Speed management: enforcement and new technologies

Fred Wegman & Charles Goldenbeld

R-2006-5

Speed management: enforcement and new technologies

R-2006-5
Fred Wegman & Charles Goldenbeld
Leidschendam, 2006
SWOV Institute for Road Safety Research, The Netherlands

Report documentation

Number:	R-2006-5
Title:	Speed management: enforcement and new technologies
Author(s):	Fred Wegman & Charles Goldenbeld
Project leader:	Fred Wegman
Project number SWOV:	41.362
Keywords:	Speed, speed limit, enforcement (law), police, surveillance, technology, intelligent transport system, adaptive cruise control, electronic driving aid, safety, traffic.
Contents of the project:	Due to the massive character of speeding and inappropriate travel speeds, speed management continues to be an important and challenging policy area. This paper reviews the scientific evidence about the effects of modern speed enforcement methods and discusses some new technologies for speed management and their potential impact on crashes.
Number of pages:	29
Price:	€ 8,75
Published by:	SWOV, Leidschendam, 2006

SWOV Institute for Road Safety Research
P.O. Box 1090
2260 BB Leidschendam
The Netherlands
Telephone +31 70 317 33 33
Telefax +31 70 320 12 61
E-mail info@swov.nl
Internet www.swov.nl

Summary

Due to the massive character of speeding and inappropriate travel speeds, speed management continues to be an important and challenging policy area. Estimates are that in about a quarter to one third of fatal crashes excessive speeds are involved, making speed one of the crucial factors in road safety. Management of speeds of drivers of motorized vehicles has a high safety potential. Until now this has been done mostly by road design, setting speed limits, and enforcing these limits. Speed limits should be safe and credible. Speed enforcement is reported to be effective (5-35% reduction in casualties) and cost-beneficial. Use of modern technologies, such as safety cameras, laser guns, section control, etc., have made speed enforcement more effective and efficient. In the future, new intelligent vehicle technology will create new possibilities for speed management. This new technology can operate independent of, or integrated with, police checks. This paper reviews the scientific evidence about the effects of modern speed enforcement methods and discusses some new technologies for speed management and their potential impact on crashes. Most part of this paper was presented at the Xth PRI World Congress, 27-29 March 2006 in Abu Dabi, United Arab Emirates.

Contents

1. Introduction

1.1. Aim of this paper

The road safety policies in highly-motorized countries such as the Netherlands, Great Britain, and Sweden have resulted in their having the lowest numbers of road deaths per 100,000 inhabitants in the world (Wegman et al., 2005a). During the last decade, the Sustainable Safety vision has been the leitmotif behind improving road safety in the Netherlands. This vision is also internationally regarded as authoritative (Peden et al., 2004). One of the fundamentals in this vision is the management of vehicle speeds. In this paper we will examine/evaluate both traditional and new methods of speed management with the principles of Sustainable Safety as a background.

This paper starts with describing key elements of the Dutch Sustainable Safety vision as a perspective for speed management. Secondly, traditional methods of speed management by police enforcement are discussed. The third section introduces some new possibilities for management of vehicle speeds offered by new technologies, paying special attention to Adaptive Cruise Control (ACC), a system that is already on the market today, and Intelligent Speed Assistance (ISA), a system that has been evaluated in several field trails. Some opportunities and threats for speed management are presented in the final section as closing remarks.

1.2. Sustainable Safety

The Sustainable Safety vision, as described in Koornstra et al. (1992) aims to prevent crashes and, if this is not possible, to reduce the crash severity in such a way that serious injury is almost excluded. In a proactive approach two possibilities are explored: the circumstances are changed in such a way that either the crash risk is almost excluded, or, if risky circumstances are inevitable and crashes occur, the chance of severe injury risk is eliminated. "Severe injury" is defined as fatal injuries, life threatening injuries, injuries causing permanent bodily damage, and injuries requiring hospital treatment.

In a sustainably safe road traffic system the road network layout has been adapted to the limitations of human capacity through proper road design. The vehicles are technically equipped to simplify driving and to give enough protection to vulnerable human beings, and road users have been properly educated, informed, and, where necessary, deterred from undesirable or dangerous behaviour. The human body's vulnerability (the biomechanical tolerance) and the important influence of speed (or more precise: local forces and decelerations acting on the body) on crash severity is the point of departure for a concept named *safe travel speeds*.

Recently, the Sustainable Safe vision has been modernized. The book *Advancing Sustainable Safety; National Road Safety Outlook for 2005-2020* (Wegman & Aarts, 2005) is an update of the original Sustainable Safety vision that was published in 1992. Within the Sustainable Safety vision the management and control of vehicle speeds is one of the crucial elements. Why is this so?

1.3. The importance of speed management

In most countries, a large percentage of drivers drive faster than the speed limit (see for example ETSC, 1999; TRB, 1998; Cauzard, 2004). In the Netherlands, 40-45% of car drivers exceed the speed limit on motorways (speed limits of 100 or 120 km/h). About the same percentage exceeds the speed limit on 80 km/h rural roads (Van Schagen et al., 2004). In Great Britain in 2003, almost 60% of drivers of motorized vehicles exceeded the 30 mph limit in urban areas and in Sweden the same percentage exceeded the rural speed limits, whereas it was somewhat lower on urban streets (Lynam et al., 2005). The question arises what these enormous numbers of violations mean for road safety?

Recently, the research on the relationship between speed and crashes has been reviewed by Aarts and van Schagen (2006). The exact relationship between speed and crashes is complex and depends on a wide range of specific factors. However, in general it can be said that the faster the speed, the greater the chance of a crash and the more severe the injuries in a crash. It is precisely these two chances that Sustainable Safety tries to minimize. When speed increases on a road, crash rates increase as well. The relationship can be described by a power function. According to an Australian research group (Kloeden et al., 1997) speeding is as dangerous as drink driving (see *Figure 1*).

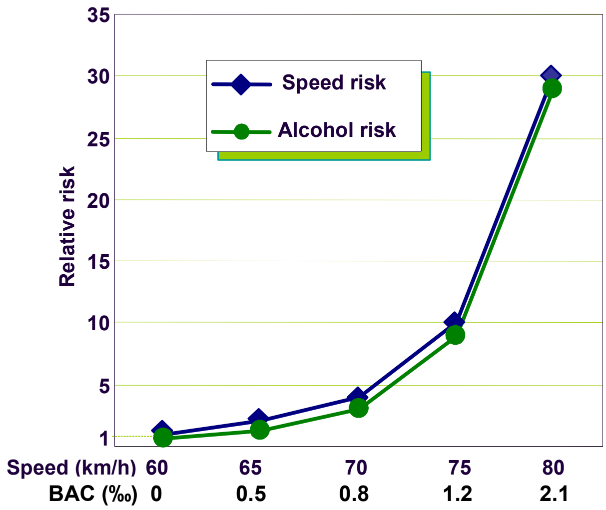

Figure 1*. Relationship between risk of driving while intoxicated and with excessive speeds on urban roads (with 60 km/h speed limit) in Australia (Kloeden et al., 1997).*

With speed management, we can influence the homogeneity of road traffic, the predictability of road user behaviour and the roads' course, and so reduce the chance of errors and mistakes made by road users. It is to be expected that fewer errors will result in fewer crashes. Speed management is thus an important means of achieving (sustainably) safe traffic and offers sufficient potential for action, both in the short and long-term. At the very basis of speed management are the legal speed limits. The Sustainable

Safety vision stresses the importance of setting safe and credible speed limits.

1.4. The importance of safe and credible speed limits

Each country has its own system of speed management in order to promote driving at safe speeds. Speed limits are the legal basis and the heart of every system of speed management. Speed limits may be seen as a trade-off between accessibility and safety. In addition to safety, a speed limit should meet the requirements of enforceability and acceptance by the community (TRB, 1998).

Speed limits can be divided in general (implicit) and specific (explicit) limits. Almost all countries have fixed speed limits for road types such as urban, rural, 'A-roads', and motorways. Besides the most common fixed sign-posted speed limits, there are variable speed limits (indicated by signed posts or Variable Message Signs), temporary speed limits (e.g. in case of roadworks), and speed recommendations (advised maximum speed). Variable speed limits are becoming increasingly common. To make headway with variable speed limits, the active support of these limits by in-car speed assistance systems is instrumental.

According to the Sustainable Safety vision, speed limits should be safe first of all, but also credible to the road user, and as much as possible directly accessible to the driver at all times (Van Schagen et al., 2004). The credibility of speed limits implies that the legal speed limit should be in concordance with the driving speed which can be expected from the prevailing road type, road conditions and road environment.

But above all, speed limits must indicate safe speeds: crashes must be prevented as much as possible and if one does occur, it must be almost impossible to sustain severe injuries. To invoke road users to actually adhere to these safe limits, it is essential that these limits correspond to the expectations that a road's layout evokes. The limits must, therefore, be credible. Speed limits should correspond with the road layout. This can be done by fitting the layout to the limit or the limit to the layout. On some roads the limit will need to be raised, whereas on others it will need to be lowered. Another important consequence of the concept of credible limits is that where one limit changes to another one, as for example is the case when leaving an urban area, road users should always be able to see a clear change in road layout.

A good compliance with speed limits also requires road users always and everywhere being clearly shown what the speed limit is. This can be done in the usual way with information on, or alongside, the road. A more advanced possibility is to present the limit inside the vehicle, e.g. linked to a navigation system.

In order to have safe and credible speed limits that most road users adhere to, four consecutive steps should be taken (see *Table 1*).

Safe and credible speed limits with appropriate enforcement	
1. Criteria safe & credible limits	Determine criteria for safe and credible limits and the minimum road user information requirements, and prepare a checklist
2. Test & adapt the road network	With the use of the checklist assess roads to see if the limits meet the criteria on safety, credibility, and information requirements
3. Re-orientate police enforcement	Re-examine speed enforcement strategy; control should be focused on deliberate offenders
4. Work towards setting dynamic speed limits	Prepare for road-regulated and vehicle-regulated systems of speed limits (pilot projects; policy choices)

Table 1*. Stepwise process to arrive at safe and credible speed limits with appropriate enforcement (Van Schagen et al., 2004).*

As already said, when road users are involved in a road crash, the issue at stake is their physical vulnerability. Sustainable Safety attempts to minimize the seriousness of the outcome with the principles of forgivingness (of the surroundings) and homogeneity (Wegman & Aarts, 2005). This last principle states that conflicts between different road user types must be avoided by separating them in the road layout. If conflicts cannot be prevented, speeds should be so low that no crash will have serious consequences. For various traffic situations, Sustainable Safety proposes a system of 'safe travel speeds' for cars (see *Table 2*).

Road types combined with allowed road users	Safe speed (km/h)
Roads with possible conflicts between cars and unprotected road users	30
Intersections with possible transverse conflicts between cars	50
Roads with possible frontal conflicts between cars	70
Roads with no possible frontal or transverse conflicts between road users	≥ 100

Table 2*. Proposal for safe speed limits for cars, given possible conflicts between road users (Tingvall & Haworth, 1999).*

2. Traditional methods of speed management

2.1. Infrastructural measures

Over the last few years, the original three Sustainably Safe vision principles (Koornstra et al., 1992) (*functionality* of roads, *homogeneity* of masses and/or speed and direction, and *predictability* of road user behaviour and the road's course) have been translated into Dutch guidelines for road design and applied in practice on a large scale. Traffic calming on urban streets (30 km/h) and on rural roads (60 km/h) has been introduced, fitting in new, functional road classification plans. Adapting the infrastructure has had a positive safety effect. Infrastructural measures implemented between 1998 and 2002 have saved about 6% of fatalities and in-patients nationwide (Wegman et al., 2005b). These measures were not supported by police enforcement; they were self-enforcing.

The speed and safety effects of changes to infrastructure have been demonstrated in several other studies as well. Mountain et al. (2005) compared speed and safety effects of engineering measures and fixed speed cameras. Using a study design that controlled for trends in crashes, regression-to-the mean effects, and crash migration, they found that engineering schemes including vertical deflections (speed humps, cushions) prevented 44% of personal injury crashes, engineering schemes with horizontal features resulted in a fall of 29% in personal injury crashes and speed cameras reduced 22% of the personal injury crashes. In conclusion, schemes with vertical deflections are more effective than schemes using horizontal deflections and cameras. However, other research suggested a wide variance in safety effects depending on the site and scheme characteristics (better quality of interventions, higher safety effects).

In a parallel study Hirst et al. (2005) developed models to predict the impact of speed management on crashes depending on speed changes and with site and scheme characteristics. Interestingly, they found that the impact of schemes with vertical deflections is independent of the change in mean speed. They found a 4% crash reduction per 1 mph mean speed reduction for cameras and 7-8% for schemes with horizontal deflections on 30 mph roads with before mean speeds in the range of 30-35 mph. The models indicate that speed management schemes are most effective on high-speed roads.

2.2. Enforcement: an integral part of speed management

According to the Sustainable Safety vision, management of vehicle speeds should be primarily arranged by intrinsic parameters of the traffic system such as road design, vehicle design, and road-vehicle interaction, rather than measures such as enforcement. Enforcement in its nature does not have a sustainable character. But, since some of the road users will be inclined to deliberately violate speed limits, irrespective of road layout and corresponding limits, police enforcement was, is and will always be an integral part of speed management.

On the basis of research, Mäkinen et al. (2003) offer the following arguments for giving speed enforcement a more prominent role in speed management:

- It has been shown that a change in travel speeds affects both the risk and the severity of a crash, although rules of thumb should be handled with care.
- Speeds are not enforced with the seriousness they deserve, the risk of getting caught for speeding is low in almost all countries.
- There is an upward trend for faster speeds due to the growing number of high performance motor vehicles.
- Speeding increases the likelihood of other traffic violations, especially of those associated with overtaking.
- Lower speeds with a reduced noise level increase the quality of life in the vicinity of road networks.
- Moderate speeds support sustainable development.

2.3. The theory behind enforcement

Police enforcement is based on ideas from the classical deterrence theory, which was formulated in the 18th century in the writings of the philosophers Bentham and Beccaria. According to this theory, rational people will abide by the laws of society because they are motivated to avoid punishment, especially when the chance of detection and punishment is large. Police enforcement of traffic laws is intended to influence the behaviour of road users in such a way that their risk of becoming involved in a crash or causing a crash decreases. It is generally accepted that traffic law enforcement influences driving behaviour through two processes: *general deterrence* and *specific deterrence* (Zaal, 1994; Mäkinen et al., 2003). General deterrence can be described as the impact of the threat of legal punishment on the public at large, while specific deterrence can be seen as the impact of actual legal punishment on those who have been apprehended. Thus, general deterrence results from a perception of the public that traffic laws are enforced and that a risk of detection and punishment exists when traffic laws are violated.

Specific deterrence is caused by actual experiences with detection, prosecution, and punishment of convicted offenders. It should be emphasized here that police enforcement can only be effective if it operates in a supportive environment of legislation - detection - prosecution - a penal system - rehabilitation. Only these combined forces act to create the deterrent effect of police enforcement.

The overall preventive effects of traffic law enforcement are generally greater if the subjective risk of the offender being caught is higher, if the penalty is more severe, if the certainty of punishment is increased, and if the penalty is imposed more rapidly (Zaal, 2004; Mäkinen et al. 2003). Each of these elements constitutes a link in the enforcement chain. The most important link is the subjective probability of the offender being caught, in other words, the personal perception on the part of the road user of his or her chances of being caught while violating a traffic regulation. The level of punishment, the certainty of being punished and the speed with which the punishment is meted out will do little to prevent traffic infringements if the perceived risk of apprehension remains small. The assumed mechanism of police surveillance is depicted in *Figure 2*.

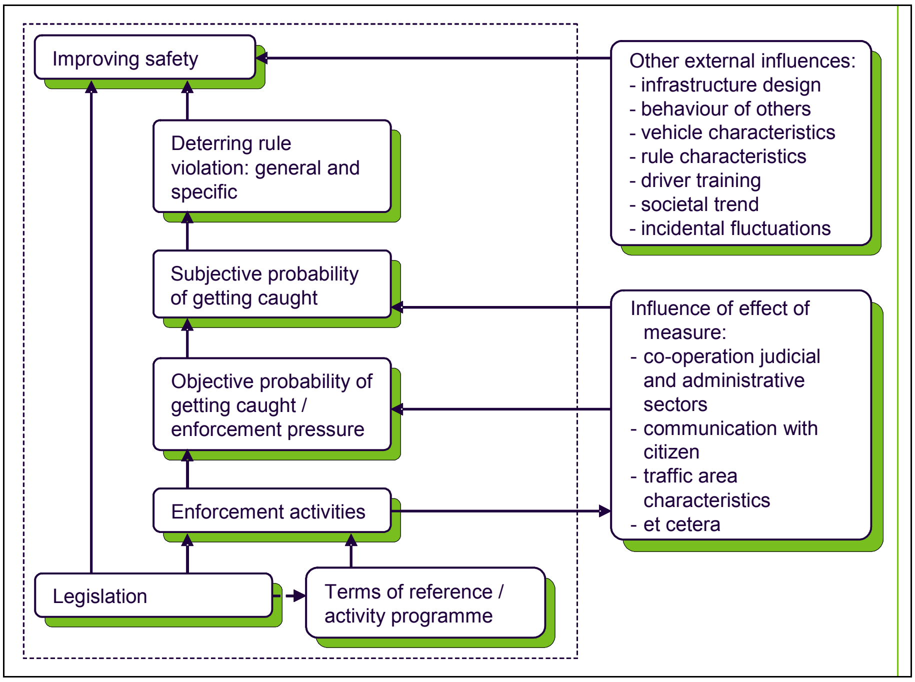

Figure 2. *The assumed mechanism of police surveillance (inside dotted frame), including the influence of external factors (outside dotted frame) according to Aarts et al. (2004).*

As can be seen in *Figure 2*, the actual enforcement activities on the street accompanied by publicity result in an increase in the perceived risk of being apprehended for a violation. Simply put, the subjective chance of detection increases as the number of speed checks increases. However, the relation between these factors is non-linear. Bjørnskau & Elvik (1992) posit that the enforcement level has to be increased with a factor 2, 3 or even 4, in order to achieve a substantial road safety effect. On the basis of 11 international studies into speed enforcement, Elvik (2001) derived a general relationship between enforcement level and percentage of change in the number of injury crashes. He concludes that by intensifying enforcement the expected extra road safety returns diminish (*Figure 3*).

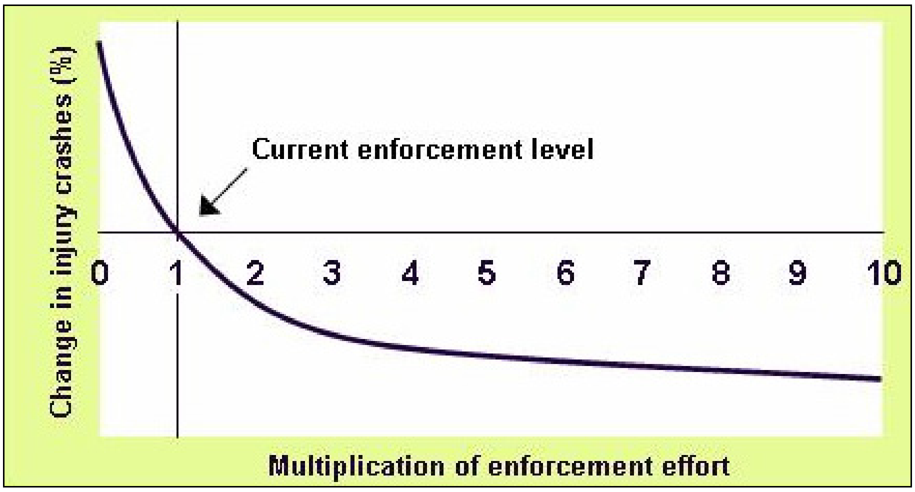

Figure 3. *Relationship between speed enforcement surveillance and change in the number of injury accidents according to Elvik (2001).*

The general assumption underlying enforcement is that police enforcement should primarily be aimed at general deterrence, which is first and foremost achieved by increasing the subjective risk of apprehension. These assumptions have led to the following ground rules of enforcement. Police enforcement of traffic rules should adhere to the following principles:
- accompanied by publicity,
- unpredictable and difficult to avoid,
- a mix of highly and less visible activities,
- primarily focused on high violation times and locations (maximum feedback to potential offenders),
- continued over a longer period of time.

Beside deterring road users from committing violations, the police may also exert influence on the behaviour of road users by doing the following:
- setting the right example in traffic,
- informing the public about police policy in matters of road safety and the reasons behind specific police activities,
- paying attention to complaints or suggestions about road safety,
- informal communication with road users,
- practical or symbolic support by other road safety organizations,
- substitution of traditional punishment by alternative sanctions that may appeal to the public and encourage them to change their attitude and behaviour.

Several of these points refer to the important role of good and informal relations between police and public. Many police decisions about involvement in traffic enforcement campaigns concern relations with the general public. Expectations of how the public will react to enforcement activities often play a pivotal role in the minds of police decision makers. Undoubtedly, social acceptance of an enforcement campaign can support and enhance its safety effects. Through publicity and the points listed above, the police can help improve this acceptance.

2.4. Effectiveness of speed enforcement

Generally, evaluation studies report positive effects of speed enforcement on speeding behaviour and the number of crashes (see e.g. Diamantopoulou & Cameron, 2002; Elvik & Vaa, 2004; ETSC, 1999; Zaal, 1994; Zaidel, 2002). The sizes of the reported effects, however, vary largely. The safety benefits of speed enforcement (mobile and fixed cameras) in terms of reduction in the number of fatalities and casualties ranges from 5% to 30%. Reductions of fatalities are higher than for injuries. Effects in urban areas are higher than on rural roads. Effects of automated enforcement (speed cameras) are larger than manual speed enforcement (physical policing methods).

Pilkington and Kinra (2005) found that the increase in safety in the immediate vicinity of the camera sites varied between studies with ranges of 5-69% for crashes, 12-65% for injuries, and 17-71% for fatalities at camera sites. These differences are most likely caused by the type, intensity, and location of the enforcement activities, as well as by the situation before the enforcement started. There is, however, a large consistency in how much speed enforcement effects are limited in terms of both time (time halo) and space (distance halo). Not surprisingly, some studies clearly show how safety effects tend to be larger when measured near camera sites (Christie et al. 2003; Hess, 2004).

A recent TRL review (Elliott & Broughton, 2005) has reviewed the literature on police enforcement. With respect to speed enforcement the review concludes the following:

- Speed cameras are more effective than physical policing methods in reducing speeds and crashes.
- Speed cameras are more effective in reducing crashes inside urban areas than on rural roads.
- Fixed speed cameras are more effective in reducing speeds and crashes than mobile speed cameras.
- Speed cameras appear to have safety benefits over a distance of 500 metres or more from the speed camera site.
- Physical policing in combination with randomization of police checks leads to distance halo effects (the durability of an enforcement effect after drivers pass the enforcement site) that are minimally five times larger than those of speed cameras.

One problem of speed enforcement is that some motorists brake before passing a speed camera and then speed up to above the speed limit after they have passed it. This sudden braking can cause dangerous situations, crashes, or tailbacks. A possible answer to this problem is *section control*, a relatively new technique for checking the speed of vehicles on longer stretches of roads. Unlike conventional speed meters, which measure the speed of a vehicle at one point, section control systems determine the average speed over a long distance (at least 500 metre, up to several kilometres). In the past few years, the Dutch Ministry of Transport has carried out successful trials with section control systems on various motorways and rural roads, including the A2 (between Amsterdam en Utrecht) and the A13 (between Rotterdam and The Hague). On the A13 the section control resulted in not more than 0.5% offenders in the total traffic (Rijkswaterstaat Directie Zuid-Holland, 2003). The number of casualties has halved on these sections. Recently, this section control technique has been expanded to another 5 locations and plans are made for further expansion. In the Netherlands there are also a number of mobile section control systems in use.

2.5. Implementation of speed enforcement programmes

In general, police enforcement may be carried out at three levels of professionalism (Goldenbeld et al., 1999). The first level may be called 'ad hoc enforcement' and is characterized by short term operations for a few weeks, mostly on a few, specific locations with strong emphasis on catching offenders (repressive enforcement). The second level, 'project-bound enforcement', is based on longer term planning over several months, often covers a certain route or number of locations, is based on explicitly described aims, and is guided by evaluation efforts. The highest professional enforcement is 'planned enforcement' which covers larger areas (regions or provinces), is in permanent operation, and is based on area-analysis, plans throughout the year, and thorough evaluation of results. We call this a systematic approach.

In Europe, the implementation of speed camera enforcement programmes has seen a large growth in the 1990s in both the United Kingdom and the Netherlands. In both countries there is evidence that camera enforcement has been successful with reductions in casualties between 20%-40% (e.g. Gains et al., 2004; Goldenbeld & Van Schagen, 2005). The SUNflower project (Lynam et al., 2005) compared the favourable and unfavourable conditions for successful implementation of enforcement programmes in the United Kingdom and the Netherlands. *Table 3* shows the results of this comparison.

Comparing speed/safety camera programmes in the Netherlands and the UK		
Country	Favourable	Unfavourable
NL	A central bureau co-ordinating all camera enforcement projects and supervising monitoring of speed behaviour. Legislation which makes the owner of the car responsible for speed violations.	The expected savings from speed cameras are anticipated in the national budget, leading to claims of revenue raising. No precise knowledge about the safety effects of fixed speed cameras due to lack of central monitoring.
UK	Concerns about cost of implementation resolved by hypothecation – controlled experiment requiring partnerships. Evaluation of both effectiveness of management and financial control and of effectiveness of cameras in reducing crashes. Extension of partnership programme to general implementation. Further debate among researchers to establish conclusive evidence .	Financial element of process led to claims of revenue raising - taken up by media. Led to high profile negative publicity despite general surveys in favour. Possible over-emphasis on role of cameras without parallel implementation of other measures.

Table 3*. Conditions for successful implementation of camera enforcement of speeding.*

Goldenbeld (1997) put forth the following guidelines for the implementation of police enforcement programmes at the 'third level':

- a clear description of the aims and targets to be achieved by the police activities,
- consideration of groups of road users which can be specifically targeted for publicity or enforcement activity,
- the choice of publicity strategy and message and publicity channels, including the internal publicity to police officers involved in executing the enforcement operations,
- clear agreements with other parties, e.g. local road safety authorities, municipalities, Public Prosecutor’s Office, citation handling authority, etc.
- the support of enforcement activities by additional measures along the road such as adding or placing road signs or road markings, or making them more visible.
- a sensible choice of locations and times of enforcement operations
- consideration of the best mix between highly visible police checks and more unexpected, less visible controls,
- the set-up and execution of police controls according to time saving operational guidelines,

- a well-considered build-up and build-down of activities over a longer period of time,
- evaluation of the extent to which agreements are fulfilled and the extent to which expected effects of enforcement activities have been realised.

In the case of automated enforcement, better results are obtained when the vehicle owner can be held legally responsible for the violation instead of the legal obligation to identify the driver. A systematic approach offers the best opportunities for evaluation of the enforcement activities and thus for learning from experience. Also, such an approach clarifies the division of tasks and responsibilities between partners involved in the traffic law enforcement activities. This will facilitate communication and cooperation of parties during the enforcement process. Ad hoc massive police controls that are not grounded in a well thought-out rationale and that are not prepared very well, may only have short-lived and minor effects on road users' behaviour and may even undermine the credibility of police traffic enforcement operations.

2.6. Limitations of police enforcement

Despite these positive findings of safety effects of police enforcement, there are some clear limitations to the use of speed enforcement methods. In general only a small part of the total network can be supervised by speed checks. For example in the Netherlands, only the most dangerous road stretches of rural roads are checked for speed. For each Dutch province, less than 10% of the total rural network is regularly checked for speed. When the roads are only checked by 24-hour operating speed cameras, the effects on speed and safety are often limited to a few hundred metres from the camera site (Elliott and Broughton, 2005). When visible and invisible mobile camera operations are combined, the effects may be more widespread over the road network (Diamantopoulou & Cameron, 2002), but this method uses up more manpower. The effects of visible camera operations along the roadside tend to dissipate after 3 days (Diamantopoulou & Cameron, 2002).

There is little proof (because of no immediate feedback on behaviour) that general driving style changes as a result of speed enforcement. Many drivers slow down on certain road stretches but maintain their normal style on stretches where they do not suspect enforcement operations. Psychologists have pointed out that speed management by enforcement is essentially a negative motivational approach, relying on fear of punishment and alienating drivers from more positive motivation to conform to the law (e.g. Zaidel, 2000).

The effects of police enforcement have been explained from the viewpoint of the deterrence theory in *Section 2.3*. Some experts point at the limitations of this theory. Insofar as deterrence theory states that behaviour is regulated by the speed, the certainty and severity of sanctions, it neglects behavioural mechanisms that may be more effective than just punishing, such as rewarding, convincing, and, in the age of new electronics, timely and to-the-point behavioural feedback that informs the drivers about potential dangers. In addition to the principles of the deterrence theory, the social norm theory stresses the importance of social acceptance of the necessity and correctness of rules that are being enforced (Andenaes, 1974; Gibbs, 1975).

Punishment as a mechanism to get people to obey laws will have much more effect if punishment corresponds with the values and sense of justice of citizens. In line with this theorizing, Sustainable Safety maintains that any traffic system should aim at spontaneous compliance with laws, i.e. unintentional compliance or compliance governed by inner motivation. To achieve this, laws must fulfil a number of preconditions. We obey laws more easily, perhaps even subconsciously, if they logically fit the road environment. Moreover, if the link with our own safety is clear and we sense that the laws are fair and neutral, we experience them as 'just' and are willing to obey them.

Automatic speed management with administrative processing of speed violations has been criticised on the grounds that it is perceived as random and unfair by citizens and that it diminishes the credibility and authority of police (Zaidel, 2000). It can be argued that a one-sided emphasis on fining and punishing does not contribute to the intrinsic motivation of drivers to abide by the speed limits. Drivers reduce speeds near camera locations from a fear of fines, not out of inner conviction, and they will speed up again a few hundred metres past the camera location. In this way road users learn behaviour that is directed towards avoidance of camera checks instead of a more general behavioural change based on safety considerations.

3. New possibilities for speed management

3.1. Introduction

The application of artificial intelligence in road traffic finds itself in an upward spiral. This shows itself in a great number of developments in the area of information and communication technologies (ICT), electronic support and driver support systems (Advanced Driver Assistance Systems – ADAS). These are generally named Intelligent Transport Systems (ITS) as an umbrella term.

Intelligent transport systems can make their own unique contribution to improving road safety and therefore deserve a prominent place in the Sustainable Safety vision. Particularly systems that aim directly at safety raise high expectations. For all OECD countries together, a casualty reduction of 40% is expected (fatalities and injured) by means of safety-orientated ITS (OECD, 2003).

In reality, however, ITS does not yet contribute very strongly to road safety. First, this is because a large part of these systems is not yet (fully) developed, and their implementation in traffic is limited. Apart from that, the nett effect of many of these systems is still somewhat uncertain due to the often unclear interaction with human behaviour, such as risk compensation, and the complexity of large-scale implementation (European Commission, 2002). A second reason why ITS for the time being does not strongly contribute to more road safety, is because the introduction of ITS has been guided to date by improving traffic management (flow and accessibility) and by driving comfort. Road safety aspects are not always addressed, possibly even undermining road safety. Despite this situation and these uncertainties, ITS potentially harbours many opportunities to improve road safety further.

The potential of ITS is also apparent when we consider the advantages and disadvantages of traditional methods of speed management. Although infrastructure plays a central role in speed management, it is clear that changes to infrastructure are costly and sometimes not feasible even when financing is possible. Speed management by police enforcement also has advantages as well as disadvantages. The main advantages is that a clearly planned, well-executed speed enforcement programme can reduce speeds and prevent crashes. Disadvantages are that speed enforcement has to be used continuously in order to be effective, that behavioural effects are rather limited in time and space, and that the enforcement programme may invite negative reactions from citizens and lobby groups. Negative reactions are especially likely if the programme does not correspond with objective safety needs and if the safety message is not clearly communicated. Moreover, from a sustainable safety point of view, it should be aspired to have road users follow the rules by other means than punishment alone, since punishment is a one-sided approach that does not influence intrinsic motivations of road users. Finally, an argument to be considered is that police enforcement always takes up police capacity.

New vehicle technology opens new possibilities for speed management and behaviour change. Speed assistance technologies can perform functions that classical engineering and enforcement measures cannot. They can inform drivers at all times and places what the speed limit is, and warn them at all times and all places when they are over the speed limit. By working at all times and places, and by enabling drivers to react to their own speed violations, these systems offer drivers a measure of insight, comfort, and support which traditional measures cannot equal. From this informative function alone, we expect an effect on driver behaviour and road safety.

3.2. Relationships between new technology and existing measures

If the future will bring us new technologies of speed management, what does this mean for other more conventional ways of speed management such as changes to road environment or police enforcement? There are three possible relationships between speed management technologies and conventional measures. Speed assistance technologies:
- coexist with conventional measures,
- are integrated in existing measures and make them more efficient,
- do something which existing measures cannot do and will partly replace conventional methods.

The first relationship is that of simple coexistence. While modern cars are increasingly being equipped with new speed assistance technologies such as ACC, police checks of speeding may continue or even intensify at the same time. Another relationship is when new technology is integrated in the system of enforcement. For example, Electronic Vehicle Identification (EVI) can be made part of the enforcement system and support this system. Finally, police enforcement as we know it may even be largely replaced by new technological systems of speed management. In principle, enforcement of speeding can happen at all times and places when the car is equipped with a black box that monitors when and for how long the car is driving over the speed limit. Zaidel (2000) sketches a Utopian view in which police enforcement of speeding is largely replaced by an alternative approach to speed management based on technology. His approach consists of five positions:
1. Compliance with speed is associated with the vehicle unit rather than a driver.
2. In-vehicle device and communication technology monitors vehicle speed at all times and keeps a record of distance travelled while speeding.
3. Vehicle owners are given redeemable credits for distance travelled at requested speed and are surcharged for distance travelled while speeding.
4. Companies and fleet owners are evaluated by authorities with respect to the aggregated speeding performance of their vehicles.
5. A marketing mechanism is created whereby non-speeding generates direct and indirect benefits to vehicle owners as well as to businesses; businesses and institutions sponsor the benefits and develop operating strategies that favour non speeding.

Zaidel sums up the following advantages of this system of speed management: self-enforcing, fair, immediate feedback, combination of carrot and stick, self-sustainable, and it lessens the need for conventional speed management.

For many intentional or unintentional violations (alcohol, fatigue, tailgating, bad night vision) in-vehicle technological solutions are present (ETSC, 2005). In this paper we focus on two speed management systems, *Adaptive Cruise Control* and *Intelligent Speed Assistance*. Both these systems have been evaluated in a number of driving simulator studies and field trials.

3.3. Speed management by Adaptive Cruise Control

A decade ago the first ACC systems appeared on the market as a supplement to the 'normal cruise control'. The standard cruise control allows the drivers to choose a fixed driving speed, starting from 50 km/h. ACC is more advanced because this system adapts the driving speed to the speed of the vehicle in front and because it allows the driver to adjust safe following distance to his or her own preferences. The industry has primarily developed these systems to improve driving comfort and this is also the main point in the marketing of these systems. Despite the fact that safety was not a primary design specification of these systems, we expect that cruise control systems can improve road safety.

The first generation of ACC systems were designed for use on motorways. The expected safety effect of ACC should in theory derive from the resulting homogenizing of speeds on motorways. The more recent generation of ACC (for example "Stop & Go") were developed with the aim of broader use on the whole road network. ACC works as follows: if there is no vehicle directly in front of the ACC vehicle, the system maintains the intended speed set by the driver, consistent with the conventional cruise control. When a vehicle in front is detected, the ACC vehicle's speed is adjusted until the distance equals that set by the driver. If the vehicle in front disappears, the ACC vehicle accelerates to the speed as selected by the driver beforehand.

Is the optimism about the safety effects supported by evidence? The effects of ACC on absolute speeds and the effects on secondary roads are not yet clearly established (Hoetink, 2003). At the moment, estimates of safety effects are based on outcomes of driving simulator studies. The results in these studies are not unanimous and sometimes contradictory.

Dragutinovic et al. (2005) analysed differences in average speed between driving with and without ACC. Their analysis shows varying results on average driving speeds: in some studies higher speeds were found with ACC as compared to without ACC (Hoedemaeker, 1999), in some others lower personal speeds. It should be pointed out that the driving simulator studies that generated these results only allowed respondents to drive in the simulator for a short time.

In conclusion, the evidence regarding safety effects of ACC is far from conclusive and the effects of ACC on driving speeds (and behaviour) remain to be verified in large scale field trails. Furthermore, it is to be recommended that safety itself is explicitly taken into account in the design phase of ACC.

3.4. Speed management by ISA

Intelligent Speed Assistance (ISA) is one of the most promising Intelligent Transport Systems in terms of its potential impact on safety. ISA is an intelligent speed management system which is based on information transfer between surroundings and vehicle. The vehicle receives information about the desired or legal speed limit from the surroundings and reacts to it. The standard system uses an in-vehicle digital road map onto which speed limits have been coded, combined with a positioning system which could be the satellite Global Positioning System (GPS).

The term ISA is often immediately associated with a completely intervening system, but in fact it is a collective name for various in-vehicle systems. Three intervention levels can be distinguished. The *open ISA* warns the driver (visibly and/or audibly) that the speed limit is being exceeded. The driver himself then decides whether to adjust his/her speed. The *half-open ISA* uses counter-force on the accelerator pedal when the speed limit is being exceeded (the 'active accelerator'). It is still possible to maintain the speed at that moment, but it is not very comfortable because of the counter-force. The *closed ISA* limits the speed when the speed limit is exceeded. The driver cannot influence this.

When discussing the concept of credible speed limits, one could think about dynamic limits in which a safe limit is adjusted to the current circumstances. For example, the speed limit information can potentially be extended to incorporate lower speeds at certain locations in the network. In the future, the speed limit information may take into account variation within current network conditions, based on weather, traffic density, the presence of incidents etc. Information about the actual speed limit, depending on these circumstances, should be given to the driver inside the vehicle everywhere and at all times. Such a system could be integrated with ISA.

The results of various studies on speed effects of different types of ISA provide a rather consistent evidence for a speed reducing effect of ISA. Closed ISA systems, that intervene in speed, are even expected to reduce traffic fatalities and casualties by 60% if all cars are equipped with this type of ISA (Carsten & Tate, 2005). At the same time, the public acceptance of this type of ISA is lowest. The assumptions underlying the calculations are not very robust and there are a number of uncertainties concerning the introduction of ISA. We do not know yet how ISA will affect general attitude and behaviour of drivers. Also, our knowledge about the extent to which ISA will generate a homogenizing effect on traffic flow is far from complete. Finally, the speed of implementation of ISA and the type of ISA system that will prevail can only be guessed at.

With regard to the possible secondary effects of ISA on behaviour there are several concerns:
- compensation behaviour (drivers sometimes compensate on road sections where the ISA system is not active)
- reduced attention (on long trips and boring roads ISA may lead to reduced attention for the surroundings possibly leading to lesser headway and slower reactions)
- overconfidence (using ISA can lead drivers to completely relying on the speed limit indicated by the system and paying insufficient attention to the 'real time' circumstances)
- feelings of frustration (ISA's speed limitation can invoke frustration in the driver himself and frustration in other drivers e.g. following traffic)

A recent review of the literature (Jamson et al., 2006) pointed out that beneficial secondary effects of ISA have also been found in studies (more attention, increase in perceived safety). However, in several studies increases in frustration and irritation have been found (Jamson et al., 2006). Frustration may be reduced once highly reliable ISA systems have been developed and once ISA loses its novelty effect. More research is needed to establish the extent of the possible negative side effects and their consequences. Very likely the safety potential for ISA will vary for different groups of drivers.

4. Discussion

The management of vehicle speed in general, and at certain locations and times in particular, is one of the fundamentals of a Sustainable Safe traffic system. At the heart of the speed management system lie the speed limits themselves which have to be safe, credible, known, and possibly flexible. With safe, credible limits and sufficient information we expect the number of speeding offences to drop considerably. Management of speed can take different forms (engineering measures, publicity campaigns, various types of mobile or fixed, conspicuous or hidden speed checks by the police, etc.). Especially inside urban areas, speed management schemes using physical speed reducing measures can be more effective than speed enforcement. Preferably the choice for implementation of these various measures is based on a general road safety policy that sets clear criteria for the application of each measure.

As long as motorists can choose their own speeds, there will always be a group that deliberately and sometimes regularly exceeds the speed limits. To reach this group, enforcement remains essential for the time being. On the longer term, new vehicle technology can have a positive safety effect on this group of road users as well. A crucial advantage of new vehicle technology is that speed violations can be monitored at any time or location, and when these systems are integrated with enforcement functions, an objective chance of detection of nearly 100% can be realised (Rothengatter, 1991).

Various countries that until recently had low levels of speed enforcement can expect to benefit in road safety from increased speed enforcement as long as police enforcement is considered as a link in the chain: legislation – detection – prosecution – penal system – rehabilitation. Although police enforcement may contribute to control of speeding and road safety, it is not without its limitations. First, effects of enforcement are often limited in time and space, and second, it is not aimed at improving intrinsic motivation to comply with speed limits. Finally, it should be noted that speed enforcement is a topic that generally invites strong public debate. Common complaints are that mostly minor offenders are caught, and that speeding fines are only meant to fill the National Treasury. In other words, the credibility of speed enforcement requires special attention and is one of the quality aspects of enforcement.

Ultimately, the ideal is to create a system of credible and dynamic limits in which the safest limit is adjusted to the current traffic circumstances. Information about the actual speed limit, depending on these circumstances, should be available to the driver inside the vehicle everywhere and at all times. Such a system could be integrated with Intelligent Speed Assistance (ISA).

Although reliable technical solutions for speed assistance systems seem nearby, this is more a mirage than reality. Before large scale penetration, there are still a lot of obstacles to overcome. We have to learn more about human responses to ACC and ISA devices. They require more support in society before facing a bright future. Furthermore, these devices require management on the national and international level to speed up these developments. In the meantime, traditional measures (physical infrastructural measures and enforcement activities, using more and more modern technologies) are known to be effective in reducing crash risks and should be applied. If that is considered, we recommend using results from research about effectiveness and efficiency of these kinds of intervention.

References

Aarts, L.T., Goldenbeld, Ch. & Schagen, I.N.L.G. van (2004). *Politietoezicht en snelheidsovertredingen; evaluatie van een handhavingsprogramma*. In: Justitiële Verkenningen, vol. 30, nr. 5, p. 93-107.

Aarts, L. & Schagen, I. van (2006). *Driving speed and risk of road crashes: a review*. In: Accident Analysis and Prevention, vol. 38, nr. 2, p. 215-224.

Andenaes, J. (1977). *The moral or educative influence of criminal law*. In: Tapp, J.L. & Levine, F.J. (eds.), Law, Justice and the Individual in Society: Psychological and Legal Issues. Holt, Rinehart and Winston, New York.

Bjørnskau, T. & Elvik, R. (1992). *Can road traffic law enforcement permanently reduce the number of accidents?* In: Accident Analysis and Prevention, vol. 24, p. 506-520.

Carsten, O.M.J. & Tate, F.N. (2005). *Intelligent speed adaptation: accident saving and cost-benefit analysis*. In: Accident Analysis and Prevention, vol. 37, p. 407-416.

Cauzard, J.-P. (ed.) (2004). *European drivers and road risk. Project on Social Attitudes to Road Traffic Risk in Europe SARTRE 3. Part 1. Report on principal results*. Institut National de Recherche sur les Transports et leur Sécurité INRETS, Arcueil.

Christie, S.M., Lyons, R.A., Dunstan, F.D. & Jones, S.J. (2003). *Are mobile speed cameras effective? A controlled before and after study*. In: Injury Prevention, vol. 9, p. 302-306.

Diamantopoulou, K. & Cameron, M. (2002). *An evaluation of the effectiveness of overt and covert speed enforcement achieved through mobile radar operations.* Report No. 187. Monash University Accident Research Centre, Victoria.

Dragutinovic, N., Brookhuis, K.A., Hagenzieker, M. & Marchau, V.A.W.J. (2005). *Behavioural effects of the Advanced Cruise Control use – a meta-analytic approach*. In: European Journal of Transportation and Infrastructure Research, vol. 4, p. 267-280.

Elliott, M. & Broughton, J. (2005). *How methods and levels of policing affect road casualty rates*. TRL Report TRL637. TRL Ltd., Workingham.

Elvik, R. (2001). *Cost-Benefit Analysis of police enforcement*. Working Paper 1 of the ESCAPE project. Technical Research Centre of Finland VTT, Espoo.

Elvik, R. & Vaa, T. (2004). *The handbook of road safety measures*. Pergamon Press, Amsterdam.

ETSC (1999). *Police enforcement strategies to reduce traffic casualties in Europe*. European Transport Safety Council, Brussels.

ETSC (2005). *In-car enforcement technologies today*. European Transport Safety Council, Brussels.

European Commission (2002). eSafety; *Final report of the eSafety Working Group on Road Safety*. European Commission, Brussels.

Gains, A., Heydecker, B., Shrewsbury, J. & Robertson, S. (2004). *The national safety camera programme. Three-year evaluation report*. PA Consulting Group, London.

Gibbs, J.P. (1975). *Crime, punishment and deterrence.* Elsevier, New York.

Goldenbeld, C. (1997). *Politietoezicht in verkeer: garantie voor meer veiligheid?* D-97-5. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Goldenbeld, Ch. & Schagen, I.N.L.G. van (2005). *The effects of speed enforcement with mobile radar on speed and accidents. An evaluation study on rural roads in the Dutch province Friesland*. In: Accident Analysis and Prevention, vol. 37, p. 1135-1144.

Goldenbeld, Ch., Jayet, M.C., Fuller, R. & Mäkinen, T. (1999). *Enforcement of traffic laws. Review of the literature on enforcement of traffic rules in the framework of GADGET.* Work Package 5. SWOV Institute for Road Safety Research, Leidschendam. [Not published]

Hess, S. (2004). *An analysis of the effects of speed limit enforcement cameras with differentiation by road type and catchment area*. In: Transportation Research Record, vol. 1865, p. 28-34.

Hirst, W.M., Mountain, L.J. & Maher, M.J. (2005). *Are enforcement cameras more effective than other speed management measures? An evaluation of the relationship between speed and accident reductions*. In: Accident Analysis and Prevention, vol. 37, p. 731-741.

Hoedemaeker, M. (1999). *Driving with intelligent vehicles; Driving behaviour with Adaptive Cruise Control and the acceptance by individual drivers*. TRAIL thesis series nr. 99/6, Delft University Press, Delft.

Hoetink, A.E. (2003). *Advanced Cruise Control en verkeersveiligheid*. R-2003-24. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Jamson, S., Carsten, O., Chorlton, K. & Fowkes, M. (2006). *Intelligent Speed Adaptation. Literature review and scoping study*. MIRA Ltd and Transport for London. University of Leeds, Leeds.

Kloeden, C.N., McLean, A.J., Moore, V.M. & Ponte, G. (1997). *Travelling speed and the risk of crash involvement. Volume 1: Findings*. Report No. CR 172. Federal Office of Road Safety FORS, Canberra.

Koornstra, M.J., Mathijssen, M.P.M., Mulder, J.AS.G., Roszbach, R. & Wegman, F.C.M. (eds.) (1992). *Naar een duurzaam veilig wegverkeer: Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010*. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Lynam, D., Nilsson, G., Morsink, P., Sexton, B., Twisk, D., Goldenbeld, Ch. & Wegman, F. (2005). *SUNflower+6; An extended study of the development of road safety in Sweden, the United Kingdom, and the Netherlands*. Transport Research Laboratory TRL, Crowthorne.

Mäkinen, T., Zaidel, D.M., Andersson, G., Biecheler-Fretel, M.-B., Christ, R., Cauzard, J.-P., Elvik, R., Goldenbeld, C., Gelau, C., Heidstra, J., Jayet, M.-C., Nilsson, G., Papaioanou, P., Quimby, A., Rehnova, V. & Vaa, T. (2003). *Traffic enforcement in Europe: effects, measures, needs and future.* Final report of the ESCAPE Consortium. European Commission, Luxembourg.

Menzel, C. (2004). *Basic conditions for the implementation of speed adaptation technologies in Germany*. Dissertation Technische Universität Kaiserslautern Fachgebiet Mobiltät & Verkehr, Kaiserslautern.

Mountain, L.J., Hirst, W.M. & Maher, M.J. (2005). *Are speed enforcement cameras more effective than other speed management measures? The impact of speed management measures on 30 mph roads*. In: Accident Analysis and Prevention, vol. 37, nr. 4, p. 742-754.

OECD (2003). *Road Safety. Impact of new Technologies*. Organisation for Economic Co-operation and Development OECD, Paris.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A.A., Jarawan, E. & Mathers, C. (2004). *World report on road traffic injury prevention*. World Health Organization WHO, Geneva.

Pilkington, P. & Kinra, S. (2005). *Effectiveness of speed cameras in preventing road traffic collisions and related casualties: systematic review*. In: British Medical Journal online, BMJ, doi:10.1136/bmj.38324.646574.AE.

Rijkswaterstaat Directie-Zuid-Holland (2003). *Evaluatie 80 km/uur-maatregel A 13 Overschie; Doorstroming en verkeersveiligheid*. Rijkswaterstaat Directie Zuid-Holland, Rotterdam.

Rothengatter, J.A. (1991). *Automatic policing and information systems*. In: Koornstra, M.J. & Christensen, J. (eds.), Enforcement and rewarding: Strategies and effects. SWOV Institute for Road Safety Research, Leidschendam.

Schagen, I.N.L.G. van, Wegman, F.C.M. & Roszbach, R. (2004). *Veilige en geloofwaardige snelheidslimieten: een strategische verkenning*. R-2004-12. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Tingvall, C. & Haworth, N. (1999). *Vision zero: an ethical approach to road safety and mobility*. In: Proceedings of the 6th ITE International Conference – Road Safety and Traffic Enforcement, Melbourne.

TRB (1998). *Managing speed*. Special Report 254. Transportation Research Board, Washington DC.

Wegman, F.C.M. & Aarts, L. (eds.) (2005). *Door met Duurzaam Veilig. Nationale Verkeersveiligheidsverkenning voor de jaren 2005-2020.* [Advancing Sustainable Safety; National Road Safety Outlook for 2005-2020]. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

Wegman, F., Eksler, V., Hayes, S., Lynam, D., Morsink, P., Oppe, S. (2005a). *SUNflower+6. A comparative study of the development of road safety in the SUNflower+6 countries. Final report*. SWOV Institute for Road Safety Research, Leidschendam.

Wegman, F., Dijkstra, A., Schermers, G. & Vliet, P. van (2005b). *Sustainable Safety in the Netherlands: the Vision, the Implementation and the Safety Effects. Contribution to the 3rd International Symposium on Highway Geometric Design, Chicago*. R-2005-5. SWOV Institute for Road Safety Research, Leidschendam.

Zaal, D. (1994). *Traffic law enforcement: a review of the literature*. Report No. 50. Monash University Accident Research Centre, Melbourne.

Zaidel, D. (2000). *Total Speeding Management (TSM) - a different way for controlling speeding*. Paper presented at the 13th ICTCT Workshop, 5-7 October 2000, Corfu, Greece.

Zaidel, D. (2002). *The impact of enforcement on accidents.* Deliverable 3 (Work Package 2) of the ESCAPE project. Technical Research Centre of Finland VTT, Espoo.