Speeding

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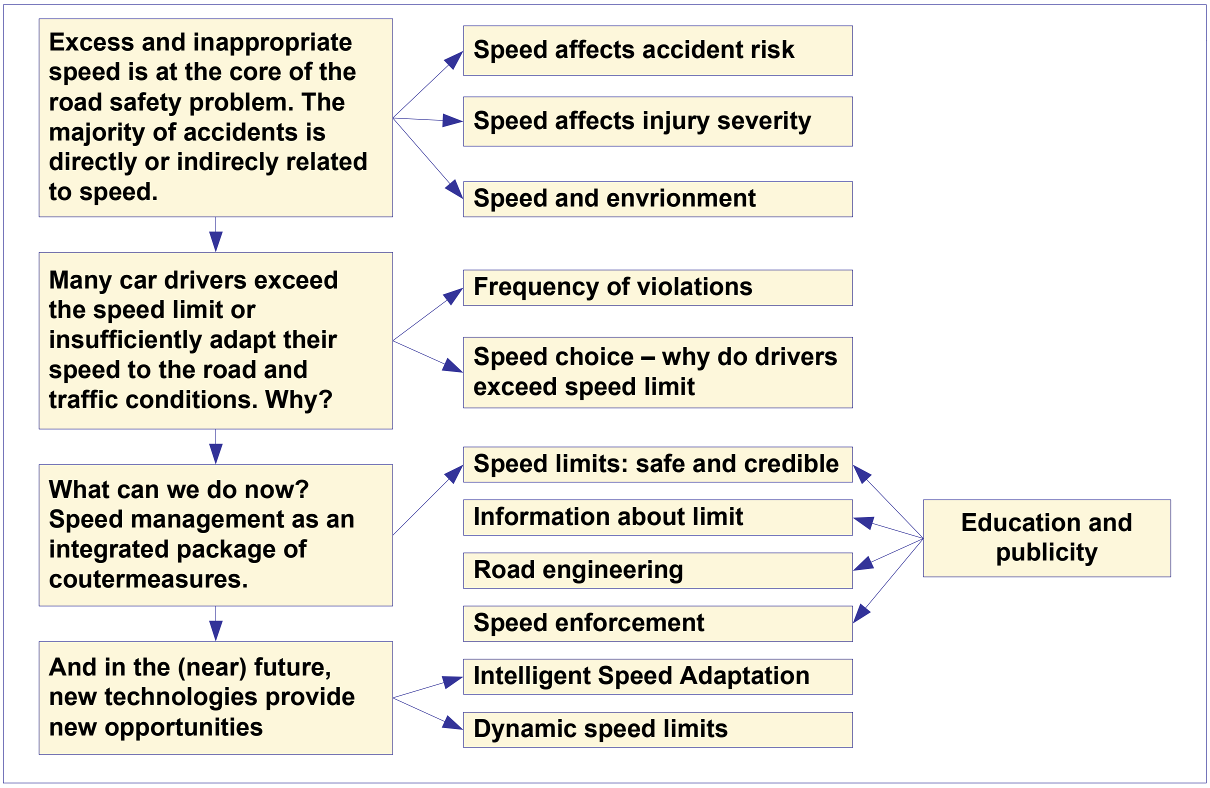
1. Speeding

Diagram & Summary



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 the 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. 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? Countermeasures 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, 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, such as speed humps and narrowing's, 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 provide information about the speed limit in force; warn the driver when exceeding the limit; or make excess speed impossible or uncomfortable. Such systems are available and likely to be introduced progressively. 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 [62]. 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.

2.1 Speed and road safety

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.

2.2 Speed and accident risk

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 rate of increase in accident risk varies with initial speed level and road type. 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; it is not yet evident that this is also the case for the slower driver.

Assessing potential effectiveness of speed reduction measures
Based on work by Nilsson in Sweden, a change in average speed of 1 km/h will result in a change in accident numbers ranging between 2% for a 120 km/h road and 4% for a 50 km/h road. This result has been confirmed by many before and after studies of different speed reduction measures. This relationship is used by other Scandinavian countries and by Australian and Dutch safety engineers.

A similar relationship is assumed in Britain, based on empirical studies by Taylor, 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.

Higher speeds: more accidents

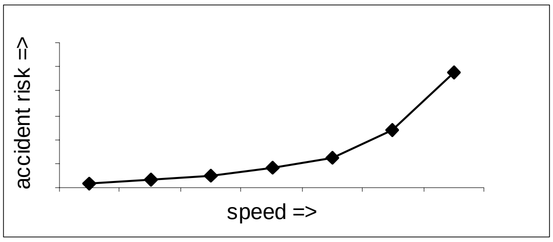
High speed reduces the possibility to respond in time when necessary. People need time to process information, to decide whether or not to react and, finally to execute a reaction. At high speed the distance covered in this period is longer. At high speeds the distance between starting to brake and a 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 [24].

1 km/h increase in speed → 3% increase in accidents

In practice the relationship is more complex. The exact relationship depends among many other things on speed level and road type.

The higher the speed, the steeper the increase in accident risk

The relationship between speed and accident risk is a power function: With increasing speed, the accident risk increases more as the absolute speed is higher.



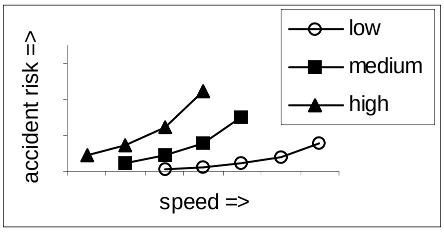
Based on the principles of kinetic energy and validated by empirical data, Nilsson [44][45] developed the following formula:

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

In words: the number of injury accidents after the change in speed (A_2) equals the number of 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.

Also road type affects the relationship speed –accident risk

On some roads the traffic situation is more complex than on other roads. This depends for example on the number and type of intersections; the absence or presence of pedestrians, cyclists, agricultural vehicles. In more complex traffic situations, the accident risk is higher. In addition, the increase of accident risk is larger as complexity increases [58][59] Taylor. An example of a low complexity road type is a motorway. An example of a high complexity road type is an urban arterial road.

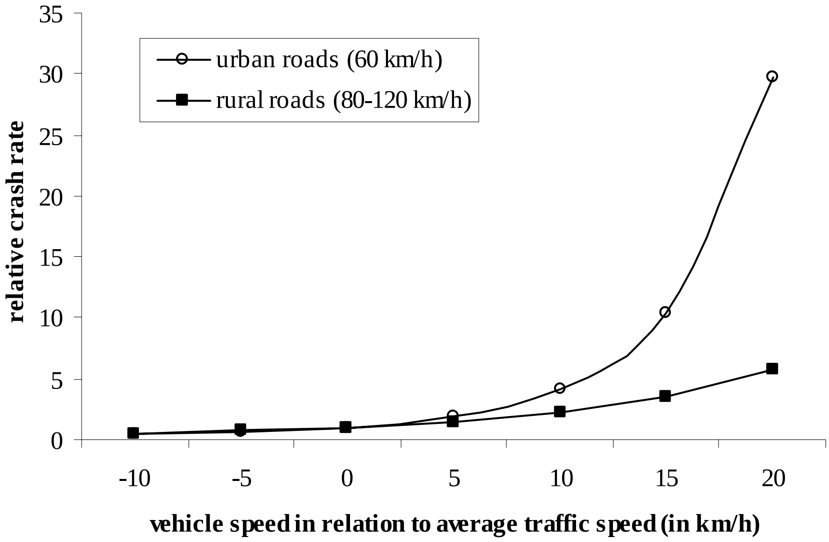


Larger speed differences: more accidents

If on a particular road, the speed variance is high, this will result in less predictability, more encounters, more overtaking maneuvers, etc. Therefore, when speed differences increase, the accident risk increases as well. Hence, a countermeasure that results in lower average speed, but in larger speed differences may not have the expected positive effect on road safety. But no reliable quantified relationship has been established for this linkage.

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. They found the 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 [36] and Great Britain [58] 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:



Relative accident rate on urban roads [37][36] and rural roads [38] for vehicles going faster and slower than average speed (=0) [36].

The risk of speeding and drink-driving

Some authors [48][35] have noted that the increased risk from driving at speeds 10-20% above the average for the road is similar to the increased risk from driving at the drink drive limits in the two countries to which the references relate (i.e. a BAC of 0.05 and 0.08). This is based on empirical research in Australia by Kloeden [37].

Australian research: the risk of speeding in comparison to drink driving risks

The Australian researchers Kloeden, McLean and colleagues performed a case control study to compare the risk of speeding and the risk of drink driving. In urban areas with a speed limit of 60 km/h, the researchers determined the speed of accident involved cars preceding the accident as well as the blood alcohol concentration (BAC) of the accident involved drivers. Similarly, they determined the speed and BAC of cars/drivers not involved in accidents, but driving in the same direction, same day of the week, same hour of the day, etc. They also controlled for other potentially confounding variables, such as age and gender. The risk of sober, non-speeding drivers was the basic risk, set at 1. The risk of speeders and drink drivers was determined relative to this basic risk. They found:

Speed	Relative risk of speeding	Blood Alcohol concentration (g/dl)	Relative risk of Drink driving
60 km/h	1.0	0.00	1.0
65 km/h	2.0	0.05	1.8
70 km/h	4.2	0.08	3.2
75 km/h	10.6	0.12	7.1
80 km/h	31.8	0.21	30.5

This study indicates that exceeding the speed limit of 60 km/h by 5 km/h is comparable to the risk of a BAC of 0.05. The risk of exceeding the 60 km/h speed limit by 10 km/h is higher than driving with a BAC of 0.08.

Source: Kloeden et al., 1997

2.3 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 [44] developed the following formula to describe the effects of a speed change on the number of injury accident rates:

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

with A_2 as the number of injury accidents after a change; A_1 as the number of accidents before; v_1 as the average speed before a 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:

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

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

More recent empirical data appeared to fit these general formulas very well [45][19].

2.4 Speed and the injury risk for different speed levels

The three formulas of Nilsson provide the relative change in the number of accidents, i.e. in percentages. They take account of the severity and they take account of the speed level at a particular road. Based on these formulas, the expected change in accidents when average speed changes with 1 km/h is:

Reference Speed	50 km/h	70 km/h	80 km/h	90 km/h	100 km/h	120 km/h
Injury accidents	4.0%	2.9%	2.5%	2.2%	2.0%	1.7%
Serious injury accidents	6.1%	4.3%	3.8%	3.4%	3.0%	2.5%
Fatal accidents	8.2%	5.9%	5.1%	4.5%	4.1%	3.3%

On average, this suggests that a 1% change in speed would lead to a 2% change in injury accidents, a 3% change in severe injury accidents and a 4% change in fatal accidents. [1]. Actual accident changes on a particular road will depend on a range of road and traffic characteristics that interact with speed and also on the characteristics and behavior of the drivers using the road, such as age, gender, drink-driving and seatbelt wearing [6].

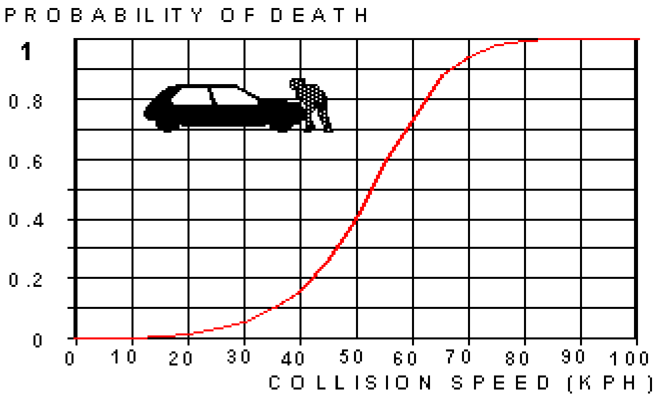
The injury risk is highest in light vehicles and for unprotected road users

When a heavy and a light vehicle collide, the occupants of light vehicles are far more at risk to sustain serious injury [7]. 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 car can easily be a factor 20. But also the mass differences between cars are large and still increasing. A mass difference of a factor 3 is not an exception. Nevertheless inappropriate speed remains a larger factor than mass differences in contributing to numbers of severe accidents.

Pedestrians, cyclists and moped riders have a large risk of severe injury when colliding with a motor vehicle. The difference in mass is huge and the collision energy is mainly absorbed by the lighter 'object'. In addition, pedestrians, cyclists and moped riders are completely unprotected: no iron framework, no seatbelts, and no airbags to absorb part of the energy. For a collision between a car and a pedestrian, the following relationship between speed and survival chance was established Ashton and Mackay (1979) [21].

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

And as a graph the probability of fatal injury for a pedestrian colliding with a vehicle looks like this (source: Pasanen, 1991):



2.5 Speed and environment; speed 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:

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

Extra time taken for a 10 km journey when speed is reduced by 5 km/h (Source: ETSC, 1995)

2.6 Speeding: societal vs. individual consequences

The negative road safety outcomes of high speed are evident at an aggregate 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 becomes clear from both objective observations and self reported speed behavior. 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

3.1.1 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, forthcoming). 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”, if they are not likely to be restricted by congestion or by local speed reducing measures.

The British Department for Transport carries out annual surveys at 27 sites on motorways, 7 sites on dual carriageways, 26 sites on rural single carriageway A class roads, and 36 sites in urban areas. Speed distributions are reported for up to ten different classes of vehicles.

The Dutch Ministry of Transport reports average speeds, percentage violations and the V90 per month, based on continuous measurements at 40 locations at motorways (100 or 120 km/h limit). A distinction is made between three vehicle types by their length. Only speeds in conditions where cars can drive faster than 75 km/h are included in the monthly average. Various regional and local road authorities collect speed data for their roads. However, there is no uniform, national processing of this data.

3.1.2 Self reported speeding behavior

The SARTRE 3 survey provides information on self reported speeding behavior for different road types. Most self-reported speed violations occur on motorways; least self reported speed violations occur in built-up areas. The percentage car drivers that 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. In assessing self-reported behavior and when developing speed campaigns, it is important to recognize that the reasons for socially unacceptable behavior such as speeding are often understated in relation to the reporting driver and overstated for other drivers [33]. Another reason could be that a few kilometres faster than the speed limit is not considered a speed limit violation by the drivers themselves.

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, the vast majority of the drivers do adapt their speed to the actual conditions. 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 [55]. So, it must be concluded that the speed adaptation is insufficient and the speed still 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. More than 80% of the European drivers state that driving too fast is often, very often or always a contributory factor in road accidents [53]. 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 characteristics of the driver, by factors related to human perceptual skills and limitations, by characteristics of the road and the road environment, and by characteristics of the vehicle.

3.4.1 Speed choice and driver characteristics

Many drivers prefer to drive faster than the objective risk justifies, but also than what they themselves 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 [27]. According to the SARTRE 3 survey [53], 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 [19] (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 are insufficiently informative about the speed limit in force.

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 [72][29].
Secondly, it is possible to distinguish different groups in relation to speed preferences. For example, it has often been found [67] that

- 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.

3.4.2 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 [30]. 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 [21][42][17]:

- 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 zone 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.

3.4.3 Speed choice and the road/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'. 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;
- Landrover-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. Countermeasures 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. 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 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 consistent roadside signing and road markings. In-vehicle systems to inform drivers about the speed limit in force are likely to be introduced progressively.

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 can 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 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. Speed limits

Speed limits are at the core of any speed management policy. Speed limits should reinforce drivers' assessment of the safe speed to travel along a road and be complied with by most drivers. Current speed limit policies differ between countries. A speed limit must reflect the function and quality of the road to ensure a safe speed limit. In addition, a speed limit will be supported by (changes in) the characteristics of the road and the road environment in order to be credible for the road user.

X-LIMITS approach used in Australia and United States
The computer program X-LIMITS originally developed by ARRB for use by Australian and New Zealand state road authorities has been further developed as "USlimits" in collaboration with FHWA for application in the United States. The program 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 crash rates. On the basis of this data, the program calculates a recommended speed limit.

Current speed limit policies

A speed limit is based on both safety and mobility considerations and increasingly also on environmental considerations. The general framework for speed limits is the responsibility of the national government. Generally, local and regional road authorities determine the speed limit on a particular road. The current general speed limits vary across EU Member States. Also the application of variable speed limits related to traffic and weather conditions vary across EU Member States

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, 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 [32][41].

Some administrations [61] are now proposing 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.

Who is responsible for setting speed limits?

Clearly, there are differences between countries in the way that speed limit setting is arranged. 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. It means, however, that local or regional road authorities have a large amount freedom in determining which speed limit would be applied where.

A common approach to determine the most appropriate speed limit for a particular road or road section is to set the limit close to the V85. The V85-speed is the speed that is not exceeded by 85% of the vehicles. Ideally, however, 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 and, in addition, that the limit is a credible limit for the majority of drivers.

Current general speed limits in EU 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. Also in the Netherlands, an increasing number of motorway sections have a permanent lower speed limit (notably 100 or 80 km/h) aiming to reduce air pollution and noise where there are adjacent residential areas.

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 km/h) and buses (varying between 80 and 100 km/h). By EU-Directive 92/24/EEC and its recent 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. Some countries apply lower HGV and bus speed limits for different road types (e.g. Denmark, Ireland and the United Kingdom).

Different speed limits in adverse weather and traffic conditions

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; these have been evaluated by Peltola [49]. 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.

5.1 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.

A safe speed limit: road function and design speed

The speed limit needs to reflect the safe speed. Whether a speed is safe depends on the function of the road and, related to this the composition of the traffic flow (e.g. mixture of pedestrians and motorized traffic); the characteristics of the traffic situation (e.g. the density of at-grade intersections).

It also depends on the road design characteristics related to design speed, such as horizontal alignment (e.g. road width, obstacle free zones); vertical alignment (e.g. type of curves, gradients, 'design consistency').

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 Haworth (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. Thus, where pedestrians are present, vehicle speeds should be no higher than 30km/h. Where vehicle to vehicle impacts occur they should be at speeds below the impact speeds at which cars can be shown (through the European New Car Assessment Programme) to safeguard occupant life. Ratings are being developed through the European Road Assessment Programme showing how well the road is designed to ensure forces involved in impact with road infrastructure also keep within the same thresholds, and these are being used in Sweden to indicate appropriate speed limits for roads with different ratings.

Road type/traffic situation	Safe speed (km/h)
Based on Tingvall & Haworth (1999) the updated Dutch Sustainable Safety philosophy presents the following requirements with regard to maximum speeds in different traffic situations	
Roads with potential conflicts between cars and unprotected road users	30
Intersections with potential side impacts between cars	50
Roads with potential head-on conflicts between cars	70
Roads where head-on and side impacts with other road users are impossible	≥100

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."

Source: Wegman & Aarts, 2005 (page 14; translated from Dutch)

Speed limits and road function

Ideally, a road network consists of a limited number of monofunctional roads. For example, in the Netherlands, Sustainable Safety distinguishes between three road functions.

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.

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 [21]. More specifically the design speed is used by road engineers to determine the various geometric design features of the roadway [2][25]. 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 the appropriate 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 likely to be introduced progressively.

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 [54][56]. 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.

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 colors). 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 behavior has been found to be very small [15].

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 that have a limit of 100 km/h instead of the general 120 km/h. These signs

(with a diameter of 150 mm) are placed every 100m integrated in the hectometre posts (see photograph). In Britain, small repeater signs are required at regular intervals, where roads have speed limits which are not the commonest for that road type.

A hectometre post with speed limit reminder at motorways in the Netherlands

In-vehicle information systems
The development of in-vehicle systems to inform drivers about the speed limit in force continues rapidly. 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 of she is. The EU-funded project SpeedAlert has been working on the definitions, classifications and standardization requirements for a European application of a speed limit information and warning system (see www.ertico.com). The SafeMap project (in the framework of the French-German DEUFRAKO-programme) works on a feasibility study and a field trial with a system to inform drivers of a safe speed at a particular location. This safe speed is not necessarily the same as the speed limit. It takes account of accident numbers and/or more generic methods to assess road hazards [70].
In-vehicle information systems are actually a type of Intelligent Speed Adaptation.

5.3 Road engineering

Overall road design should indicate 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 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. Newly developed residential areas were designed as 30km/h zones. The roads in these zones were redesigned using road humps, road narrowing's and mini-roundabouts to ensure the speed limits were respected. As part of the Sustainable Safety initiative, there was subsequently a major increase in investment in these zones and between 1997 and 2002 the proportion of roads treated has increased to 50%. Engineering work within the zones was however less extensive than in the earlier zones.

In parallel since 1985, engineering work has also been used on the urban roads where speed limits were not reduced to 30km/h to maximize separation of vulnerable road users and maintain low traffic speeds.

Source: Koornstra et al, 2002

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 [66][16][57]. Many studies also found a substantial effect on the number of injury accidents in 30 km/h zones with this type of supportive engineering measures. Elvik [18] performed a meta-analysis on a large number of evaluation studies and reported a 25% reduction in injury accidents. Although this study dealt primarily with traffic calming, similar conclusions can be drawn for 30km/h zones.

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 [20] report an injury accident reduction between 10-40%, depending on the number of legs and the previous form of traffic control. The largest reduction was found for four-legged junctions with traffic signals before. Fatal and serious accidents are reduced more than slight injury accidents. The effect on pedestrian accidents is similar to that of other accident types; the effects for cyclists are somewhat smaller (10-20%). The meta-analysis showed an increase in the number of damage-only accidents at roundabouts.

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 another traffic behavior, and primarily to another speed [31].
Of special concern is the entrance of a village from a major through road. ETSC 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,

culminating at 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 in 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 [31].
Taylor and Wheeler 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 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 the 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 in appropriate for approaching hazards have proved effective in Great Britain [71]. 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 [23]. 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 [42]

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.

What are the general mechanisms of effective police enforcement?

Police enforcement is based on the principle that people try to avoid penalty. Most important is that people have the impression that there is a high chance that they will be penalized when violating a rule (the subjective chance of apprehension). The subjective chance of apprehension is first of all affected by the actual level of enforcement (i.e. the objective chance of apprehension). In addition, it is affected by how much people see or hear about police enforcement. Therefore, the subjective chance of apprehension can be increased by:

- Applying both visible and hidden enforcement activities
- Publicity about specific enforcement activities (e.g. in national or regional media)
- Feedback on the results of enforcement activities (e.g. in national or regional media)

When drivers are caught for a speeding violation, the specific penalties differ in different countries. Generally, the fines are related to the level of speeding: the larger the speed violation, the higher the fine. Speeding at motorways is generally seen to warrant lower fines than speeding on other road types; speeding at working zones is generally given higher fines. All of these systems are only effective in so far as the fines are paid. In countries that apply a penalty point system, penalty points are assigned for the more severe speed violations in addition to a monetary fine. If a speed violation exceeds a certain threshold, the driving license can be suspended for a particular period of time. In some countries convicted drivers can or must follow a driver improvement course after a serious speed limit violation.

Which tools and methods are available for speed enforcement?

There are many tools and methods available for speed enforcement. A main distinction can be made between automatic and non-automatic speed enforcement. With non-automatic speed enforcement a speed violation is detected and the violator is immediately afterwards stopped by a police officer who can either warn or fine the driver. With automatic speed enforcement, the license plate number of a speed-violating vehicle is registered, and several weeks later the license plate holder will receive a fine by mail.

Tools and methods for non-automatic speed enforcement:

- Spot control: radar or laser gun equipment alongside the road (visible or hidden)
- Distance control: conspicuous or inconspicuous police cars

Tools and methods for automatic speed enforcement

- Spot control: fixed or mobile speed cameras
- Distance control: trajectory or section control (control between two points)

Which automatic speed enforcement tools can be used partly depends on the legal system in a particular country and, more particularly, on liability and privacy legislation related to the identification of the license plate holder. Experience shows that a speed camera enforcement programme requires good national and local partnerships working to clear and transparent rules to ensure public acceptability. Achieving compliance requires legislation that enables vehicle owners to be liable for the offence.

UK: safety camera partnerships

In UK a pilot scheme in 2000 among eight police force areas led to a Safety Camera Funding Scheme which now covers the majority of police areas in the country. In order to take part in the scheme partnerships of police and local authority agencies must be established. These are able to recover the costs of operating speed and red light cameras (known collectively as safety cameras) from the fines resulting from enforcement. Any extra revenue from the fines went to central government as with other fines. There are clear guidelines covering where and how safety cameras should be placed, and ensures to be taken to ensure drivers are aware of them (published on www.dft.gov.uk under the Road safety area).

National guidelines require cameras to be clearly visible and to be located primarily at accident sites. Evaluations have indicated a 33% reduction in personal injury accidents at sites where cameras had been introduced, and a 40% reduction in accidents resulting in fatal or serious injuries. But the number of speeding offences detected has reached almost 2 million per year, and emphasis is now being given to ensuring other speed reduction measures are considered fully before cameras are installed, to maintain public support for the programme.
Source: Lynam et al., 2005

The Netherlands: 6 million speed offences recorded automatically
In the Netherlands two developments have been important for the use of speed cameras in the Netherlands: (1) A new administrative law in September 1990 which covers minor traffic offences and which stipulates that in cases involving registration of speed offences by radar, the party in whose name the vehicle is registered is liable and (2) the start of a central bureau of traffic enforcement in 1998 which co-ordinates regional enforcement projects and supervises the monitoring of speed behavior.

In 2004, the Bureau of Traffic Enforcement had about 800 fixed speed camera poles under supervision of which about 20% actually contains a camera. The cameras rotate amongst the poles. Also, provincial and municipal authorities manage a number of fixed camera poles. According to a website dedicated to providing information about speed checks, the total number of fixed speed camera poles in the Netherlands would be more than 1600. There are currently about 6 million speeding offences recorded annually.

Source: Lynam et al., 2005

France: automatic enforcement of speed violations since 2003
On the 14th of July 2002, the national holiday in France, the French President Jacques Chirac announced that the 'fight against road unsafety' would be one of his three main objectives for the next 5 years. A year later, summer 2003 a road safety action plan was adopted. One of the most important actions concerns the introduction of an automatic enforcement and penalty system for speed violations. In November 2003, the first speed cameras were installed. At the end of 2004 there were 400 speed cameras (232 fixed and 168 mobile) and it is expected that by the end of 2005, there will be 1000 systems in function (700 fixed and 300 mobile). Unlike other countries, every box will hold a camera. Sites are clearly signed and publicized. Revenue can be used for other road safety operations. In the first full year of operation (2004), two million speeding violations were recorded.

Source: Canel and Nouvier, 2004

Sweden: a speed camera box every 4.5 km
In Sweden the police and the National Road Administration carried out a trial of automatic speed cameras from 2002. By the end of 2003, about 500 km of the main roads were covered with camera boxes in which cameras can be placed randomly. A further 250 km was completed in 2004. The total number of boxes was then 335. The total road length covered is 750 km, so there will be a box on average every 4.5 km. Forty four road links are involved. 9 500 vehicles were photographed by speed cameras in 2003 but the driver was only identified in 6 000 cases, and legislation does not yet allow the owner of the car to be held responsible. Some efforts are being made to implement this change in law. Normally cameras are installed on accident prone roads with speed limits of 90 km/h. There is however an increasing use of camera boxes at local speed limits of 70 or 50 km/h at intersections etc. The regions of the Road Administration (7 regions) together with the county police (21 counties) decide on the placement and the number of camera boxes.

Early accident studies are consistent with existing models showing the effect of speed on safety. The preliminary effect on fatal accidents is a reduction of 50% and on all injury accidents 25%. The speed reduction is 5-10 km/h.

How effective is speed enforcement?

First of all, it must be noted that the effects of speed enforcement are very limited to both time and place. When the enforcement stops, the effects will disappear within a few weeks

[63]. The effects are largest in the immediate vicinity of the enforcement location, and fade away when distance increases [11]. However, during the enforcement activities and on the enforced roads, the effects of speed enforcement can be very positive. Most evaluation studies looked at automatic enforcement by fixed speed cameras. The effects of non-automatic enforcement have not been studied as systematically as the effects of automatic enforcement. The effectiveness of enforcement depends on many factors, but some elements are essential for success, one of them being publicity.

Automatic enforcement

The best estimate is that automatic speed enforcement results in an accident reduction of 15 to 20% [20]. Individual evaluation studies differ widely in the reported effects. For fixed speed cameras, the effects varied from a 5 to 69% reduction in accidents, a 12 to 65% reduction in injuries and a 17-71% reduction in fatalities [51]. The actual effectiveness depends on many factors, such as the actual enforcement effort, the initial speed and safety level and the type and amount of supporting publicity. In addition, not all evaluation studies take sufficient account of the regression-to-the-mean effect, which may lead to an overestimation of the effect.

It has been claimed that fixed, visible speed cameras may lead to dangerous traffic situations, because of sudden deceleration at the approach of a camera and acceleration after having passed it: 'the kangaroo effect'. While one can actually see this happen, so far there is no scientific proof that this leads to dangerous situations or accidents.

Reported effects of (generally hidden) mobile speed cameras range between 15 and 35% [27]. The advantage of mobile cameras is that drivers are less aware where exactly they will be applied. The disadvantage is that they require more manpower.

Trajectory control is still very new, not yet widely applied and not yet evaluated on substantial scale. The first indications are very positive with hardly any speed violations left at the enforced section [52].

Factors increasing the effectiveness of national programmes of automatic enforcement include clear guidance on the criteria for enforcement sites, public information that maximizes acceptability of the programme, and a short time interval between violation and fine to maximize the educational impact of the sanction [8].

Non-automatic enforcement

At least in theory, non-automatic enforcement has three advantages compared to automatic enforcement. The advantages are related to the fact that violators are immediately stopped by the police:

- The violator receives immediate feedback
- The police officer has the opportunity to explain why they are enforcing speed
- If violators are stopped at a clearly visible spot, other drivers can see that the police is around and as such it increases the subjective chance of apprehension

The disadvantage is that non-automatic enforcement is far more labour-intensive and that it is virtually impossible to reach the same enforcement level as with automatic enforcement. Hence the objective chance of apprehension is much smaller. This is even more the case with non-automatic distance control than with non-automatic spot control. A police car that follows the traffic stream has a relatively small chance of detecting a speed violator and if so to follow that car for a sufficiently long time.

Essential elements for successful speed enforcement

Essential elements for successful speed enforcement are:
Selection of roads or road sections with a safety problem related to speed

- A good organizational framework
- Enforcement level made dependent on observed speed/speeding levels
- Application of a combination of visible and hidden, fixed and mobile enforcement tools

And last but not least, a large amount of publicity on the enforcement project.

The role of publicity in enforcement initiatives

The effect of any speed enforcement initiative is substantially increased if it is supported by targeted information to the road user:

- Emphasizing that safety is the goal of the enforcement activities
- Avoiding the appearance of collecting revenues to go to the national treasury
- Preferably illustrating that the revenues of fines are used for road safety purposes
- Providing feedback on the (interim) results of the enforcement activity (in terms of speed levels or safety)

Information at local or regional level is more effective than information on national level. The problem and the need to take action can be illustrated on the basis of examples that are known to the target drivers. Local newspapers, local radio or television and door-to-door leaflets are all suitable media for this purpose.

Drivers' opinions about and experience with speed enforcement?

European drivers are fairly positive about speed enforcement. However, they are more positive about drink driving enforcement. The SARTRE 3 survey [53] provides information:

On average around 60% of the drivers in the EU are (strongly) in favor of more severe penalties for speeding. With respect to drink driving approximately 85% are (strongly) in favor of more severe penalties.

On the other hand, European drivers think that they are more often checked for speeding than for drink driving. On average around 30% have the perception that on a typical journey they are often, very often or always checked for speeding, as compared to 10% for drink driving. There are huge differences between countries, in particular related to speeding. For example in Cyprus, Slovenia and the UK almost 40% of the drivers think they are (very) often or always checked on speeding, whereas in Sweden, Denmark and Italy this is around 5%.

Actual experience with speed and drink driving enforcement shows that penalties for speeding are far more common than for drink driving. On average, in the previous three years, almost 20% of the European drivers had been penalized for speeding as compared to less than 2% for drink driving. Clearly, this is not only related to the enforcement level, but certainly also to the frequency of both types of violations. With regard to speeding there are again large differences between countries. Drivers in the Netherlands are most often detected and penalized for a speed limit violation (46% in the last three years), followed by Germany (36%) and Slovenia and Austria (30%). Least often detected and penalized were drivers in Portugal (6%), France (8%) and Sweden and the UK (9%).

In particular for the UK, there is a remarkable difference between the subjective likelihood of being penalized for a speed limit violation (the UK belonging to the top 3) and the actual experience with speed penalties (the UK belonging to the bottom 3). This may be related to the large amount of publicity and discussions in the British media about the 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 road users 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 behavior is likely to be 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 behavior of the pupils are limited. Perhaps it is possible to introduce children to the 'speed' problem, with the purpose of them talking to their parents about their speed behavior.

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 (too) fast. That driving too fast leads to more and more severe crashes applies to mopedists just as much as to motorists. The question remains, of course, of the extent to which this sort of information influences the actual speed behavior of the novice mopedist and later on as motorist.

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 fixed 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. In addition, if the (learner) car driver does keep to the speed limit, he/she will often be overtaken. The (learner) driver will practically never see the negative consequences for these 'speeders': i.e. a crash, a fine. This does not exactly contribute to a deep respect for speed limits nor 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 behavior must considered to be limited. Nevertheless, education and the driver training is essential to provide information on the why and how of speed limits, and the risks of excess and inappropriate speed.

Publicity campaigns

Publicity campaigns and (other) information do not or hardly ever, on their own, lead directly to behavioral change, but they are a prerequisite for other measures [14]. It is generally known that campaigns and information can considerably increase the effectiveness of police control. Publicity campaigns could also be used more often in order to explain the goal, necessity, and effects of measures such as physical speed limiters and 30 km/h zones. Besides this, campaigns can be used to make people aware of the problem of driving (too) fast. Research has shown that a convincing, emotional approach is more effective than a rational, informative approach [13].

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.

One of the problems in convincing people not to speed is the discrepancy between the individual advantages and societal disadvantages. The Netherlands recently launched the 'The New Driving Force' campaign, which links the (especially environmental) social advantages with the individual advantages. This campaign is an initiative of the Dutch Ministry of the Environment and the Dutch Ministry of Transport. It aims at a calm, fuel-efficient driving style for both private and commercial drivers. The emphasis is on increased comfort and money saving for the individual driver, and increased environmental and safety quality for society as a whole (http://www.hetnieuwerijden.nl/english.html)

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 related to speed offences, e.g. Austria, Switzerland, Finland [26]. 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 [34][20] or non-existent [43].

6. New technologies, new opportunities

New technologies that can make speed 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 likely to be 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 behavior and expect 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.

Field trials of ISA
Practical experiments with ISA have been carried out in Sweden and the Netherlands. In Sweden it concerned large-scale experiments with the open ISA (warning/informing) and the half-open ISA (the active accelerator) in four different town/cities. In the Dutch town of Tilburg, there was an experiment with the closed ISA. The experiments in both countries concerned urban areas. Other field trials have taken place in Belgium, Denmark, Britain, Finland, Germany, France, Hungary and Spain (see www.prosper-eu.nl for more details).

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 can support drivers in helping them to comply 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:

- 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.
- 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-dependant (advisory) speed limits. It will become increasingly possible to include dynamic speed limits that take account of the actual circumstances at a particular moment in time.

How effective is ISA?

The experiments in both Sweden and the Netherlands show a positive effect of the system. Driving speeds with ISA were slower and more homogenous. In Sweden, no differences were found between the two tested systems.

There has also been a lot of research using driving simulators. For example, in Britain [9] [10], the effects of ISA on speed behavior have been studied in a driving simulator. They tested three ISA systems: an open, advisory system; a combination of half-open/closed system at a voluntary basis (on-off switch); and the same system at a mandatory basis (without on-off switch). They also looked at three different types of speed limits: fixed, variable and dynamic. Based on the speed data, the effects on the number of accidents have been estimated. The estimates show that all systems had a positive effect on safety, with the largest effect of the mandatory system based on dynamic speed limits. Besides the safety improvement, Carsten and Fowkes claim ISA also leads to a reduction in fuel consumption.

Does ISA have negative side effects?

No negative side effects of ISA were found in the experiments in Sweden [5]. However, there is still some concern about this point. Issues that have been reported include:

- Compensation behavior: there are indications that drivers compensate by driving faster on road segments where the ISA system is not active [50].

- Diminished attention: ISA can result in reduction of attention for the road and traffic situation, when the system is not active. This diminished attention expresses itself in, for example, 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 [12][65]
- Over confidence: 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.
- Feeling frustrated: the speed limiting by ISA can produce frustration in the driver and in other traffic [64][12].

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

It is generally considered that the current focus should be on developing appropriate principles for human machine interface systems, while various forms of automated control systems, including for example systems such as electronic stability control, are developing, rather than on regulation.

How acceptable is ISA?

According to the SARTRE survey (2004) around a quarter of the European drivers are of the opinion that it is 'very useful' to have a device in the car that restrains you from exceeding the speed limits. This is a little bit lower than for devices preventing drink-driving and driving when fatigued (for both 32% is of the opinion that it is very useful). The practical experiments in both Sweden and the Netherlands have shown that the acceptance of ISA increases if concrete experience with it has been gained.

To assess the political acceptance of ISA systems, the EU-funded PROSPER project performed a survey among different stakeholders (politicians, governmental institutes, research institutes, pressure groups and commercial groups) in eight EU countries. It is reported, that despite differences between countries and between different stakeholder groups, ISA is generally seen as an effective safety measure. An introduction among all driver groups, on all road types and on a mandatory basis is preferred. A half-open system or the active accelerator was considered to be the best option for now. According to the stakeholders, this scenario would result in the best results for safety, environment and congestion. Barriers to the implementation of ISA that were identified included the technical functioning, applicability to the whole network, benefits for the road users and liability issues [4].

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.

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Appendix

What is kinetic energy?
Kinetic energy is the energy that is built up by movement of an object. The faster the movement and the heavier the object, the more energy is built up. The formula for kinetic energy (Ek) is:

$Ek = ½ * m * v^2$

with m is mass and v is speed.

Hence, a moving vehicle builds up kinetic energy. In case of a collision the energy must somehow flow away. The two objects involved in the collision will have to absorb it.

What is Sustainable Safety?
Sustainable safety is the road safety vision of the Netherlands. It was launched at the beginning of the 1990s and accepted as a formal part of Dutch policies in the mid 1990s. As summarized by Wegman et al. (2005, page 1)

"The Sustainable Safe vision is based on two leading ideas: how to prevent human errors as far as possible, and how to ensure that the crash conditions are such that the human tolerance is not exceeded and severe injury is practically excluded. The starting point of 'sustainable safety' was to drastically reduce the probability of crashes in advance through safety conscious planning and design. Where traffic crashes still occur, the process that determines the severity of these crashes should be influenced, so that serious injury is virtually excluded. Within sustainable safety, man is the reference standard (human error and human tolerance). A sustainable safe traffic system has an infrastructure that is adapted to the capabilities and limitations of humans through proper planning and road design, has vehicles that are equipped to simplify the driving task and offer protection to the vulnerable human being (crash protection), and finally, has road users that are properly educated and informed, and which driving behavior is regularly controlled. The key-issue of 'sustainable safety' is that it has a preventative rather than a curative (reactive) nature."

What is a regression-to-the-mean effect?
"Regression-to-the-mean denotes the tendency for an abnormally high number of accidents to return to values closer to the long term mean; conversely abnormally low numbers of accidents tend to be succeeded by higher numbers. Regression-to-the-mean occurs as a result of random fluctuation in the recorded number of accidents around the long-term expected number of accidents. Regression-to-the-mean threatens the validity of before-and-after studies, but is, at least in large samples, perhaps a less serious threat to validity in cross-sectional studies."

Regression-to-the-mean is particularly likely to occur if locations for safety measures, such as speed enforcement, are selected on the basis of their bad accident record, as is normally the case. This means that evaluation studies must take account of the likely regression-to-the-mean effect to get a reliable estimate of the effectiveness [20].

What is the SARTRE study?

SARTRE is an acronym for 'Social Attitudes to Road Traffic Risk in Europe'. The SARTRE study is funded by the EU and participating countries and aims to study the opinions and reported behaviours of car drivers throughout Europe. The study applies questionnaires that are presented to the respondents in face-to-face interviews. To date three surveys have been performed. The first one was in 1991-1992 (15 countries); the second one in 1996-1997 (19 countries); and the third one in 2002-2003 (23 countries). More information is available at http://sartre.inrets.fr.