New South Wales, four surveys conducted with 750 randomly selected drivers from metropolitan and rural areas between 2000 and 2002 revealed a number of interesting findings (Road Traffic Authority, 2003). Knowledge of the fixed speed camera program increased over the period from a high initial figure of 64% to 82%. Consistent with previous research highlighting paradoxical attitudes regarding speed (Fleiter & Watson, 2006), while more than 50% of respondents believed the cameras would have a positive impact on crash rates, as many as 45% also suggested the cameras were a revenue raising tool.

Similarly, more recent findings (ARRB Group Project Team, 2005) suggest increasing exposure to, and awareness of, the cameras. Unprompted answers to the perceived purpose of fixed cameras showed that most respondents (as many as 55%) reported ‘reducing speeds’, ‘reducing crashes’ or ‘improving road safety’ as the predominate function of the cameras. Conversely, only between 15 and 25% suggested the cameras primary role was revenue-raising. A greater proportion of respondents (average of 45%) were likely to report speeding infringements issued as a result of the cameras to be a revenue-raising mechanism. Overall, acceptance of fixed speed cameras was found among approximately 75% of respondents.

In the United Kingdom, there is evidence of public support for speed cameras, both fixed and mobile (Gains et al., 2005). Specifically, driver surveys have revealed that as many as 71% of respondents report that the primary purpose of speed cameras is to reduce fatalities. Similarly, Corbett (1995) found that 57% of all drivers were content with the current level of speed camera operation, 24% believed more cameras would be beneficial, while 16% stated that fewer cameras were needed. Greater proportions of drivers observed at lower travelling speeds reported a perceived need for more cameras, while the opposite was found for drivers observed travelling at greater speeds. Overall, 64% of drivers agreed that speed cameras reduce crashes in the immediate vicinity of the camera site and 68% believed that speeding drivers had equal chances of being detected.

In a policy review, Willis (2006) reported that high levels of public acceptance of fixed cameras have been found in association with the use of the method at crash black-spot locations, however driver acceptance is considerably lower at locations perceived to be low-risk. In relation to mobile speed camera operations, he argues while many drivers approve of covert operations in principle, there is a tendency for the approach to be viewed as predominately serving a revenue-raising mechanism rather than a road safety benefit.

A number of factors make enforcing the exact speed limit difficult including inconsistent variations in vehicle speedometers and the calibration of speed detection equipment. As a result, most jurisdictions use an enforcement tolerance level, which allows drivers to be detected a specific margin above the posted speed limit within which they will not be cited for a speeding offence (Fildes et al., 2005). In some jurisdictions, this level is publicly available, however in other states, such as Queensland and Victoria, the exact tolerance is not publicised (Elliott, 2001). Not making this information publically available to drivers is designed to ensure that a de facto speed limit is not created and that the onus remains with drivers to travel at the posted speed limit. Research indicates that perceived enforcement tolerances have an impact on preferred driving speeds. Indeed, data from a recent national survey suggests that 53% of Queensland participants reported the belief that speeds of at least 65 km/hour in a 60 km/hr zone are tolerated by police, and 21% reported the belief that 110 km/hour in a 100 km/hour zone is tolerated (Pennay, 2008). In addition, a survey of preferred driving speeds among Queensland drivers revealed a general preference for speeds approximately 10% above posted speed limits, with perceptions of enforcement tolerance levels one of the leading reasons why respondents reported driving above posted speed limits (Fleiter & Watson, 2006; Fleiter, Watson, Lennon, King, & Shi, 2009).

A number of implementation strategies for best practice have been reported to increase driver acceptance (Cameron et al., 2003). Firstly, speed cameras must be accurate, reliable and must not represent the entire approach to speed management. Secondly, speed cameras should be used to deter, rather than catch, speeding drivers. Thirdly, speed camera use is optimal in areas with high crash risks and where crash consequences are most severe. Extensive use of speed cameras in low-risk areas can result in reductions in the perceived legitimacy of speed cameras and public scepticism regarding the purpose of cameras. Fourthly, policy and practice regarding the operation of speed cameras should be highly transparent and public education of the role of speed cameras to improve road safety must be clearly conveyed.

7. BEST PRACTICE IN SPEED ENFORCEMENT

Overall, there are a number of critical challenges to reduce vehicle speeds and related crashes. Specifically, speeding is, by its very nature, a transient, frequent and evasive behaviour. As a result, many enforcement approaches are likely to detect only a small proportion of all speeding offenders. Punishment avoidance associated with speeding behaviour may act as a significant reinforcement for further speeding behaviour and so police must increase the risk of detection and reduce the ability for offenders to adopt strategies to avoid detection (Fleiter et al., 2009; Zaal, 1994). Non-automated approaches, such as police patrol and radar operation, are typically associated with low rates of detection however produce other benefits by also targeting a range of other illegal driving behaviours. In many jurisdictions there is a tendency to rely heavily on automated approaches, such as speed cameras, which are able to detect a larger proportion of offending drivers. Automated approaches also tend to be more cost-effective given the relative costs associated with both implementing operations, and in regards to the revenue raised by subsequent fines.

From the available research, a number of best practice principles for the implementation of speed enforcement operations, and particularly speed cameras, are evident.

Speed enforcement programs need to utilise a variety of enforcement strategies which are tailored to specific situations.

There is growing evidence to suggest that a mixture of covert and overt, as well as stationary and moving, operations produces the greatest road safety benefits, however the precise optimal combination of approaches is difficult to ascertain from the available research (McInerney, Cairney, Toomath, Evans, & Swadling, 2001; Zaal, 1994). Indeed, as identified in the work of Cameron (2008), a one-size-fits-all approach is unlikely to be as effective as one which incorporates a range of enforcement methods and is tailored to the variety of roads and situations across the road network. Typically, automated, stationary methods are most effective in crash black-spots, given the limited distance and time halo effects commonly associated with such approaches and the fact that observed effects are generally localised to the camera site only (Champness et al., 2005). On the contrary, moving approaches are most beneficial in instances where more network-wide approaches are desired, however such approaches are burdened by lower detection rates and relative costliness.

Overt operations serve a primarily general deterrent effect and clearly create an enforcement presence. While there is evidence suggesting overt operations are commonly associated with halo effects, the vast majority of this research has been generated from evaluations of overtly operated stationary methods, such as fixed and mobile speed cameras. Few studies have specifically analysed whether localised effects are associated with overt approaches operated in a moving fashion, such as routine patrols in marked vehicles. Future research should more closely analyse the application of overtly operated moving approaches to produce network-wide behavioural effects.

Covert operations appear to increase the unpredictability of enforcement operations and minimise the impact of punishment avoidance strategies and halo effects. Such approaches are ideally implemented in conjunction with intensive publicity campaigns. Indeed, it has been shown that well constructed publicity of covert operations can lead to perceptions of high levels of police enforcement activity, even when actual enforcement levels are relatively moderate (Cameron, Delaney et al., 2003). Moving, covert enforcement methods are also likely to represent an effective approach to the detection and apprehension of more deviant offenders and thus serve an important specific deterrence purpose. Finally, there is evidence to suggest that semi-covert operations, involving inconspicuous placement of overtly marked vehicles (in relation to mobile speed camera enforcement), may also be an effective approach (Dowling & Holloman, 2008).

Fixed speed cameras are most effective at locations with localised speed-related problems and where other speed enforcement approaches are not practical or safe.

Fixed speed cameras are most likely to be beneficial in the management of vehicle speeds and related crashes at locations with high levels of speed-related problems. That is, fixed speed cameras are likely to produce the greatest benefits at crash black spots or at locations with high speeding offence rates. While the automated, stationary nature of fixed cameras often results in localised effects of vehicle speeds and crash rates, this still represents an effective approach when speed-related problems are also localised. In addition, fixed cameras also provide an appropriate enforcement method at locations where other speed enforcement approaches are not safe or practical, such as on limited access roads, freeways and in tunnels. Finally, fixed cameras provide the optimal approach at locations requiring consistent enforcement.

Operations should be sufficiently intensive so as to produce an "atmosphere" of enforcement presence and be randomly scheduled to increase unpredictability of enforcement activities.

Obviously, a perceived enforcement presence is critical to the success of any speed enforcement approach. Operations must be implemented with a sufficient level of intensity such that the driving population perceives their likelihood of exposure to enforcement activities as being high, thus increasing the risk and reducing the benefits associated with exceeding the speed limit (Delaney et al., 2003; McInerney et al., 2001; Newstead et al., 1999; Zaal, 1994). In addition, there is evidence to suggest that optimal levels of effectiveness are achieved when enforcement operations are randomly scheduled, such that unpredictability of enforcement activity is increased (Delaney et al., 2003; Leggett, 1997; Newstead et al., 1999). Random scheduling can involve directing available resources across a number of pre-selected sites, such as mobile speed camera sites chosen on the basis of speed-related criteria, or across the entire road network, in the case of moving approaches such as routine patrol.

More wide-spread implementation of innovative approaches, particularly point-to-point systems, will likely produce more network-wide effects on vehicle speed and crashes.

Point-to-point speed enforcement has been found to be extremely effective in reducing vehicles speeds and increasing compliance with speed limits (Soole & Watson, 2009). More widespread use of this approach would likely result in more network-wide impacts on both vehicle speeds and crash rates. In addition, the evidence that such an approach is perceived as being more fair and legitimate by drivers, as well as the ancillary benefits such as reduced traffic congestion, suggests that such an approach has the potential to result in substantial changes to underlying attitudes regarding speed choices if drivers are able to regularly associate driving at the posted speed limit with smoother traffic flows and reduced congestion. However, the relatively high cost of the approach calls for careful consideration in regard to locations where such systems are used.

The use of ISA should be considered as a punishment for recidivist and high-range speeders.

The use of ISA in general to reduce the incidence of speeding among the general public should be fully explored, however such provisions are likely to be met with stiff opposition from vehicle manufacturers and drivers alike. This will be particularly true for more intervening systems which have been found to be associated with the greatest behavioural effects. One particular application of the technology which warrants further attention is the use of intervening ISA systems as a punishment option (or mandated response) for recidivist and high-range speeding offenders (Watson et al., 2009). Such an approach is similar to the use of alcohol ignition interlocks amongst drink driving offenders, and may prove beneficial in addressing the behaviour of the most at-risk offenders.

Policy and practice regarding the operation of speed cameras should be highly transparent and public education of the role of speed cameras to improve road safety must be clearly conveyed.

Accompanying speed enforcement operations with publicity campaigns has been shown to bolster the effectiveness of operations, particularly if the publicity specifically relates to the method of speed enforcement being used and uses an emotive-style approach (Cameron, Newstead, Diamantopoulou, & Oxley, 2003; Delaney et al., 2003; McInerney et al., 2001; Rogerson et al., 1994; Zaal, 1994). Moreover, publicity campaigns present a unique channel of communication between traffic authorities, the police and the general driving public. As such, the communication of messages to debunk stereotypes and misconceptions regarding speed enforcement policy and practices may increase the perceived legitimacy and transparency of enforcement efforts, and in turn encourage greater levels of compliance.

The feasibility of reducing enforcement tolerance levels should be examined.

Enforcement tolerance levels should be set at the lowest acceptable level to increase the perceived certainty of punishment associated with speeding behaviour. That is, drivers must be encouraged, through threat of punishment, to drive at or below the posted speed limit rather than at a de facto speed limit based on perceived enforcement tolerances. While the enforcement tolerances used in Queensland are not made public, a recent survey of preferred driving speeds among Queensland drivers revealed a general preference for speeds approximately 10% above posted speed limits, with perceptions of enforcement tolerance levels one of the leading reasons why respondents reported driving above posted speed limits (Fleiter & Watson, 2006; Fleiter, Watson, Lennon, King, & Shi, 2009).

The aim of any speed management program should be to deter, rather than catch, speeding drivers.

The fundamental principle of any speed management program must be the promotion of safe travelling speeds. That is, operations must be geared such that they are designed to deter drivers from exceeding the speed limit, rather than identifying the most effective way to apprehend speeding drivers (Zaal, 1994). However, that is not to suggest that the apprehension of speeding drivers should not be an aim of speed enforcement; simply that it should be secondary to deterrence. Ideally, enforcement activities that are intensive, randomly scheduled and involve a mixture of approaches should create an atmosphere such that the general public is deterred from exceeding the speed limit. This will largely be achieved through increased perceptions of enforcement presence, unpredictability of operations and perceived risk of detection, apprehension and punishment.

Speed management programs must be multifaceted.

Speed enforcement represents but one element of an effective speed management program. Indeed, speed management must involve a multifaceted approach incorporating not only enforcement but also community initiatives, public education, media campaigns, offender rehabilitation programs and traffic engineering initiatives (e.g., reviewing speed limits). In addition, innovative approaches such as Intelligent Speed Adaptation (ISA) provide a promising new line of approaches to speed management. Finding the precise optimal mix of various components, while also balancing issues such as driver acceptability and perceived legitimacy and transparency of policies and practices, is an arduous task. Future empirical research should seek to rectify the methodological shortcomings of prior evaluations and identify the unique contribution of various approaches to road safety.

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