European Commission

Speed and Speed Management 2015

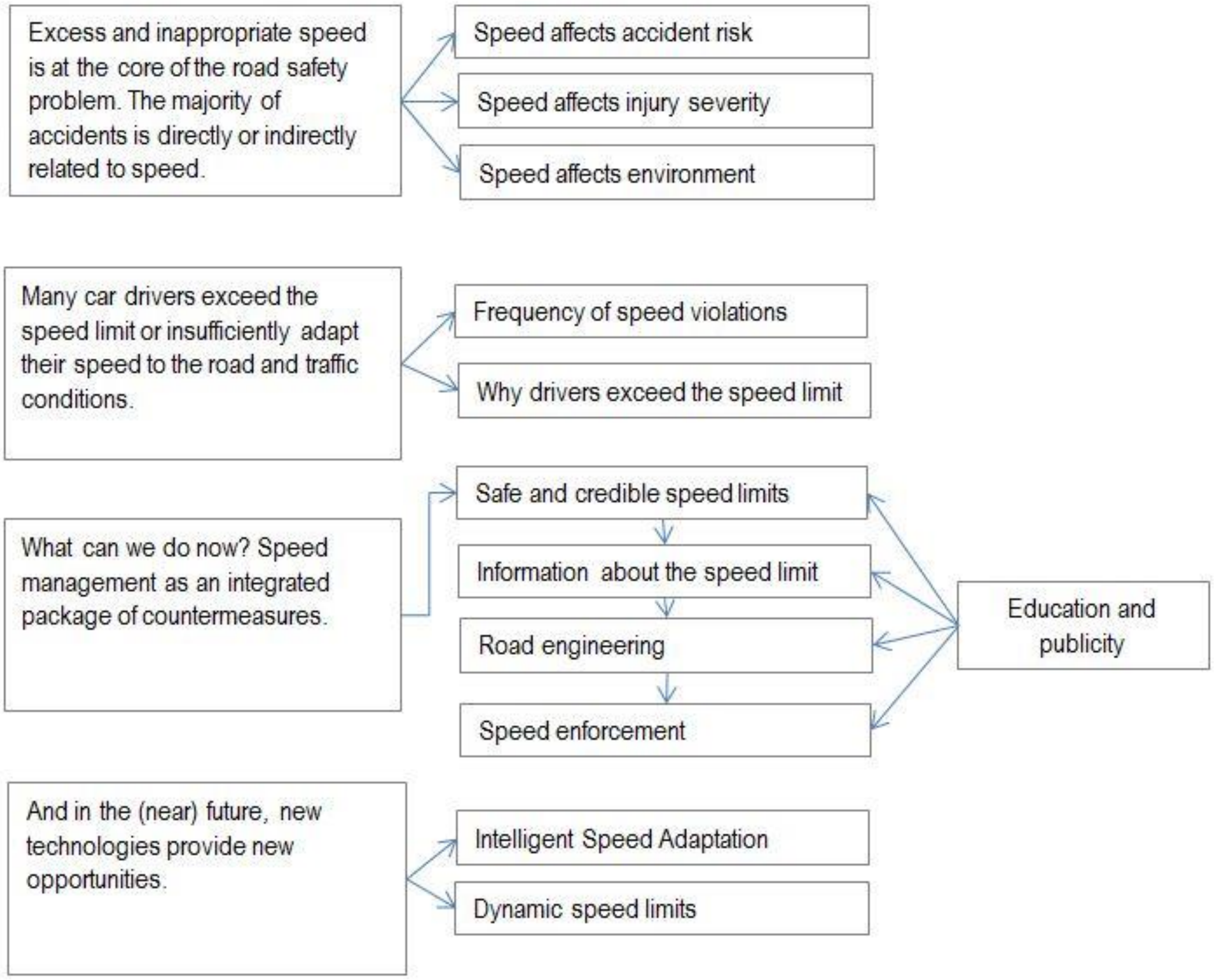
European Road Safety Observatory
www.erso.eu

Transport

CONTENTS

1 Speed and speed management: a summary

Figure 1: Speed management and road safety



Speeding: more and more severe accidents
Speed is at the core of the road safety problem. In fact, speed is involved in all accidents: no speed, no accidents. In around 30% of fatal accidents, speed is an essential contributory factor. Firstly, speed affects the risk of being involved in an accident. At a higher speed, it is more difficult to react in time and prevent an accident. Secondly, speed affects the injury consequences of an accident. At a higher (impact) speed, more energy is released when colliding with another vehicle, road user or obstacle. Part of this energy will need to be absorbed by the vulnerable human body. Very strong relationships have been established between speed and accident risk and severity.

Excess speed and inappropriate speed are very common
Speed limits provide information to the drivers about the safe speed to travel in average conditions. Exceeding the speed limits is very common. Typically, 40 to 50% of the drivers travel faster than the speed limit. Typically, 10 to 20% exceed the speed limit by more than 10 km/h. Given the strong relationship between speed and accident risk and severity, very many casualties could be saved if all drivers would only obey the current speed limits. In addition, drivers adapt

their speed insufficiently to local and temporary conditions related to traffic and weather. They often choose a speed that is inappropriate for the prevailing conditions. Speed choice is related to the drivers' motives, attitudes, risk perception and risk acceptance. Furthermore, speed choice is affected by characteristics of the road and the road environment and by characteristics of the vehicle.

What to do? Speed management as a package

There is no single solution to the problem of excess and inappropriate speed. A package of countermeasures is necessary, increasing the effectiveness of each of the individual measures. The most appropriate combination of measures will differ with circumstances. As a start, a good balance between road design, speed limit, and public perception of appropriate speed is vital.

At the core of speed management are the speed limits. Speed limits must define a safe speed, reflecting the function of the road, traffic composition and road design characteristics. Speed limits must also be credible for drivers, reflecting the characteristics of the road and the road environment. Drivers must be aware of the local speed limit at all times. This can be realized by good and consistent signing as well as consistent application of road markings and delineation, specifically related to particular speed limits.

Road engineering, like speed humps and narrowings, helps to reduce speed at locations where low speed is essential. If applied in a consistent way, these measures also help drivers to recognize the traffic situation and the corresponding speed limit. Despite these measures, there always will be drivers who exceed the speed limit. For these intentional violators enforcement remains a necessary instrument. Speed management has to be accompanied by education and information to make road users aware of the speed and speeding problem and about the 'why' and 'what' of countermeasures.

And what about new technologies?

New technologies enable in-vehicle systems that support drivers to comply with the speed limits. These systems, generally known as Intelligent Speed Adaptation (ISA), provide information about the speed limit in force; warn the driver when exceeding the limit; or make excess speed impossible or uncomfortable. The technology for such systems is available, but there are still some uncertainties that prevent large-scale implementation. New technologies also enable communication between road and vehicle, allowing for full dynamic speed limits, based on the actual traffic and weather conditions. These systems are still under development.

2 Speed is a central issue in road safety

Speed is a central issue in road safety. In fact, speed is involved in all accidents: no speed, no accidents. Speed has been found to be a major contributory factor in around 10% of all accidents and in around 30% of the fatal accidents (TRB, 1998; OECD, 2006). Both excess speed (exceeding the posted speed limit) and inappropriate speed (faster than the prevailing conditions allow) are important accident causation factors. In addition, speed generally has a negative effect on the environment, but a positive effect on travel time. The negative effects are mainly a societal problem and are hardly noticed by individual drivers; individual drivers on the other hand, particularly notice the positive effects.

Related to road safety, speed affects

- The risk of being involved in an accident;
- The severity of an accident.

In general: the higher the speed, the higher the accident risk and the more severe the accident consequences (see Aarts & Van Schagen, 2006, for an overview).

2.1 Speed and accident risk

Given a particular road, a higher speed increases the likelihood of an accident. Very strong relationships have been established between speed and accident risk. The general relationship holds for all speeds and all roads, but the exact rate of increase in accident risk varies with initial speed level and road environment. Large speed differences at a road also increase the likelihood of an accident. In addition, drivers driving much faster than the average driver have a higher accident risk.

Assessing potential effects of speed reduction measures

Based on work by Nilsson in Sweden, and applying a more recent empirical update (Elvik, 2009) a change in average speed of 1 km/h will result in a change in serious injury accidents of just over 2% for a 120 km/h road and around 3% for a 50 km/h road.

A similar relationship is assumed in Britain, based on empirical studies by Taylor (2000; 2002), where changes in accident numbers associated with a 1 km/h change in speed have been shown to vary between 1% and 4% for urban roads and 2,5% and 5,5% for rural roads, with the lower value reflecting good quality roads and the higher value poorer quality roads.

The exact relationship between speed an accidents on a particular road or in a particular area will depend on a range of road and traffic characteristics that interact with speed and also on the characteristics and behaviour of the drivers using the road, such as age, gender, drink-driving and seatbelt wearing.

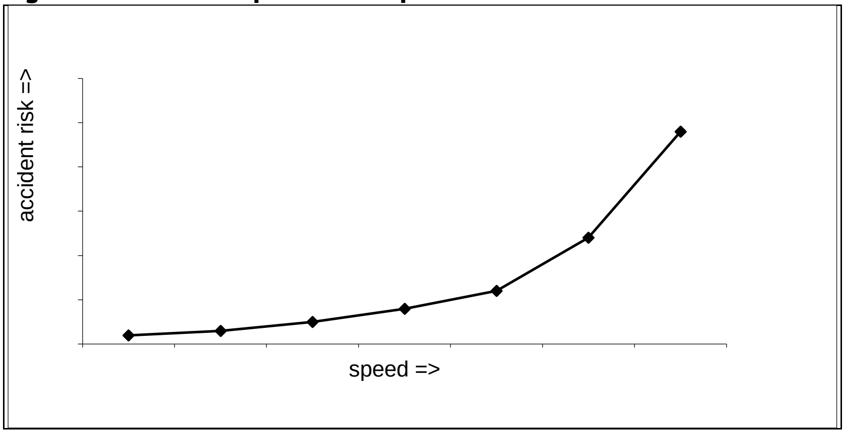
Higher speeds: more accidents

High speeds reduce the possibility to respond in time when necessary. People need time to process information, to decide whether or not to react and, finally to execute a reaction. At high speed the distance covered in this period is longer. At higher speeds the distance between starting to brake and a complete stand still is longer as well. The braking distance is proportional to the square of speed (v^2). Therefore, the possibility to avoid a collision becomes smaller as speed increases. This is well illustrated at a broad average level by Finch et al. (1994).

1 km/h increase in speed results in 3% increase in accidents
In practice the relationship is more complex. The exact relationship depends among many other things on original speed level and road environment.

The larger the increase in speed, the steeper the increase in accident risk
The relationship between speed and accident risk generally has been considered to be a power function: Given a particular road, with increasing speed, the accident risk increases more as the absolute speed gets higher (Figure 2).

Figure 2: Relationship between speed and accident risk.



Based on the principles of kinetic energy and validated by empirical data, Nilsson (1982; 2004) developed the following formula:

$$A_2 = A_1 \left(\frac{v_2}{v_1} \right)^2$$

In words: the number of injury accidents after the change in speed (A_2) equals the number of injury accidents before the change (A_1) multiplied by the new average speed (v_2) divided by the former average speed (v_1), raised to the square power.

Initial speed affects the relationship speed – accident risk
Several recent re-analyses of the speed-accident relationship (Cameron & Elvik, 2010; Elvik, 2013) found that the exact relationship between speed and accident risk depends on the initial speed. This suggests that the relationship between speed and accidents can be better described by an exponential function. Given a particular relative change in speed, the effects are smaller when the initial speed is lower. For example, bringing about a reduction of average speed of 10% will have a smaller effect when it concerns a reduction from 50 to 45 km/h than when it concerns a reduction from 100 to 90 km/h. In absolute sense, e.g. realizing a reduction of average speed of 10 km/h, a reduction in speed will result in a comparable reduction of the number of accidents independent of the initial speed (see IRTAD, in preparation).

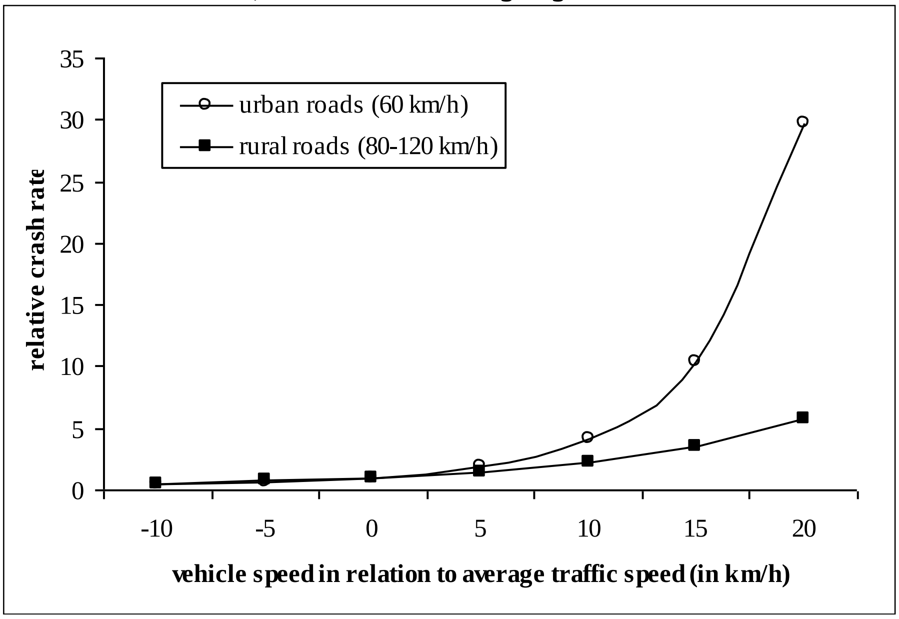
Larger speed differences: more accidents

If on a particular road, speed differences are large, this will result in less predictability, more encounters, more overtaking manoeuvres, etc. Therefore, when speed differences increase, the accident risk can be expected to increase as well. This was confirmed by a review of thirteen studies that assessed the effect of speed variance on accident rates, based on loop detector data (Elvik, 2014). Almost all of these studies did indeed find a positive relationship between speed variance and accident risk. There were, however, substantial differences in the exact numerical relationship. Moreover, the studies applied different research methods, making it impossible to compare the results in a meaningful way. Hence, so far, no reliable quantified relationship has been established for the relationship between speed variance and accident risk.

Higher accident risk for the faster driver

A number of studies looked at the risk of the individual driver in relation to speed. These studies compare the (estimated) speed of drivers who were involved in an accident with the average speed at that particular road. The first studies date from the 1960 and 1970s in the United States (e.g. Solomon, 1964). They found that both the faster driver and the slower driver had a higher risk of being involved in an accident. This was known as the U-curve speed-accident relationship. More recent studies, mainly conducted in Australia (Kloeden, McLean & Glonek, 2002) and Great Britain (Taylor, Lynam & Baruya, 2000) also found a higher accident risk for the faster driver. However, they did not find evidence for a higher accident risk for the slower driver. As an example, the results of the Australian studies are presented in Figure 3:

Figure 3: Relative accident rate on urban roads (Kloeden et al., 1997; Kloeden et al., 2002) and rural roads (Kloeden et al., 2001) for vehicles going faster and slower than average speed (=0)



2.2 Speed and injury severity

For any given road, clear physical relationships lead to higher severity of injury outcomes as speed increases. When the collision speed increases, the amount of energy that is released increases as well. Part of the energy will be 'absorbed' by the human body. However, the human body tolerates only a limited amount of external forces. When the amount of external forces exceeds the physical threshold serious or fatal injury will occur. Hence, higher speeds result in more severe injury. This is particularly true for occupants of light vehicles when colliding with more heavy vehicles, and for unprotected road users, such as pedestrians and cyclists when colliding with motorized vehicles.

Higher speeds: more severe injury

Road safety effects of speed changes are directly related to the change in kinetic energy that is released in a collision. Based on this, Nilsson (1982) developed the following formula to describe the effects of a speed change on the number of injury accidents:

$$A_2 = A_1 \left(\frac{v_2}{v_1} \right)^2$$

with A_2 as the number of injury accidents after a speed change; A_1 as the number of injury accidents before the speed change; v_1 as the average speed before the change, and v_2 as the average speed after.

Subsequently, Nilsson reasoned that the severe injury accident rate would be affected more by a change in speed than the overall accident rate. Based on empirical data of the effects on accidents after a speed limit change on Swedish roads, he increased the power of the function to calculate the number of severe injury (*I*) and fatal accidents (*F*) to respectively 3 and 4:

$$I_2 = I_1 \left(\frac{v_2}{v_1} \right)^3$$

$$F_2 = F_1 \left(\frac{v_2}{v_1} \right)^4$$

Most of the empirical data relate to speed changes on motorways and rural roads and they appeared to fit these general formulas very well (Nilsson, 2004; Elvik, Christensen & Amundsen, 2004). When more data for urban roads became available, it was found that the exact relationship between speed and accidents depends on the initial speed and that, in urban areas, speed changes have a somewhat smaller effect than on non-urban roads (Elvik, 2009; Cameron & Elvik, 2010; Elvik, 2013).

Relationship between speed and road safety

The relationship between speed and road safety can be described in terms of a power function, indicating that changes in speed affect the severe accidents substantially more than the less severe accidents. The Table below shows the power for different accident severities for rural roads/motorways and for urban/residential roads, based on empirical data from 115 studies containing 526 results (Elvik, 2009).

Accident /injury severity	Rural roads/motorways		Urban/residential roads	
	Best estimate	95% Confidence interval	Best estimate	95% confidence interval
Fatal accidents	4,1	(2,9-5,3)	2,6	(0,3-4,9)
Fatalities	4,6	(4,0-5,2)	3,0	(-0,5-6,5)
Serious injury accidents	2,6	(-2,7-7,9)	1,5	(0,9-2,1)
Serious injuries	3,5	(0,5-5,5)	2,0	(0,8-3,2)
Slight injury accidents	1,1	(0,0-2,2)	1,0	(0,6-1,4)
Slight injuries	1,4	(0,5-2,3)	1,1	(0,9-1,3)

2.3 Speed, injury risk and mass differences

When a heavy and a light vehicle collide, the occupants of light vehicles are far more at risk to sustain serious injury (Broughton, 2005). This is because the energy that is released in the collision is mainly absorbed by the lighter vehicle. Currently, the differences in mass between vehicles are very large. The difference between a heavy goods vehicle and a passenger car can easily be a factor of 20. But also the mass differences between passenger cars are large and still increasing. A mass difference of a factor of 3 is not an exception.

The difference in mass between pedestrians, cyclists and moped riders on the one hand and a motor vehicle on the other is extremely large. Hence, these road users have a particularly large risk of severe injury when colliding with a motor vehicle. In addition, pedestrians, cyclists and moped riders are largely unprotected: no iron framework, no seatbelts, and no airbags to absorb part of the energy. In the late seventies, Ashton and Mackay (1979; in ETSC, 1995) report the following relationship between car speed and survival chance of a pedestrian in car-pedestrian collisions:

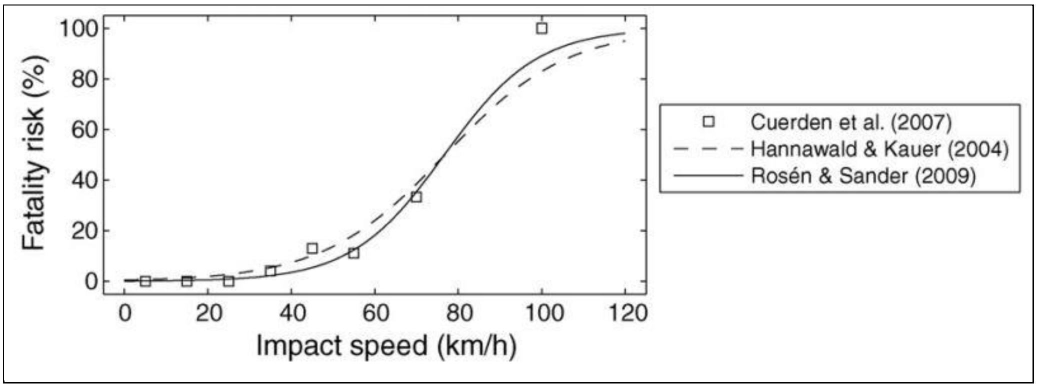
Table 1. Relationship between car speed and survival chance of a pedestrian in the seventies

Car speed	% fatally injured pedestrians
32 km/h	5
48 km/h	45
64 km/h	85

Source: Ashton & Mackay, 1979, in ETSC, 1995

Comparing older and newer research results, Rosén, Stigson & Sander (2011) conclude that later studies still show a steep increase of risk with increased impact speeds, but that in an absolute sense the recently reported risks are somewhat lower than those reported previously (Figure 4).

Figure 4: Fatality risk as a function of impact speed for pedestrians struck by the front of a passenger car.



Source: Rosén et al., 2011

2.4 Speed, environment and travel time

Speed not only affects road safety, but also the environment such as:

- The level of exhaust emissions
- The level of traffic noise
- Fuel consumption
- Quality of life for people living or working near the road.

In general, high speeds and large speed variation have a negative effect on each of these factors. High speeds and large speed variation also have a negative effect on road safety. Hence, with regard to speed management, road safety aims and environmental aims have much in common. Co-operation between road safety and environmental organizations may increase the political and public acceptability for speed management measures.

Speed also affects travel time. In principle, higher speeds result in a reduction of the travel time. However, higher speeds lead to more accidents and accidents are an important cause of congestion. In addition, in particular on short journeys, the perceived gain of time is much larger than the objective gain of time, which is in fact only marginal:

Table 2: Extra time taken for a 10 km journey when speed is reduced by 5 km/h

Original speed	50 km/h	70 km/h	90 km/h	110 m/h	130 km/h
Extra time taken (minutes)	1,33	0,66	0,39	0,26	0,18

2.5 Speeding: societal vs. individual consequences

The negative road safety outcomes of high speed on safety and environment are mainly evident at an aggregate, societal level. At the level of the individual driver, the risk of an accident is very small; at higher speeds the risk is higher, but still very small. Hence, an individual driver will hardly ever experience the safety consequences of excess speed. More or less the same applies for the environmental effects of speeding. These are also noticeable at an aggregate level, but hardly at the individual level (possibly with the exception of fuel consumption).

Contrary to the disadvantages, the advantages of higher speeds are experienced at the individual level. Individual advantages include just reaching traffic lights while still green, (subjectively) shorter journey times, thrill and enjoyment of speed or speeding.

This contradiction between societal and individual consequences makes persuading drivers of the value of speed management a difficult mission.

3 Many drivers exceed the speed limit

Many drivers drive faster than the posted speed limit. This is the case for all road types as it becomes clear from both objective observations and self-reported speed behaviour. In addition, people often drive at an inappropriate speed, because they fail to adapt their speed sufficiently to the actual road and traffic conditions. The reasons for speeding are diverse and may relate to temporary motives (e.g. being in a hurry), to more permanent personality characteristics (e.g. risk taking), to human perceptual skills and limitations, as well as to characteristics of the road, the road environment and the vehicle.

3.1 The frequency of speed limit violations

Observed speed limit violations

Speed limit violations are very common. Typically 40% to 60% of the drivers exceed the limit. Typically, around 10 to 20% exceed the speed limit by more than 10 km/h (OECD, 2006). The amount of violations on an individual road depends on many different, local aspects, including

- The local speed limit
- Characteristics of the road and road environment
- Traffic density and traffic composition
- The level of enforcement
- The country.

Drivers may intentionally or unintentionally exceed the speed limit, since speed choice and motives for speeding are affected by many factors.

Monitoring vehicle speeds nationally

To assess the extent of speeding violation nationally, countries should carry out speed surveys annually on a representative sample of their roads with different speed limits. Speed survey sites should be at locations where drivers can choose “free-speeds”, where they are not likely to be restricted by congestion or by local speed reducing measures.

Self-reported speeding behaviour

The SARTRE 3 survey (SARTRE, 2004) provides information on self-reported speeding behaviour for different road types. Most self-reported speed violations occur on motorways; least self-reported speed violations occur in built-up areas. The percentage of car drivers who report to violate the speed limit often, very often or always on different road types are:

- Motorways: 24%
- Main roads between towns: 18%
- Country roads: 12%
- Built-up areas: 8%

The percentage of self-reported speed violators is considerably smaller than the observed percentages. A reason could be that a few kilometres faster than the speed limit is not considered a speed limit violation by the drivers themselves.

In the SARTRE 4 survey (Cestac & Delhomme, 2012) European car drivers were asked to what extent they thought other car drivers would exceed the speed limit. According to the respondents the share of other car drivers that would exceed the speed limit “very often” or “always” was the following:

- On motorways: 52%
- Main roads between towns: 42%
- Country roads: 37%
- Built-up areas: 29%

Casualties to save

Given the strong relationship between speed and accident risk and severity, and the large proportion of drivers exceeding the existing speed limits, many casualties could be saved if drivers would just obey these limits. For example, for Norway it has been estimated that the number of fatalities could be reduced by about 22%, if speeding was completely eliminated (Elvik, 2008), which would mean an overall speed reduction from 78,5 to 74,3 km/h. For countries with higher levels of speeding a larger fatality reduction can be expected.

3.2 Inappropriate speed

Many drivers exceed the posted speed limits. But even if they keep to the posted speed limit, their speed may be inappropriate for the prevailing traffic, road or weather conditions. Objective data on the prevalence of inappropriate speed is difficult to obtain. One reason is that we do not know enough about the appropriate speed for specific conditions.

However, several studies conclude that drivers do adapt their speed to the actual conditions, but not sufficiently. For example, in rainy conditions the average speed is lower than when it is dry. At the same time the accident risk is higher during rain (SETRA-CSTR, 1990). Similarly, in Norway it was found that speed is reduced considerably when snow is falling or when the ground is covered by snow, but that road users insufficiently adapted their driving speed to offset the adverse effects on the number of accidents (Elvik & Kaminska, 2011). So, it must be concluded that the speed adaptation is often insufficient and that the speed remains inappropriate for rainy conditions and other adverse conditions.

3.3 Speed choice: why do drivers exceed the speed limit?

A large majority of the drivers consider speed as a very important problem for road safety. According to the SARTRE 3 study (2004), more than 80% of the European drivers state that driving too fast is often, very often or always a contributory factor in road accidents. At the same time, many drivers exceed the posted speed limits. Sometimes this may be intentionally, sometimes it is unintentionally. Speed choice is affected by the characteristics of the driver, by factors related to human perceptual skills and limitations, by the characteristics of the road and the road environment and by the characteristics of the vehicle.

Speed choice and driver characteristics

Many drivers prefer to drive faster than the objective risk justifies, but also faster than what they consider to be a safe speed. Motives for exceeding the speed limit are both rational and emotional and may depend on the temporary state of the driver or the actual situation. There are also more permanent personality characteristics that affect speed choice and explain differences between individual drivers and groups of drivers. These types of driver characteristics are related to speed preferences and speed violations.

People generally prefer to drive faster than is safe

Drivers, who prefer higher speeds, also consider higher speeds to be safe. In addition, almost all drivers want to drive faster than the speed that they themselves consider to be a safe speed (Goldenbeld & Van Schagen, 2007). According to the SARTRE 3 survey, around 20% of the European drivers report driving a little faster or much faster than other drivers. At the same time, only around 5% state that they drive more dangerously than other drivers. Apparently, dangerous driving is not related to speed in the mind of most of these drivers.

What are drivers' motives for exceeding the speed limit?

Most drivers openly admit that they more or less regularly exceed the speed limit. They provide the following reasons for these intentional speed limit violations:

- They adapted their speed to that of the general traffic stream
- They were in a hurry
- They generally enjoy driving fast
- They were bored

The arguments are both rational and emotional. Enjoying driving fast is a very common argument. According to the SARTRE 3 survey almost 10% of the European drivers agreed that they very much enjoy driving fast.

Another reason for exceeding the speed limit is that the driver is unaware of the speed limit. It may be assumed that this is an unintentional violation. Either a speed limit sign was absent or the driver missed it; in both cases the road characteristics were insufficiently informative about the speed limit in force.

Not all drivers are the same

Not all drivers are the same, not all drivers choose the same speed. First of all, there are differences between individual drivers. These individual differences may have to do with personality characteristics. For example, a clear relationship has been established between preferring to drive fast and a general preference for risky, sensational and challenging activities (Zuckerman & Neeb, 1980; Heino, 1996).

Secondly, it is possible to distinguish different groups in relation to speed preferences. For example, it has often been found that (e.g. Webster & Wells, 2000):

- Young drivers prefer to drive faster than elderly drivers;
- Male drivers prefer to drive faster than female drivers;
- Drivers driving for professional purposes prefer to drive faster than drivers driving for private purposes.

Perceptual skills: underestimation of driving speed

All motor vehicles have a speedometer to check the driving speed objectively. Nevertheless many drivers seem to rely as well on their subjective perception or 'feeling' of their speed when it comes to speed choice (Haglund & Åberg, 2000). However, human perceptual skills (and limitations) affect the subjective experience of speed and may lead to overestimation or underestimation of the driving speed. Hence, the subjective perception of speed is not very reliable. From a safety point of view, underestimation is the most dangerous.

Three types of situations easily lead to underestimation of one's own driving speed (ETSC, 1995; Martens, Comte & Kaptein, 1997; Eliott, McColl & Kennedy, 2003):

- Situations in which a high speed has been maintained for a long period, for example on long-distance trips on motorways. In these cases, the travel speed will increasingly be underestimated, resulting in higher speeds without the driver noticing.
- 'Transition' situations, where drivers must reduce their speed significantly after a period of driving at a high speed. When entering the lower speed zone, drivers will underestimate their travel speed. This is, for example, the case when leaving the motorway and entering a lower-speed two-lane rural road and when entering a village from a major through road. It may also be the case when a long straight section of road is followed by one or more curves.
- Situations where there is little peripheral visual information. For example, wide roads without points of reference, driving at night or in fog provide little peripheral information and are likely to lead to underestimation of the driving speed.

Speed choice and road and vehicle characteristics

The road environment may also elicit speed limit violations. There are large differences in the amount of speeding between individual roads of the same category and with the same speed limit. Incompatibility between the posted speed limit and the (implicit) message of the road and the road environment may be the reason. The road is insufficiently 'self-explanatory' and the speed limit may be considered as inappropriate. Either intentionally or unintentionally an imbalance between speed limit and the road characteristics may cause drivers to exceed the speed limit.

The characteristics of the car fleet continue to develop, particularly for cars. Some of these characteristics may affect speed choice:

- Engine power increases: cars can be driven faster;
- Comfort increases: there is less discomfort at high speed;
- Number of Land Rover-type cars increase: SUVs (Sport Utility Vehicles) and other 'Land Rover' type of cars become increasingly popular. This type of cars has high wheels, distorting the perception of speed. Speed will be underestimated.

4 Speed management as an integrated package

There is no single solution to the problem of excess and inappropriate speed. A package of countermeasures is necessary, increasing the effectiveness of each individual measure (OECD, 2006). The most appropriate combination of measures will differ with circumstances. In principle, effective speed management requires an integrated, systematic and stepwise approach. Within the current system of largely fixed speed limits, the following steps are important:

Step 1: Setting speed limits

The basis for any speed management policy is setting speed limits. Speed limits need to reflect the safe speed on that particular road, related to road function, traffic composition, and road design characteristics. Furthermore, speed limits need to be credible, i.e. they must be logical in the light of the characteristics of the road and the road environment.

Step 2: Information about the speed limit

The driver must know, always and everywhere, what the speed limit is. The conventional way is to use roadside signing and road markings. In-vehicle systems to inform drivers about the speed limit in force are being introduced progressively, e.g. via navigation systems.

Step 3: Road engineering measures

At particular locations low speeds may be crucial for safety (perceived or actual). Examples are near schools or homes for the elderly, at pedestrian crossings, at intersections. At these locations, physical speed reducing measures such as speed humps, road narrowing's and roundabouts help to ensure cars maintain a safe speed.

Step 4: Police enforcement to control the intentional speeder

If steps 1 to 3 are applied, it can be assumed that the unintentional speed violations are an exception. Drivers who still exceed the speed limit do so intentionally. Police enforcement will remain necessary to control and punish that group of drivers.

Information and education for drivers

All of steps 1 to 4 have to be accompanied by information to the driver on the problem of speed and speeding, what the speed limit system is based on and why, what additional measures are taken and why, and preferably also on the (positive) outcomes of these measures.

5 The elements of a speed management policy

In the five sections of this Chapter each of the five elements of an integrated speed management policy is discussed separately: setting speed limits, providing information about the speed limit in force, implementing road engineering measures, speed limit enforcement and, last but not least, education and publicity.

5.1 Setting appropriate speed limits

Until not so long ago, a common approach to determine the most appropriate speed limit for a particular road or road section was to set the limit close to the V85. The V85-speed is the speed that is not exceeded by 85% of the vehicles. However, increasingly it has been realized that the speed limit should be based on an analysis of the road and traffic characteristics to make sure that the limit represents a safe speed.

X-LIMITS approach used in Australia and United States

The computer programme X-LIMITS originally developed by the Australian Road Research Board (ARRB) for use by Australian and New Zealand state road authorities has been further developed as "USLIMITS" in collaboration with the Federal Highway Administration (FHWA) for application in the United States. The programme requires data to be input on density of development, frequency of access, road function, carriageway characteristics (such as number of lanes and carriageway separation), flow, interchange spacing, existing vehicle speeds, adjoining limits, and any special features such as high local accident rates. On the basis of this data, the program calculates a recommended speed limit.

A balance between safety, mobility and environmental considerations

Safety is only one element that affects what speed limit is applied. Also the effects on travel time and mobility must be considered. Setting limits aims to meet the optimum total cost by balancing safety and mobility consequences. There may be a different optimum for different roads depending on their accident rate and their function for mobility. What the optimum is, is largely determined by the method and assumptions that are applied to calculate the costs of road accidents and mobility loss, and increasingly also the costs of air pollution and noise. This, in the end, is a political decision. Assessment frameworks have been proposed to support these decisions (Kallberg & Toivanen, 1998; Lynam, Hill & Barker, 2004).

The Vision Zero approach (Tingvall & Howarth, 1999) proposes that the "balance" between safety and mobility should be judged from a more ethical standpoint. This requires that an upper limit is put on the injury risk that could occur on the road (e.g. virtually eliminating the chance of a fatality occurring). The speed limit and the design of the road infrastructure would then be matched to ensure that the injury risk was not exceeded.

Matching speed limits to human injury tolerance in different potential impacts

In Sweden, the concept of a safe speed, as originally discussed by Tingvall and Howarth (1999), has been adopted as a basis for considering appropriate speed limits. The driver-vehicle-road system should operate such that, in the event of an impact, forces are not exerted on vehicle occupants or other road users which are likely to lead to a fatality. Based on this, the updated Dutch Sustainable Safety philosophy presents the following requirements with regard to safe speeds in different traffic situations (Source: Wegman & Aarts, 2006):

Road type/traffic situation	Safe speed
Roads with potential conflicts between cars and unprotected road users	30 km/h
Intersections with potential side impacts between cars	50 km/h
Roads with potential head-on conflicts between cars	70 km/h
Roads where head-on and side impacts with other road users are impossible	≥100 km/h

Unfortunately, there is not yet sufficient knowledge to define the safe speeds for motorized two-wheelers and heavy good vehicles. Also from a practical point of view this problem is as yet unsolved. The best solution is the separation from other traffic, but it is not clear how to realize that in practice.

Who is responsible for setting speed limits?

Generally, the national government decides on the general, national speed limits for different road types. The national government may also determine which exceptions to the general limits can be applied. It generally is the road authority that decides what speed limit is applied for a specific road or road section in their jurisdiction. This decision, of course, must fit within the national speed limit framework, but in general it means that local or regional road authorities have a large amount of freedom in determining which speed limit would be applied where.

Current general speed limits in EU Member States

Current general speed limits vary across Member States. The general speed limit for motorways in EU Member States is mostly 120 or 130 km/h. Germany does not have a general speed limit for motorways, but a recommended speed of 130 km/h. The general speed limit for rural roads in EU Member States is mostly 80 or 90 km/h and for urban roads 50 km/h.

In most countries speed limits that differ from these general limits are applied. Widespread and well known are the 30 km/h zones in residential areas.

In Germany, where there is no general speed limit for motorways, many sections of the motorway have a local posted speed limit which may range from 80 km/h to 130 km/h, related to both safety and environmental considerations.

EU countries apply a lower speed limit for heavy good vehicles (HGVs) and buses/coaches. The majority of countries only apply an overall maximum speed limit for HGVs (generally 80 or 90 km/h) and buses (varying between 80 and 100 km/h). By EU Directive 92/24/EEC and its adaptation (2004/11/EEC), speed limiters are compulsory for HGVs of 3.500 kg and more and for buses of 10.000 kg or more.

Different speed limits in adverse weather and traffic conditions

Also the use of variable speed limits related to weather and traffic conditions vary across EU Member States.

Weather

In the EU, only France applies lower general speed limits for bad weather conditions. In case of rain or snow, the speed limit for motorways changes from 130 km/h to 110 km/h and at rural roads from 90 km/h to 80 km/h. In case of fog (visibility less than 50 meters) the speed limit on all types of roads is 50 km/h. In other countries (e.g. Germany, United Kingdom) matrix signs on motorways provide advisory or compulsory reduced speed limits when weather conditions are bad.

Both Finland and Sweden apply different general speed limits in wintertime. In Finland, the speed limit at motorways changes from 120 km/h to 100 km/h and, on main rural roads, from 100 km/h to 80 km/h. Similarly in Sweden the speed limits change respectively from 110 km/h to 90 km/h and from 90 km/h to 70 km/h.

In France, it is common to reduce the general speed limit by 20 or 30 km/h on a temporary basis, generally in case of high temperatures, with the aim to reduce air pollution and smog.

Traffic conditions

An increasing number of countries monitor traffic flow and use this information to inform through matrix signs drivers about (the chance of) congestion. This application is generally restricted to motorways and some of the most important rural roads. The information may consist of a general message, that congestion is ahead or may arise, to advisory reduced speed limits and compulsory reduced speed limits.

Speed limits and road function

The speed limit needs to reflect the function of a road. Ideally, a road network consists of a limited number of mono-functional roads. For example, in the Netherlands, Sustainable Safety distinguishes between three road functions (Wegman & Aarts, 2006; see Table).

Table 3: The three road functions according to the Dutch sustainable safety approach.

Flow function:	Roads with a flow function allow efficient throughput of (long distance) motorized traffic. All motorways and express roads as well as some urban ring roads have a flow function. The number of access and exit points is limited.
Area distributor function:	Roads with an area distributor function allow entering and leaving residential areas, recreational areas, industrial zones, and rural settlements with scattered destinations. Intersections are for traffic exchange (allowing changes in direction etc.); road links facilitate traffic in flowing.
Access function:	Roads with an access function allow actual access to properties alongside a road or street. Both intersections and road links are for traffic exchange.

Source: Wegman & Aarts, 2006

In line with human injury tolerance, at roads with a flow function and at the links of roads with a distributor function speeds of motorized traffic can be allowed to be high if:

- Motorized traffic is physically separated from pedestrians, cyclists, mopeds and slow moving agricultural vehicles; and
- Road design standards are good.

At roads with an access function and at intersections of roads with a distributor function speed must be low since here all road users make use of the same space. At these locations road engineering measures may be required to support the low speed requirement.

Speed limits and design speed

In general terms, the design speed of a road can be defined as the highest speed that can be maintained safely and comfortably when traffic is light (ETSC, 1995). More specifically the design speed is used by road engineers to determine the various geometric design features of the roadway (AASHTO, 2001; Fitzpatrick, & Carlson, 2002). The exact definition differs from country to country.

In principle, the required design speed depends on the function of the road and, hence, on the desired speed level. If, because of the road function, high speeds are desired, road quality and roadside protection need to be of an appropriate standard. The alternative to improving road standard is to reduce the speed limit consistent with the standard and risk of the road. The exact values for design standards of different road types differ as well from one country to another.

Clearly, the design speed must never be lower than the speed limit. It is not wise to have a speed limit which is much lower than the design speed of a road. This may damage the credibility of a speed limit.

Furthermore, it is important that the design speed is consistent over a longer stretch of road. A substantial reduction of design speed at a particular site must be supported by more than just a sign with the reduced speed limit. Additional warning signs should preferably be accompanied by a change in road design characteristics and/or road markings.

Credible speed limits: characteristics of the road and road environment

A credible speed limit is a limit that is considered to be logical by (the majority of) drivers for that particular road in that particular road environment. It is incredible when, for example:

- The speed limit sign for built-up areas is located 'in the middle of nowhere' when actual buildings and town activities are not yet visible
- The same speed limit is applied for a wide, straight rural road and a narrow, winding rural road
- If different limits are applied for motorway sections with a similar cross section and a similar (rural) environment. (If other reasons than safety are the basis of these different limits, e.g. noise protection, environmental pollution, this must be clearly communicated to the road users (compare the German sign 'Lärmschutz', i.e. noise protection)

In general, the principle of credibility implies that any transition from one speed limit to another must be accompanied by a change in the road or road environment characteristics.

Credibility of speed limits can be further enhanced by applying different speed limits for different weather and traffic conditions, i.e. by a system of dynamic speed limits.

5.2 Information about the speed limit in force

Setting an appropriate, credible speed limit is of course the first step. The second step is to assure that the driver always and everywhere knows what the speed limit in force is. The conventional way is the use of roadside signing and road markings. In-vehicle systems to inform drivers about the speed limit in force are being introduced progressively, e.g. integrated in navigation systems.

Signing and marking

Whereas almost all drivers know what the general speed limits in their country are, there is still often uncertainty about the speed limit in force when driving at a particular road (Silcock et al., 2000). There are several supplementary ways to reduce the uncertainty:

Roadside signing

The conventional way to inform road users about the speed limit at a particular road or road section is roadside signing. The Vienna Convention provides guidelines for roadside signing in general, for example regarding uniformity, consistency, simplicity and legibility. With regard to speed limit signs it is important that they are placed on a regular basis; for example, a sign is usually needed after a junction. As with all other road side signs, speed limit signs need to be placed such that they are very visible. They also need to be maintained adequately. Signs may fade in sunshine or become illegible by dirt or overgrown trees. It must be noted that in many countries, e.g. in Norway and The Netherlands, general speed limits are not signed, only the exceptions.

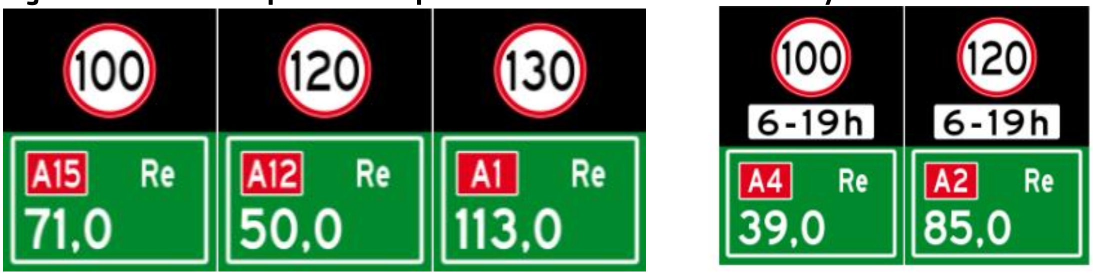
Road markings

To support the road side signs, a speed limit sign can also be painted on the pavement, for example at speed limit transitions. Furthermore, the speed limit regime at a particular road type can be supported by differential, but consistent longitudinal lines (line present/absent, broken/solid, different colours). The meaning of the differential lines with regard to the required speed must be clearly communicated to the road users. The 'automatic' effect of longitudinal marking on speed behaviour has been found to be very small (Van Driel, Davidse & Van Maarseveen (2004).

Small repeater signs as reminder

In addition to the regular speed signs, small repeater signs can help to remind the drivers of the speed limit in force. For example, in the Netherlands these small repeater signs are used at motorways in order to distinguish between the general limit of 130 km/h and permanent or time-dependent limits of 100 or 120 km/h. These signs are placed every 1.000m integrated in the hectometre posts (xx,0; see Figure 5). In Britain, small repeater signs are required at regular intervals, where roads have speed limits which are not the commonest for that road type.

Figure 5: Hectometre posts with speed limit reminders on motorways in the Netherlands.



Source: Dutch Ministry of Infrastructure and the Environment

In-vehicle information systems

The development of in-vehicle systems to inform drivers about the speed limit in force continues rapidly and is already often integrated in navigation systems. This type of in-vehicle information systems make use of detailed digital maps that are linked to a speed limit database. These systems enable the driver to get information on the speed limit in force, wherever he or she is. This speed limit database, however, is not always up-to-date and does not have information on temporary speed limits, e.g. related to work zones.

5.3 Road engineering

Overall road design should reflect the function of a road and, in combination with design speed, the appropriate speed limit. At specific locations, additional road engineering measures may be necessary to ensure the safe speed of cars. If applied in a consistent way, this type of measures may also help drivers to recognize the traffic situation and the speed limit. Locations where physical speed reduction measures are often necessary are residential areas, at-grade intersections at main urban and rural roads, high speed to low speed transition zones, and midblock pedestrian crossings.

Use of 30 and 60 km/h zones and accompanying measures in the Netherlands

In the Netherlands between 1985 and 1997, about 10-15% of the urban residential roads were converted to 30km/h zones. The roads in these zones were redesigned using road humps, road narrowing's and mini-roundabouts to ensure the 30 limits were respected. Subsequently, as part of the Sustainable Safety initiative, there was a major increase in investment in these zones between 1998 and 2007. In this period, the proportion of urban access roads treated has increased to 90%. Engineering work within the zones was however less extensive than in the earlier zones. According to Sustainable Safety, rural access roads should have a reduced speed limit of 60 km/h. Between 1998 and 2007, around 75% of these roads categories were redesigned into 60 km/h zones.

In parallel, engineering work has also been used on the urban and rural roads where speed limits were not reduced to 30/60 km/h to maximize separation of vulnerable road users.

Source: Weijermars & Wegman (2011)

Residential areas: 30 km/h + supportive engineering measures

An increasing number of countries apply 30 km/h zones in residential areas, based on the known relationship between speed and the chance for vulnerable road users to survive a collision. In order to ensure that the 30 km/h limit is not exceeded, the limit is best supported by engineering measures such as speed humps, road narrowing's, chicanes and raised areas at intersections. The application of these vertical and horizontal measures has been found to have a substantial effect on speed (e.g. Van Schagen, 2003). In addition, this type of measures makes roads less attractive for motorized traffic, resulting in less through traffic. Both reduced speeds and less traffic (traffic calming) can substantially improve safety. A review by Bunn et al. (2009) resulted in the conclusion that, as a best estimate, traffic calming measures result in a reduction of fatal and non-fatal injuries of 15%.

Roundabouts and midblock pedestrian crossings
Speed reduction is also particularly appropriate at at-grade intersections at main urban and rural roads. For these locations, the application of roundabouts is a very effective speed reduction measure. In addition, at roundabouts the angle of impact is smaller, resulting in less severe consequences in case of a collision. Based on a meta-analysis (Elvik et al., 2009) it is reported that overall, a roundabout can be expected to reduce the number of injury accidents with 40 to 50%. The effect on fatal accidents is even somewhat larger. The exact effect depends on various factors. The largest effects are found of roundabouts in rural areas, of roundabouts that replace a previous non-signalized intersection and of roundabouts that replace a previous four-legged junction.

At mid-block pedestrian crossings the speed of motorized vehicles should also be kept low. A raised crossing will make high speeds less likely.

Transition zones
When entering the lower speed zone, in particular after a period of driving at a high speed, drivers will easily underestimate their travel speed, and hence insufficiently adapt their speed. Here specific measures help to indicate the transition from one traffic environment to another, to other traffic behaviour, and primarily to another speed.

Of special concern is the entrance of a village from a major through road. ETSC (1995) describes two principles for measures in such transition zones. The first principle is that complementary measures along the through route within the urban area are required. The second principle is that measures at the transition zone should be such that they achieve a cumulative effect towards the actual gateway to the towns or villages. The latter can be achieved, as the ETSC reports says, by a combination of road narrowing and the introduction of vertical elements, culminating at the gateway. This is an example of a psychological measure that relies on the driver's perception of the appropriate speed: speeds are lower where the height of the vertical elements is greater than the width of the road (Herrstedt et al., 1993).

Taylor and Wheeler (2000) evaluated the effects of 56 traffic-calming schemes in British villages on main interurban roads where the speed on the approach to the villages was typically 90 km/h. It was found that the schemes with only gateway measures resulted in a reduction in fatal and serious accidents within the villages of 43%; the number of slight accidents increased by 5%. The accident reduction was higher for pedestrians and cyclists than for motor vehicles. Higher accident reduction rates were reported for schemes with additional measures inside the villages (chicanes, road narrowing, mini-roundabouts, speed humps and speed cushions). Here, the number of fatal and serious accidents decreased by about 70% and the number of slight injuries by about 37%.

The transition between motorways and adjacent lower speed zones is another situation where underestimation of speed may result in insufficient speed adaptation. A roundabout at the exit of the motorway may restore speed perception and facilitate choosing the appropriate speed.
Where a long straight stretch of road enters a winding section, physical speed reduction measures are less suitable. Currently, roadside warning signs and advisory speed limits are the most commonly used in this type of situations. Vehicle actuated signs warning of speeds being inappropriate for approaching hazards have proved effective in Great Britain (Winnett & Wheeler, 2002). There is also experience with (combinations of) transverse and longitudinal pavement markings at dangerous curves as a perceptual rather than a physical speed reduction measure (Fildes & Jarvis, 1994). Similar pavement markings have been used at village gateways. Evaluation studies generally show a positive effect on driving speed, but there is uncertainty over how long this effect will last over time (Martens, Comte, & Kaptein, 1997).

5.4 Speed enforcement

Speed enforcement aims to prevent drivers exceeding the speed limit by penalizing those who do. This not only affects the speed violators who actually get caught (specific deterrence), but also those who see or hear that others get caught (general deterrence). Speed enforcement will remain an essential speed management measure as long as the speed problem is not solved in a structural way by road design, engineering measures or in-vehicle technology. There are various tools and methods available for speed enforcement. Police enforcement can be a very effective measure, even though the effects are limited both in time and place. Surveys show that road users are generally fairly positive about it. A separate Erso web text deals with the subject of Speed Enforcement.

5.5 Education and publicity campaigns

Road users can be made better aware of the risk of inappropriate speeds to themselves and others through education and driver training, publicity campaigns and driver (improvement) courses. In addition, these instruments can be used to inform road users about specific speed management measures, in particular about the reasons, the expected benefits and, preferably, also about the realized effects. Education and publicity are conditional on other speed reduction measures, such as speed enforcement and the acceptance of legal changes. On its own, the effect of education and publicity in changing actual speed behaviour is limited.

Road user education and driver training

Structural traffic education as part of the school curriculum is generally limited to primary schools. At that age, the possibilities of influencing later speed behaviour of the pupils are very limited. Perhaps it is possible to introduce children to the 'speed' problem, with the purpose of them talking to their parents about their speed behaviour.

For the young in secondary schools, the (theoretical) preparations for a driver license or, in some countries, a moped certificate may be the right moment to turn their attention to the consequences of driving or riding (too) fast. That driving/riding too fast leads to more and more severe accidents applies to moped riders just as much as to car drivers. The question remains, of course, of the extent to which this sort of information influences the actual speed behaviour of the novice moped riders and later on as car driver.

Subsequently there is the driver training. Clearly, the future motorist has to learn what a safe speed is and how speed and speeding relate to road safety. This concerns, for example, speed limits and why they have been set at the speeds they are, and adapting one's speed to the circumstances, etc. They also have to be taught to anticipate and adapt their speed in time. However, during driving lessons, the driving instructor has a difficult message. On the one hand, there is the message 'keep to the speed limit', and, on the other hand there is the message that 'going with the flow' is safer. But 'the flow' is often faster than the speed limit. More than that, if the (learner) car driver does keep to the speed limit, he/she will often be overtaken and the (learner) driver will practically never see the negative consequences for these 'speeders': i.e. an accident, a fine. This does not exactly contribute to either a deep respect for speed limits or to realizing the need for obeying speed limits.

All together, the effects of road user education and driver training on their own on actual speed behaviour must be considered to be limited. Nevertheless, education and the driver training is essential to provide information on the risks of excess and inappropriate speed and the why and how of speed limits.

Publicity campaigns

Publicity and information campaigns about speed are very useful in various ways (Delhomme et al., 1999). They can be used to explain the goal, necessity, and effects of measures such as physical speed limiters and 30 km/h zones. They have been found to considerably increase the effectiveness and acceptance of speed enforcement. Besides this, campaigns can be used to make people aware of the problem of driving (too) fast. The direct effect of publicity campaigns on speed behaviour is limited. A meta-analysis of the effects of road safety campaigns in the CAST project (Vaa & Phillips, 2009) showed that, overall, speed campaigns resulted in a reduction of speeding of 16%. Most effective were local campaigns in combination with enforcement; the effect of mass media campaigns (i.e. using television, radio or newspaper as the communication channel) was not significant. Probably related to this, the same analysis showed that achieving a feeling of intimacy and immediacy increases the effect of a campaign. When using mass media campaigns, Delaney et al. (2004) found that a convincing, emotional approach is more effective than a rational, informative approach.

Publicity campaigns are usually aimed at the road user him/herself. However, they can also be aimed at his/her social surroundings. The success of this has been shown by campaigns against drink-driving, which is socially unacceptable nowadays. An attempt should be made to discover if the same applies to speeding.

Driver improvement courses

Driver improvement courses generally follow a serious traffic violation or are related to a particular level of demerit points. A course can be compulsory or voluntary, e.g. in combination with a reduction of the fine. Most driver improvement courses are related to drink-driving offences. Driver improvement courses also relate to safe/defensive driving in general. Only a few countries apply driver improvement courses specifically related to speed offences, e.g. Austria, Switzerland, Finland, UK, and Belgium. For methodological reasons, it is very difficult to assess the effectiveness of driver improvement courses. Those studies that did, generally found that the effects on accident risk are small (Ker et al., 2005), or non-existent (Masten & Peck, 2003).

6 New technologies, new opportunities

New technologies that can make traffic management more intelligent and flexible emerge rapidly. They are based on digital maps in relation to vehicle positioning information, e.g. through GPS. They are also based on the possibilities of vehicle-roadside communication and the automatic detection of the actual traffic, road and weather circumstances. Some systems are already available and being introduced progressively. With respect to speed management, there are interesting and promising developments related to ISA and dynamic speed limits.

6.1 Intelligent Speed Adaptation (ISA)

Intelligent Speed Adaptation (ISA) is an in-vehicle system that supports drivers' compliance with the speed limit. ISA is in fact a collective term for various different systems. Field trials and driving simulator studies show positive effects on speed behaviour and imply large safety effects. Some studies report negative side effects of ISA, but there is yet insufficient insight in the size of these possible negative side effects and their consequences. Around one quarter of European car drivers considers a speed-limiting device like ISA to be very useful; actual experience with ISA seems to increase acceptance. Yet, wide implementation of ISA is still far away.

What is ISA?

Intelligent Speed Adaptation (ISA) is an in-vehicle system that uses information on the position of the vehicle in a network in relation to the speed limit in force at that particular location. ISA supports drivers in complying with the speed limit everywhere in the network. This is an important advantage in comparison to the speed limiters for heavy good vehicles and coaches, which only limit the maximum speed.

ISA is a collective term for various systems with various levels of support:

- The open ISA warns the driver (visibly and/or audibly) that the speed limit is being exceeded. The driver him/herself decides whether or not to slow down. This is an informative or advisory system, currently integrated as an option in most navigation systems.
- The half-open ISA increases the pressure on the accelerator pedal when the speed limit is exceeded (the 'active accelerator'). Maintaining the same speed is possible, but less comfortable because of the counter pressure.
- The closed ISA limits the speed automatically if the speed limit is exceeded. It is possible to make this system mandatory or voluntary. In the latter case, drivers may choose to switch the system on or off.

The currently available ISA systems are based on fixed speed limits. They may also include location-dependent (advisory) speed limits. It will become increasingly possible to include dynamic speed limits that take account of the actual traffic and weather circumstances at a particular moment in time.

How effective is ISA?

In the 1990s and 2000s, in a number of European countries field trials with different types of ISA have been carried out, for example in Sweden (Biding & Lind, 2002), the Netherlands (Besseling & Van Boxtel, 2001), France (Ehrlich et al., 2006), Belgium (Vlassenroot et al., 2007) and United Kingdom (Carsten et al., 2008). There has also been several studies using driving simulators to assess effectiveness of ISA (e.g. Carsten & Tate, 2005; Van Nes & Van Schagen, 2010).

Studies generally find a substantial decrease in average speed, speed variance and speed limit violations. Closed ISA variants are more effective than half open variants and half open variants are more effective than open variants of ISA. Based on trials in the UK, Carsten (2012) estimates that a non-overridable closed ISA that eliminates virtually all speed limit violations could halve the number of fatal accidents. In the UK speed limit compliance is relatively high; the potential gain in poorer performing countries would probably even be larger.

ISA also positively affect fuel use and exhaust emissions, but the effects are marginal as compare to its effect on accidents (Lai et al., 2012).

How effective is ISA for speed offenders?

A study in the Netherlands (van der Pas et al., 2014) specifically looked at usefulness of ISA for serious speed offenders. The two systems that were tested, one a closed variant, the other an open variant, had a large positive effect on the level of speeding. Also mean speed and standard deviation of speed were reduced. However, the offenders regularly applied the 'emergency' button that was available and that allowed the driver to switch off the system for 15 seconds (after 15 seconds, and still above the threshold, the system produced a loud beep every 2 seconds). Furthermore, it appeared that the offenders fall back to their habitual speed behaviour after the ISA has been removed.

Does ISA have negative side effects?

ISA may have some negative side effects, in particular the voluntary ISA systems. Issues that have been reported are:

- Compensation behaviour: there are indications that drivers compensate by driving faster on road segments where the ISA system is not active (Persson et al., 1993).
- Diminished attention: ISA can result in reduction of attention for the road and traffic situation, when the system is not active, e.g. forgetting to slow down when entering a lower speed zone or to accelerate when entering a higher speed zone, but also in forgetting to use the direction indicator (Comte, 2000; Várhelyi et al., 2002).
- Overconfidence: it is possible that using ISA could result in the driver completely relying on the speed limit indicated by the system, and insufficiently observing the real-time circumstances that might require lower speeds.
- Insufficient adaptation: when ISA is switched on and without additional training, drivers may insufficiently adapt to changed vehicle features, e.g. longer time for overtaking (Jamson et al., 2012).

At present there is insufficient insight into the size of these possible negative side effects and their consequences.

How acceptable is ISA for the public?

In the SARTRE 4 survey (Cestac & Delhomme, 2012) almost two thirds of the European drivers (63,7%) stated to be very or fairly much in favour of a speed limitation device that prevents drivers from exceeding the speed limit. There were large differences between countries, with drivers from southern countries being somewhat more in favour of speed limiting devices than drivers from northern countries. The practical experiments in the Netherlands have shown that the acceptance of ISA increases if concrete experience with it has been gained (Besseling & Van Boxtel, 2001). On the other hand, there are indications that long-term use leads to more frustration (Lai et al., 2010). And drivers who "need" ISA most were found to be least willing to use it (Vlassenroot, 2011).

What are the main barriers for implementation?

Overall, as Carsten (2012) concludes, the public attitudes towards ISA are fairly positive and the technology is available. Nevertheless, wide implementation of ISA, other than the noncommittal warning option in most navigation systems, seems still far away. Based on a literature review and a survey amongst research and policymaking experts, Van der Pas (2012) identified the uncertainties that formed the most important barriers for wide-scale implementation of different types of ISA (warning, assisting, restricting). Table 4 shows the top 3 of barriers according to the 75 experts who completed the survey.

Table 4. The top 3 of barriers to the implementation of three types of ISA, as identified by Van der Pas et al., 2012.

	Warning ISA	Assisting ISA	Restricting ISA
	Uncertainty regarding:		
1	Reliability of speed limit database	Liability allocation in case of malfunctioning	Liability allocation in case of malfunctioning
2	Liability allocation in case of malfunctioning	Willingness of people to use the system	Willingness of people to use the system
3	The factors that contribute to ISA acceptance and to what degree	The best implementation strategy (voluntary, mandatory, incentives)	Which stakeholder involved in implementation and their importance

6.2 Dynamic speed limits

Fixed speed limits represent the appropriate speed for average conditions. Dynamic speed limits, on the other hand, are limits that take account of the real time traffic, road and weather conditions. Dynamic limits can better reflect the safe speed. If, for example, 80 is a safe speed in average conditions, 90 km/h may still be safe in optimal conditions, whereas 60 may still be too high in very busy, or dark and slippery conditions. Dynamic limits are also expected to increase the credibility of the speed limit system in general.

A number of countries apply dynamic speed limits on their motorways, related to traffic flow or weather conditions. Increasing technological developments would allow for dynamic speed limits at other road types as well and eventually integrated into intelligent speed adaptation devices.

References

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

AASHTO (2001) A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials (AASHTO). Washington DC.

Besseling, H. & van Boxtel, A. (2001) Intelligent speed adaptation; results of the Dutch ISA Tilburg trial. Ministry of Transport, Transport research Centre AVV, Rotterdam, NL.

Biding, T. & Lind, G. (2002) Intelligent Speed Adaptation. Results of large-scale trials in Borlänge, Linköping, Lund and Umea during the period 1999-2002. Vägverket, Borlänge, Sweden.

Broughton, J. (2005) Car Occupant and Motorcyclists Deaths 1994-2002. TRL Report TRL629. Transport Research Laboratory, Crowthorne.

Bunn, F. Collier, T. Frost, C. Ker, K. Steinbach, R. Roberts, I. & Wentz, R. (2009) Area-wide traffic calming for preventing traffic related injuries (review). The Cochrane Database of Systematic Reviews, No. 4, CD003110.

Cameron, M. H. & Elvik, R. (2010) Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads. Accident Analysis and Prevention, 42, 1908-1915.

Carsten, O. (2012) Is intelligent speed adaptation ready for deployment? Accident Analysis and Prevention, 48, 1-3.

Carsten, O., Fowkes, M., Lai, F., Chorlton, K., Jamson, S., Tate, F. & Simpkin, B. (2008) Intelligent Speed Adaptation ISA - UK: final report. Leeds, University of Leeds.

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

Cestac, J. & Delhomme, P. (Eds.) (2012) European road users' risk perception and mobility. The SARTRE 4 survey. Brussels, European Commission, Directorate-General Mobility and Transport.

Comte, S.L. (2000) New systems: new behaviour? Transportation Research Part F, 3, 95-111.

Delaney, A., Lough, B., Whelan, M. & Cameron, M. (2004) A review of mass media campaigns in road safety. Report No. 220-2004. Monash University Accident Research Centre, Victoria, Australia.

Delhomme, P., Vaa, T., Meyer, T., Goldenbeld, C., Jarmark, S., Christie, N., Harland, G., & Vlasta, R. (1999) Evaluated road safety campaigns: an overview of 265 campaigns and some meta-analysis on accidents. In Guiding Automobilists Through Technology & Education. European Commission. Brussels, EC-DGVII. Deliverable 4. Contract RO-97-SC.2235.

Ehrlich, J. Saad, F. Lassarre, S. & Romon, S. (2006) Assesmment of “Lavia” speed adaptation systems: initial results on system use and speed behaviour. In: Proceedings of the 13th World Congress and Exhibition on Intelligent Transport Systems (ITS) and Services, London, United Kingdom, 8-12 October 2006, 13 p.

Elliott, M.A., McColl, V.A. & Kennedy, J.V. (2003) Road design measures to reduce drivers speed via ‘psychological’ processes: A literature review. TRL Report 564. Transport Research Laboratory, Crowthorne.

Elvik, R. (2008) Dimensions of road safety problems and their measurement. Accident Analysis and Prevention, 40, 1200 – 1210.
Elvik, R. (2009) The Power Model of the relationship between speed and road safety: update and new analyses. TØI Report; 1034/2009. Institute of Transport Economics TØI, Oslo.

Elvik, R. (2013). A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims. Accident Analysis and Prevention, 50, 854-860.

Elvik, R. (2014). Fart og trafikksikkerhet. Nye modeller. (Speed and road safety; new models) TØI Report 1296/2014. Institute of Transport Economics TØI, Oslo.

Elvik, R., Christensen, P. & Amundsen, A. (2004) Speed and road accidents. An evaluation of the Power Model. TØI report 740/2004. Institute of Transport Economics TØI, Oslo.

Elvik, R., Høye, A., Vaa, T. & Sorensen, M. (2009) The handbook of road safety measures, 2nd edition. Amsterdam [etc.], Elsevier.

Elvik, R. & Kaminska, J. (2011) Effects on accidents of reduced use of studded tyres in Norwegian cities: analyses based on data for 2002-2009. TØI Report; 1145/2011. Institute of Transport Economics TØI, Oslo.

ETSC (1995) Reducing Traffic Injuries resulting from excess and inappropriate speed. European Transport Safety Council, Brussels.

Fildes B.N. & Jarvis, J.R. (1994) Perceptual countermeasures: literature review. Research Report CR4/94. Road and Traffic Authority of New South Wales, Rosebury, Australia.

Finch, D. J., Kompfner, P., Lockwood, C. R. & Maycock, G. (1994) Speed, speed limits and crashes. Project Record S211G/RB/Project Report PR 58. Transport Research Laboratory TRL, Crowthorne.

Fitzpatrick, K. & Carlson, P. (2002) Selection of Design Speed Values, In: Geometric design and the effects on traffic operations. Transportation Research Record TRR 1796, p. 3-11.

Goldenbeld, C. & van Schagen, I. (2007) The credibility of speed limits on 80 km/h rural roads: the effects of road and person (ality) characteristics. Accident Analysis & Prevention, 39(6), 1121-1130.

Heino, A. (1996) Risk taking in car driving; perceptions, individual differences and effects of safety incentives. PhD Thesis; University of Groningen, NL.

Haglund M. & Åberg, L. (2000) Speed choice in relation to speed limit and influences from other drivers. Transportation Research Part F, 39-51.

Herrstedt, L., Kjemtrup, K., Borges, P. & Andersen, P. (1993) an improved traffic environment - a catalogue of ideas. Danish Road Directorate, Ministry of Transport, Herlev, DK.

IRTAD (in preparation) The impact of speed changes on crash occurrence and severity. International Transport Forum at the OECD, Paris.

Jamson, S., Chorlton, K. & Carsten, O. (2012). Could intelligent speed adaptation make overtaking unsafe? Accident Analysis and Prevention, 48, 29-36.

Kallberg V.-P., & Toivanen, S. (1998) Framework for assessing the impact of speed in road transport. MASTER project report. Technical Research Centre of Finland VTT, Espoo, Finland.

Ker, K., Roberts, I., Collier, T., Beyer, F., Bunn, F. & Frost, C. (2005) Post-licence driver education for the prevention of road traffic crashes: a systematic review of randomised controlled trials. Accident Analysis and Prevention, 37, 305-313.

Kloeden, C. N., McLean, A. J. & Glonek, G. (2002) Reanalysis of travelling speed and the rate of crash involvement in Adelaide South Australia. Report No. CR 207. Australian Transport Safety Bureau ATSB, Civic Square, ACT.

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

Kloeden, C. N., Ponte, G. & McLean, A. J. (2001) Travelling speed and the rate of crash involvement on rural roads. Report No. CR 204. Australian Transport Safety Bureau ATSB, Civic Square, ACT.

Lai, F., Carsten, O. & Tate, F. (2012) How much benefit does intelligent speed adaptation deliver: an analysis of its potential contribution to safety and environment. Accident Analysis and Prevention, 48, 63-72.

Lai, F., Hjälmdahl, M., Chorlton, K., & Wiklund, M. (2010) The long-term effect of intelligent speed adaptation on driver behaviour. Applied Ergonomics, 41, 179-186.

Lynam, D., Hill, J. & Barker, J. (2004) Developing a speed management assessment framework for rural single carriageway roads. TRL Published Project Report PPR025. Transport Research Laboratory, Crowthorne.

Martens, M., Comte, S. & Kaptein, N. (1997) The effects of road design on speed behaviour - a literature review. MASTER Deliverable D1. Technical Research Centre of Finland VTT, Espoo.

Masten, S.V. & Peck, R.C. (2003) Problem driver remediation: a meta-analysis of the driver improvement literature. Insurance Institute for Highway Safety, Arlington (USA).

Van Nes, N., Brandenburg, S. & Twisk, D. (2010) Improving homogeneity by dynamic speed limit systems. Accident Analysis & Prevention, 42, 944-952.

Van Nes, N. & Van Schagen, I. (2010) Opportunities to improve speed behavior: credibility of speed limits and the use of ISA. Advances in Transportation Studies an international Journal, Vol. 20, Section A, 39-46.

Nilsson, G. (1982) The effects of speed limits on traffic crashes in Sweden. In: Proceedings of the international symposium on the effects of speed limits on traffic crashes and fuel consumption, Dublin. Organisation for Economy, Co-operation, and Development (OECD), Paris.

Nilsson, G. (2004) Traffic safety dimensions and the power model to describe the effect of speed on safety. Bulletin 221, Lund Institute of Technology, Lund.

OECD (2006) Report on speed management measures. Organisation for Economic Co-operation and Development, Paris.

Persson, H., Towliat, M., Almqvist, S., Risser, R. & Magdebuirg, M. (1993) Speed limiters for cars. A field study of driving speeds, driver behaviour, traffic conflicts and comments by drivers in town and city traffic. Department of Traffic Planning and Engineering, University of Lund, Lund, Sweden.

Rosén, E., Stigson, H. & Sander, U. (2011) Literature review of pedestrian fatality risk as a function of car impact speed. Accident Analysis and Prevention, 43, 25-33.

SARTRE 3 (2004) European drivers and road risk; Part 1: report on principal results. INRETS, Paris.

SETRA-CSTR (1990) Étude de l'effect de la pluie sur la sécurité; analyse statistique. Circulation Sécurité Equipement Exploitation 77. Bagneux (F), Service d'Études Techniques des Routes et Autoroutes (SETRA).

Silcock, D., Smith, K., Knox, D., & Beuret, K. (2000) what limits speed? Factors that affect how fast we drive. AA Foundation for Road Safety Research, Farnborough (UK).

Solomon, D. (1964). Accidents on main rural highways related to speed, driver and vehicle. Bureau of Public Roads, U.S. Department of Commerce, Washington, D.C.

Taylor, M., Lynam, D.A. & Baruya, A. (2000) The effect of drivers' speed on the frequency of accidents. TRL Report TRL421. Transport Research Laboratory, Crowthorne.

Taylor, M., Baruya, A., & Kennedy, J.V. (2002) The relationship between speed and accidents on rural single carriageway roads. TRL Report TRL511. Transport Research Laboratory, Crowthorne.

Taylor, M. & Wheeler, A. (2000) Accidents reductions resulting from village traffic calming. In: Demand management and safety systems; proceedings of seminar J, Cambridge 11-13 September 2000, p. 165-174.

Tingvall, C. & Howarth, N. (1999) Vision Zero: an ethical approach to safety and mobility. The 6th Institute of Transport Engineers International Conference on Road Safety and Traffic Enforcement: Beyond 2000. Melbourne 1999.

TRB (1998) Managing speed; review of current practice for setting and enforcing speed limits. Special report 254. Transportation Research Board (TRB). National Academy Press, Washington, DC.

Vaa, T. Phillips, R. (eds.) et al. (2009) Campaigns and Awareness Raising Strategies in Traffic Safety (CAST). Deliverable 1.3: Results of meta-analysis: effects of road safety campaigns. European Commission, Directorate-General for Transport and Energy, Brussels.

Van der Pas, J.W.G.M., Kessels, J., Veroude, B.D.G. & Van Wee, B. (2014) Intelligent speed assistance for serious speeders: the results of the Dutch speedlock trial. Accident Analysis and Prevention, 72, 78-94.

Van der Pas, J.W.G.M., Marchau, V.A.W.J., Walker, W.E., Van Wee, G.P. & Vlassenroot, S.H. (2012) ISA implemnatation and uncertainty: a literature review and expert elicitation study. Accident Analysis and Prevention, 48, 83-96.

Van Driel, C.J.G., Davidse, R.J. & Van Maarseveen, M.F.A.M. (2004) The effects of an edge line on speed and lateral position: a meta-analysis. Accident Analysis & Prevention, 36(4), 671-682.

Van Schagen, I. (ed.) (2003) Traffic calming schemes: opportunities and implementation strategies. SWOV Report R-2003-22. SWOV Institute for Road Safety Research, Leidschendam.

Várhelyi, A., Hjälmdahl, M. Risser, R. Draskóczy, M. & Hydén, C. (2002) The effects of large scale use of active accelerator pedal in urban areas. In: proceedings of the 15th workshop of the International Cooperation on Theories and Concepts in Traffic Safety ICTCT, Brno, Czech Republic, October 23-25, 2002, p. 235-241.

Vlassenroot, S., Broekx, S., De Mol, J., Int Panis, L., Brijs, T. & Wets, G. (2007) Driving with intelligent speed adaptation: Final results of the Belgian ISA-trial. Transportation Research A, 41, 267-279.

Vlassenroot, S., Molin, E., Kavadias, D., Marchau, V., Brookhuis, K. & Witlox, F. (2011) What drives the acceptability of Intelligent Speed Assistance (ISA)? European Journal of Transport and Infrastructure Research, 11, 256-273.

Webster D.C. and Wells P.A. (2000) The characteristics of speeders. TRL Report TRL440 Transport research Laboratory, Crowthorne.

Wegman, F. & Aarts, L. (red.) (2006) Advancing Sustainable Safety; National Road Safety Outlook for 2005-2020. SWOV Institute for Road Safety Research, Leidschendam.

Wegman, F., Dijkstra, A., Schermers, G. & van Vliet, P. (2005) Sustainable Safety in the Netherlands: the vision, the implementation and the safety effects. Proceedings of the 3rd International Symposium on Highway Geometric Design. Chicago, June 2005.

Weijermars, W. & Wegman, F. (2011) Ten years Sustainable Safety in the Netherlands; an assessment. Journal of the Transportation Research Board, 2213, 1-8.

Winnett, M.A. & Wheeler, A.H. (2002) Vehicle-activated signs; a large scale evaluation. TRL Report 549. Transport Research Laboratory, Crowthorne.

Zuckerman, M. & Neeb, M. (1980) Demographic influences in sensation seeking and expressions of sensation seeking in religion, smoking and driving habits. Personality and Individual Differences, 1, 197-206.

Notes

1. Country abbreviations

Belgium	BE	Italy	IT	Romania	RO
Bulgaria	BG	Cyprus	CY	Slovenia	SI
Czech Republic	CZ	Latvia	LV	Slovakia	SK
Denmark	DK	Lithuania	LT	Finland	FI
Germany	DE	Luxembourg	LU	Sweden	SE
Estonia	EE	Hungary	HU	United Kingdom	UK
Ireland	IE	Malta	MT		
Greece	EL	Netherlands	NL	Iceland	IS
Spain	ES	Austria	AT	Liechtenstein	LI
France	FR	Poland	PL	Norway	NO
Croatia	HR	Portugal	PT	Switzerland	CH

2. This 2015 edition of Traffic Safety Synthesis on Speed and Speed Management updates the previous versions produced within the EU co-funded research projects SafetyNet (2008) and DaCoTA (2012). This Synthesis on Speed and Speed Management was originally written in 2008 by Ingrid van Schagen, SWOV and David Lynam, TRL and then updated in 2012 and in 2015 by Ingrid van Schagen, SWOV and Rune Elvik, TØI.

3. All Traffic Safety Syntheses of the European Road Safety Observatory have been peer reviewed by the Scientific Editorial Board composed by: George Yannis, NTUA (chair), Robert Bauer, KFV, Christophe Nicodème, ERF, Klaus Machata, KFV, Eleonora Papadimitriou, NTUA, Pete Thomas, Un.Loughborough.

4. Disclaimer
This report has been produced by the National Technical University of Athens (NTUA), the Austrian Road Safety Board (KFV) and the European Union Road Federation (ERF) under a contract with the European Commission. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, the Partners cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.
Any information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use that may be made of the information contained therein.

5. Please refer to this Report as follows:
European Commission, Speed and Speed Management, European Commission, Directorate General for Transport, September 2015.

European
Road
Safety
Observatory

www.erso.eu