Speed and Speed Management in Road Safety Policy

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Input paper

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Contents

1. Introduction

The European Commission and EU transport ministers have set themselves ambitious targets for road safety for the coming decade: to halve the number of fatalities and the number of serious injuries on European roads by 2030.

This paper addresses one of the key factors – speed and speed management. It is a collection of contributions from a number of distinguished researchers and experts on the various aspects of the topic: vehicles and technology, infrastructure design, speed limits and enforcement, as well as links with other policy areas.

Speed is a crucial factor in the road safety equation in the EU as elsewhere – indeed excessive or inappropriate speed is a factor in about one third of fatal crashes. The risk to be involved in a crash when speeding well above the limit or driving too fast for the conditions is 12.8 times higher than for non-speeders. And the higher the speed of the crash, the higher the likelihood of an outcome involving death and serious injury. Which is why speed is one of the eight agreed Key Performance Indicators for which data will be gathered from 2021, across the EU, of the observed percentage of vehicles travelling within the speed limit,.

Rules and regulations on speed, including most obviously speed limits, differ between EU Member States. In our jargon, road traffic law is a Member State (or sometimes even a regional or local) "competence". But the situation is evolving – for example:

- as driver assistance technology like Intelligent Speed Assistance will become commonplace thanks to EU regulation,
- as we extend the scope of the EU rules governing road infrastructure safety management,
- as we are developing stronger road safety guidance in Sustainable Urban Mobility Plans.

Hence our view that it is time for a closer look at the issue of speed and speed management at European level. The paper is intended as informal input and background for the planned discussion at the "Executive Seminar on Speed and Speed Management", organised by the European University Institute (EUI) and the European Commission on 8 October 2020. The Commission is extremely grateful to those who have contributed such excellent and thought provoking work on a voluntary basis at short notice, and which together provide the perfect background to our seminar.

On behalf of the contributors, we should make plain that the Commission together with the EUI suggested the topics and requested contributions. Although the contributors have provided very useful references and academic "embedding", the paper is not intended to be definitive on the subject. Because the topics are not always completely distinct, it is natural that there are overlaps. So the paper should be seen as an informal contribution from all those involved to bring their experience and expertise to our discussions on 8 October. One possibility would be to publish the paper subsequently, perhaps in modified form, but that is a decision for later, so at least for the time being, the paper should not be quoted or cited without the express prior permission of the authors.

Questions for reflection based on the contributions include (but we are open to ideas):

- What implications does the latest knowledge from research have for road safety policy?
- To what extent are existing policies adequate whether at local, national and European level?
- In particular, what could and should the EU do?

Once again, the European Commission road safety team thanks all the authors for their excellent contributions.

European Commission Road Safety Team

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2. Understanding the factor speed: Theory and evidence

This section of the paper addresses the fundamentals – the underlying and evolving science on speed and crash risk; the role that excessive speed plays in the "Safe System" analysis of deaths and serious injuries, and the issues involved with effective measuring of excessive speed.

2.1 Speed and the risk of crashes and injuries: A summary of current knowledge

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This paper gives a short summary of current knowledge about the relationship between speed and the risk of crashes and injuries. It is based on papers published in scientific journals (Elvik 2005, 2012, 2013, 2019, Elvik et al. 2019) as well as reports published by the Institute of Transport Economics (Elvik, Christensen and Amundsen 2004, Elvik 2009, 2014). The main objective of the paper is to describe what is known about the relationship between speed and road safety and indicate the precision of this knowledge.

A major review of studies of the relationship between speed and road safety was made during 2002-2004 and is presented in Elvik, Christensen and Amundsen (2004) and Elvik (2005). The review included a meta-analysis of 98 studies containing 460 estimates of the relationship between changes in speed and changes in the number of crashes, specified according to crash severity, and the number of injured road users, specified according to injury severity. A distinction was made between fatal crashes, severe injury crashes, slight injury crashes, all injury crashes and property-damage-only crashes. Injuries were specified as fatal, serious, slight and unspecified (i.e. a mixture of injuries at different levels of severity). The study was an evaluation of the Power Model of the relationship between speed and road safety, originally proposed by Swedish researcher Göran Nilsson in 1981, but explained in detail in Nilsson (2004). The Power Model states that changes in speed produce changes in safety according to a power function:

Change in number of crashes or victims = $Crashes_{before}\left(\frac{Speed_{after}}{Speed_{before}}\right)^{Exponent}$

The value of the exponent varies according to crash or injury severity. Thus, Nilsson proposed a value of 4 for fatal crashes. If speed is reduced from 100 to 90 km/h, the ratio of speed after to speed before becomes 90/100 = 0.9. Raised to a power of four, this is 0.9 · 0.9 · 0.9 · 0.9 = 0.656. If there were 100 crashes before, this will be reduced to 100 · 0.656 = 65.6 ≈ 66 crashes.

The evaluation of the Power Model found that, in well-controlled studies, the best estimates of the exponent (standard error in parenthesis) were 4.90 (0.17) for fatal injury, 1.76 (0.42) for serious injury, 1.56 (0.26) for slight injury and 2.61 (0.55) for injury accidents. Thus, increasing speed increases the risk of an injury accident and risk of serious or fatal injury.

Hauer and Bonneson (2006) and Hauer (2009) pointed out an anomaly of the Power Model. It predicts the same changes in crashes or injuries irrespective of initial speed. Thus, a reduction of speed from 10 to 7 km/h is predicted to give the same reduction in the number of fatalities as a reduction of speed from 100 to 70 km/h. This is implausible, as a fatal injury is very unlikely to occur at a speed of 10 km/h. They proposed an exponential model according to which changes in crashes or injury depend both on initial speed and the change in speed. Their model was, however, somewhat complex and Elvik (2013) asked whether a simpler model could be developed.

He was able to do so by "chaining" crash modification factors developed by means of the Power Model for different levels of initial speed. In the example above, initial speed was 100 km/h and final speed was 90 km/h. The crash modification factor, or the relative change in crashes, was 0.656. Now, if 90 km/h is taken as the initial speed in the next step of the chain, and 80 km/h as the final speed, the Power Model for fatal crashes, assuming a constant exponent of 4, implies a crash modification factor of 0.624. Starting from a speed of 100 km/h, and setting the initial number of crashes to 100, the number of crashes will be reduced to 100 · 0.656 = 65.6 when speed is reduced to 90 km/h. When it is further reduced to 80 km/h, the number of crashes will be reduced to 65.6 · 0.624 = 41.0. Proceeding this way, a set of data points was generated which can be interpreted as a curve relating speed of crashes or injuries starting at a level of 100 for the highest initial speed found in a data set.

It was found that the value of the exponent varied depending on initial speed. There was a tendency for the exponent to take on lower values the lower initial speed was. A power function and an exponential function were fitted to the data sets developed by chaining crash modification factors. Figure 1 shows an example.

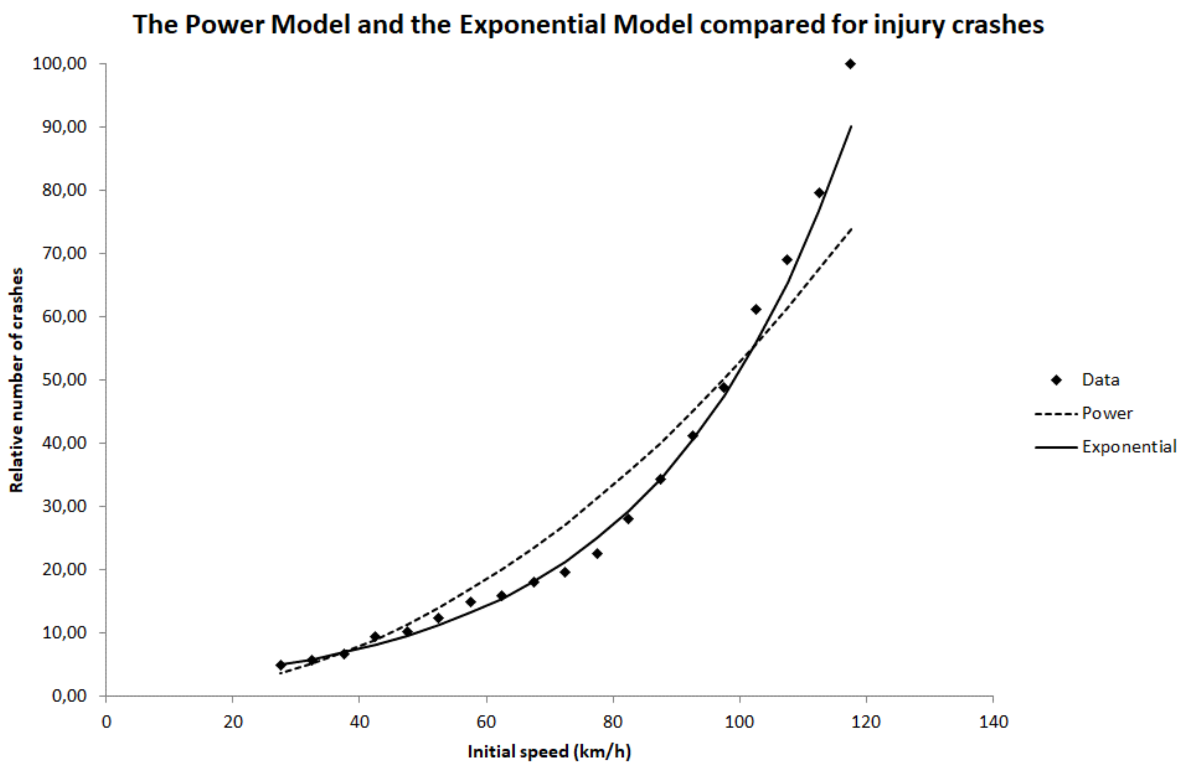

Figure 1: Comparison of the Power Model and the Exponential Model for injury crashes. Based on Elvik (2013)

The exponential function fitted in Figure 1 was of the form:

Number of crashes = $Constant\ term \cdot Exp^{(Speed\ term \cdot Speed)}$

The constant term and the speed term were estimated. In Figure 1, the constant term was 2.1 and the speed term 0.032. Exp is the exponential function, or the base of natural logarithms (2.71828) raised to the expression in parenthesis.

It is seen that the Exponential Model fits better to the data points than the Power Model, in particular at high speeds. Whereas the Power Model predicts a constant percentage change in the number of crashes or injured road users whenever the ratio speed after/speed before is constant, the Exponential Model predicts a constant percentage change in the number of crashes or injured road users when the difference in speed is constant. The Exponential Model can be applied to any change in speed by relying on the coefficient estimated for the full data set, i.e. it can be rewritten as:

Change in crashes or victims = $Exp^{\left((Speed_{after} - Speed_{before}) \cdot Coefficent\right)}$

This property makes it possible to apply the Exponential Model to specify a speed distribution and estimate the risk of crash or injury for any part of the speed distribution. It then becomes possible to develop a unified framework for analysis integrating knowledge about how individual driver crash risk varies as a function of speed with knowledge of how the mean speed of traffic is related to crashes or injuries.

Elvik (2013) estimated the speed coefficient in the Exponential Model (standard error in parenthesis) to values of 0.069 (0.012) for fatal crashes, 0.034 (0.001) for injury crashes and 0.032 (0.001) for property-damage-only crashes. Elvik (2014) extended the analysis to injured road users. The coefficients of the Exponential Model were estimated to 0.065 (0.006) for fatal injury, 0.065 (0.008) for serious injury and 0.039 (0.005) for slight injury. These estimates are all very precise.

However, the overall pattern shows inconsistencies. The coefficient for fatal crashes (0.069) has a higher value than the coefficient for fatal injuries (0.065). This is somewhat implausible, as it implies that there will be a larger reduction in the number of fatal crashes for a given reduction in speed, than the reduction in the number of fatal injuries. In other words, if speed is reduced, the number of fatalities per fatal crash will increase. A numerical example can show this. Suppose there are 100 fatal crashes with a total of 112 fatally injured road users. If speed is reduced by 10 km/h, the number of fatal crashes is reduced to 50. The number of fatally injured road users is reduced to 58. The number of fatally injured road users has thus increased from 1.12 (112/100) to 1.16 (58/50). Experience shows that when there is a reduction in the number of fatal crashes, the number of fatal injuries per fatal crash will also be reduced.

In the past 20 years, car safety has improved considerably. New safety systems like air bags, electronic stability control, automatic emergency braking and many others mean that modern cars are better equipped both to avoid crashes and to protect occupants in case of a crash than cars were only 20 years ago. Does this mean that speed has become less important for safety? Elvik et al. (2019) studied this by reviewing and synthesising studies of speed and safety published after 2000 and based on data collected fully or partly after 2000. Meta-analysis was made of 18 estimates referring to fatal injury and 31 estimates referring to injury crashes. Four summary estimates (based on different models of analysis and data points included) found coefficients for fatal injury in the Exponential Model of between 0.081 and 0.086 (with standard errors varying between 0.003 an 0.008). For injury crashes, the coefficient estimates for the Exponential Model varied between 0.060

and 0.067 (standard errors varied between 0.002 and 0.008). These values are higher than found in previous studies, suggesting that, if anything, speed is more important for road safety than it has ever been.

Elvik et al. (2019) also re-analysed three Australian studies of the relationship between individual driver speed and crash involvement (Moore et al. 1995, Kloeden et al. 1997, Kloeden et al. 2001). Although these studies have been criticised (Hauer 2004), they are the most recent and most well-controlled studies of the relationship between a driver's speed and his or her risk of crash involvement. The reason for re-analysing them, was to find out whether the relationship between speed and crashes has the same shape and strength at the individual level as it has at the aggregate level, i.e. between the speed of traffic and the total number of crashes. The Exponential Model fitted better than the Power Model in all three studies. The coefficient for speed (Exponential Model) was estimated to values varying between 0.026 and 0.069. A weighted mean value was 0.046 (standard error 0.001). The crashes included were injury crashes.

The coefficient for injury crashes at the aggregate level, referring to the mean speed of traffic, was estimated to 0.034 (0.001) by Elvik (2013) and to 0.067 (0.002) by Elvik et al. (2019). The former estimate is the more precise and is based on a larger data set than the latter. If the two estimates are combined by the inverse variance method, the weighted mean is 0.041, which is close to the weighted mean coefficient in the Australian studies. It may therefore be concluded that:

The shape and strength of the relationship between speed and the risk of crashes or injuries is the same at the individual level (i.e. for each driver) as it is at the aggregate level (i.e. for the speed of traffic).

Based on this knowledge, Elvik (2019) developed a comprehensive and unified framework for the analyses of the impacts on crashes or injuries of changes in speed or changes in the speed distribution. The framework is referred to as unified because it integrates the micro (individual driver) and macro (traffic) levels of analysis. It is referred to as comprehensive because it enables analysis not just of changes in mean speed, but also of changes affecting higher speeds more than lower speeds, changes in speed variance, and changes in the distribution of drivers between intervals of the speed distribution.

The assumption is made that speed has a normal distribution. It is further assumed that the entire speed distribution is contained within plus or minus three standard deviations of the mean speed of traffic. The speed distribution is divided into twelve intervals, each comprising half a standard deviation. This allows for quite precise analyses. Table 1 illustrates the framework for analysis.

Table 1: Framework of analysis of impacts of changes in speed and in the shape of the speed distribution. Based on Elvik (2019)

Interval (standard deviations)	Share of distribution (%)	Mean speed (km/h)	Relative fatality rate	Contribution to fatalities
2.5-3 above	0.6	95.9	4.874	2.92
2.5-2 above	1.7	92.3	3.655	6.21
2-1.5 above	4.4	88.7	2.740	12.06
1.5-1 above	9.2	85.1	2.054	18.90
1-0.5 above	15.0	81.5	1.540	23.11
0.5-0 above	19.1	77.9	1.155	22.06
0-0.5 below	19.1	74.3	0.866	16.54
0.5-1 below	15.0	70.7	0.649	9.74
1-1.5 below	9.2	67.1	0.487	4.48
1.5-2 below	4.4	63.5	0.365	1.61
2-2.5 below	1.7	59.9	0.274	0.47
2.5-3 below	0.6	56.3	0.205	0.12
Total or mean	100.0	76.1	1.000	118.21

Table 1 shows the speed distribution for roads in Norway with a speed limit of 80 km/h. In 2017, the mean speed of traffic on these roads was 76.1 km/h. For each interval of the speed distribution, the relative rate of fatalities, serious injuries and slight injuries for drivers driving at the mean speed within that interval has been estimated. The relative rate of fatalities and injuries has been set to 1.000 at the mean speed of traffic.

The exponential model of the relationship between speed and road safety has been used to estimates the relative rates. For a driver in the first interval above the mean, relative fatality rate is:

Relative fatality rate (0-0.5 above mean) = $Exp^{((77.9-76.1)\cdot 0.08)}$ = 1.155.

Relative rates of serious and slight injuries have been estimated the same way, using the coefficients of 0.06 and 0.04, respectively. The contribution of drivers in each speed interval to the total number of fatalities or injuries is estimated by multiplying relative rate with the percentage of traffic belonging to an interval. For the uppermost interval, the contribution to fatalities becomes: 0.6 · 4.874 = 2.92.

Elvik (2019) showed how this framework can be applied to estimate the impacts on the number of injured road users of:

1. A uniform reduction in speed, i.e. speed in every part of the speed distribution is reduced by the same amount (e.g. reduced by six km/h).
2. A larger reduction in high speeds than in low speeds – this is often how speed cameras influence speed.
3. A reduction in speed variance, while keeping the mean speed of traffic constant.
4. A change in the share of drivers belonging to the different intervals of the speed distribution, in particular a migration from high-speed intervals to lower speed intervals – this is often how an increase in fixed penalties for speeding influences speed.

There can be no doubt about the strong relationship between speed and road safety. The higher the speed of traffic, the greater and more serious the number of crashes. The higher the speed of a driver, the greater are his or her chances of becoming involved in a crash with a serious outcome. The Exponential Model, with speed coefficients of 0.08 for fatal injury, 0.06 for serious injury and 0.04 for slight injury, is an unbiased and precise summary of the relationship between speed and the number of fatal, serious or slight injuries. For injury crashes, a coefficient of slightly more than 0.04, say 0.045, is a reasonable estimate. These estimates are all statistically highly precise, with standard errors of, in general, less than 0.005.

There is no evidence that speed is less important for safety now than it was some 20 or 30 years ago. If anything, evidence suggests that speed is more important than before.

Intelligent Speed Adaptation (ISA) is a mature technology that can be installed in motor vehicles to eliminate speeding. The technology is not very expensive and cost-benefit analyses of it indicate that benefits greatly exceed costs (Carsten and Tate 2005).

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2.2 Speed in the Safe System

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Introduction

Speed and its management are the core in a Safe System approach and cuts across most Safe System intervention categories. In a safe system, three main strategies to eliminate fatalities and severe injuries due to road crashes can be identified: prevent people from exposure to risks, reduce the risk level, and protect people from harmful energy in the event of a collision. Managing and controlling speed is therefore at the center of developing a Safe System. The objective of managing speed in a safe system includes, besides protecting road users from severe injuries and deaths, a desire to create a sustainable society addressing livable cities, health, security, and equity.
Safe speeds and safe speed limits are on the global agenda. In advance of the Third Ministerial Conference on Global Road Safety 2020, an Academic Expert Group, consisting of road safety experts from around the world, developed 9 recommendations to advise on priority directions for road safety following the first Decade of Action, Tingvall et al (2020). Two of these recommendations are about safe speeds and speed limits in a Safe System, namely Recommendation #7: Zero Speeding and Recommendation #8: 30 km/h in urban areas. These recommendations are based on the introduction of Agenda 2030, often referred to as the Sustainable Development Goals (SDGs).

The speed limits constitute the legal objectives for the monitoring and enforcement of the speeds in the road system. Historically, the motives and criteria for setting the speed limits in a country has often changed over time. In Sweden for example, in the beginning of the era of speed limits there was a focus on driver acceptance and the advice was that the speed limit should be around the 85th percentile. Soon it became obvious that road alignment and crash rates needed to be considered as well and criteria related to these issues were considered when deciding speed limits. During the 70'ies there were discussions about whether speed limits should be established from a cost benefit perspective. However, after Vision Zero has been implemented in Sweden there has been a shift towards that the road users' tolerance against external forces should be the basic design parameter for the speed, Belin and Vadeby (in press).

Speed limits in a Safe System

According to Safe System principles, road users' vulnerability and tolerance against external forces should be the main design parameter for the speed and consequently the speed limits. This requires that the speed limits be related to the infrastructure, human vulnerability, and best practices in vehicle design. The safer the roads and vehicles, the higher the speed that can be accepted.

Based on the human vulnerability, it has been suggested that the risk for different crash types should set the maximum speed. For example, in the situation where there are risks for crashes with cars and unprotected road users, the speed limit should not be higher than 30 km/h. If there is a risk for head-on collisions (i.e. cars to cars), a speed not higher than 70 km/h can be allowed, Tingvall and Haworth (1999). See Table 1, where possible safe system speed limits related to the infrastructure and crash type are shown.

Table 1. Possible safe system speed limits related to the infrastructure, given best practice in vehicle design and 100% restraint use, source Tingvall and Haworth (1999) and https://roadsafety.piarc.org/en/road-safety-management-safe-system-approach/safe-system-elements.

Type of infrastructure and traffic	Crash type	Possible safe system speed limits (km/h)
Locations with possible conflicts between pedestrians and cars.	Car/pedestrian, Car/cyclist, car/motorcyclist	30
Intersections with possible side impacts between cars.	Car/car (side impact)	50
Roads with possible frontal impacts between cars	Car/car (head-on)	70
Roads with no possibility of a side impact or frontal impact (only impact with the infrastructure)		100+

In certain parts of the road network, such as high standard motorways, the risk of crash outcomes involving high levels of energy transfer (and therefore being fatal) is low in relation to the traffic mileage. Typically, these are roads with no at-grade intersections, median barriers installed to prevent head-on crashes, and forgivable roadsides or roadside barriers installed to protect vehicle occupants from roadside objects. These roads also separate vulnerable road users from higher speed traffic. In these circumstances, and subject to limitations on vehicle flow volumes per lane, higher operating speeds (such as 100 or 110 km/h) can generally be safely supported for vehicles with a high standard of safety features.

On the other hand, for two-lane, two-way roads in rural environments with unprotected roadside hazards, frequent intersections, unsealed shoulders and variable standards of horizontal and vertical geometry, the risks of serious casualty crash outcomes are much higher and therefore lower speed limits might be necessary, https://roadsafety.piarc.org/en/road-safety-management-safe-system-approach/safe-system-elements.

If higher speeds than 30 km/h in an urban environment is desired, the option is to separate the vulnerable road users, pedestrians, and cyclists from the motor vehicle traffic. If not, the speeds at pedestrian crossings etc. should be limited to 30 km/h.

How speed limits should be designed in a Safe System is also acknowledged in two of the nine recommendations of the Academic Expert Group, Tingvall et al. (2020). Vehicles that meet UN or equivalent national standards are designed to limit crash forces to their occupants to survivable levels in side impacts up to collision speeds of 50 km/h. Standards also require that vehicles limit crash forces to their occupants to survivable levels in frontal crashes up to 70 km/h. These design rules have been developed for passenger cars and further research is needed to confirm safe travel speeds for other vehicle types in various environments, Ohlin et al (2019). The expert group also suggest a speed limit of 30 km/h in urban areas unless strong evidence exists that higher speeds are safe.

In a literature review by Hussain et. al (2019), the relationship between impact speed and the probability of pedestrian fatality during a vehicle-pedestrian crash is investigated. The results show that the risk of a fatality for the pedestrian reaches 5 % at an impact speed of 30 km/h and 10 % at

37 km/h. Hussain et al concludes that the results support setting speed limits of 30 – 40 km/h in areas where there are many pedestrians. Jurewicz et al (2016) studies vehicle impact speed and injury severity for different crash types by reviewing scientific literature. They found that, if allowing a 10 % risk for MAIS3+, the critical impact speed for a pedestrian- vehicle crash is about 20 km/h.

A recent paper by Doecke et al (2020) investigates the relationship between impact speed and the risk of serious injury in light vehicle crashes using data from an event data recorder (EDR) where the impact speed is known. Studying at which impact speeds the risk of serious injury reaches 1%, they found that it was at 28 km/h for head on impacts, 51 km/h for side impacts, 64 km/h for front impacts, and 67 km/h for rear impacts. These results clearly emphasize the importance of measures that reduce the impact speeds and highlight the need to prevent head on crashes. Measures to reduce impact speed can be road designs, vehicle technologies or enforcement.

Measures and enforcement

In addition to setting speed limits according to safe system principles, other measures are also suggested in the nine recommendations along with a strong recommendation that the system owners must take responsibility for integrating effective speed management methods to ensure that vehicles remain in compliance. Some examples of measures mentioned are:

- Effective enforcement methods and practices, along with substantial penalties for offenders. The use of automated speed cameras is shown to be effective to increase compliance.
- Vehicle technologies that detect speed limits and prevent higher speeds or provide warnings when the speed limit is exceeded.
- Connected vehicle technology can be used in conjunction with speed limiters and geo-fencing to control speeds in specific areas.
- Businesses, governments, and other fleet owners practice a zero-tolerance approach to speeding in their own or procured transport operations.
- Design roads so that drivers find it most comfortable to travel at safe speeds.
- Public education on the risks associated with speeding along with awareness of active enforcement activity.

A case-study: changed speed limits in Sweden

To have better possibilities to adapt the speed limits to the safety classification of the roads, Sweden's speed limit system was reformed in 2008. The motives behind the speed limit changes were based on a government commission in 2004 whereby the Swedish Road Administration (SRA) were to present a strategy for gradual adjustment of the speed limits in line with the concept of Vision Zero but also consider accessibility requirements, good environment, regional development and a gender equal transport system. SRA was also commissioned within the framework of this approach to propose a new speed limit system or changes in the current speed limit system that had the possibility within a balanced fulfilment of the transport policy goals to contribute to the interim road safety targets. A new set of limits—that is, 40, 60, 80, 100, and 120 km/h—was introduced on to complement the previous limits of 30, 50, 70, 90, and 110 km/h.

In the following years, the Swedish Transport Administration reviewed the speed limits according to guidelines established for different types of roads. The long-term vision was that speed limits should be adapted to the safety classification of each road and be in line with the ideas of Vision Zero. One main criterion is that roads with a speed limits of 90 km/h or above should have median barriers. The main category of roads with new speed limits was rural two-lane roads, where the speed limit was reduced from 90 to 80 km/h, Vadeby and Forsman (2014, 2018). During 2008 and 2009, major changes on the road network took place and the revision resulted in that approximately 20,500 km of roads, corresponding to 21 percent by length of all state roads in Sweden, were assigned new speed limits. The main group of roads with new speed limits was rural 2-lane roads, where the speed limit was reduced from 90 to 80 km/h. This group accounted for more than 60 percent by length of the roads with changed speed limits. It predominantly included roads of a low safety standard—that is, with inadequate roadsides and no median barriers—that were selected for reduced speed limits, whereas roads of a good safety standard were selected for increased speed limits. In addition, roads important to local economic activity, transport, and commuting were assigned higher speed limits than were roads less important from a local economic perspective.

The evaluation showed that on rural roads where the speed limit was reduced from 90 – 80 km/h, the mean speed decreased by 3.1 km/h, the number of fatalities decreased by about 40 % (17 fatalities) and the number of seriously injured did not change significantly. On motorways where the limit was increased, the mean speed increased by 3.4 km/h, the number of seriously injured increased by about 120 % (15 seriously injured), but no significant change was seen in the number of fatalities, Vadeby and Forsman (2018) and ITF (2018).

Implications for a Europe-wide Safe System approach

In ITF (2018), recent trends in speed management policies in OECD countries are investigated. Many of the countries have witnessed several changes in speed limits and enforcement practice on various road types. Change in speed limits is often subject to intense social and political debates. In many countries, raising the speed limit on the motorway network is a recurrent political argument.

In urban areas, all countries have progressively moved towards a maximum speed limit of 50 km/h or less. In 2017, nearly all IRTAD countries had a default speed limit in urban areas of 50 km/h, with often lower speed limits (20, 25, 30 or 40 km/h) in residential areas or around schools. When there are discussions whether to change the speed limits in urban areas, they mostly concern lowering the speed in residential areas. Some countries are considering adopting a 30 km/h default speed limit, with higher limits on main arterial roads. In the Netherlands, following a full review of road classification, 70% of road in urban areas are limited to 30 km/h.

Outside built-up areas, and excluding motorways, speed limits typically vary between 80 and 100 km/h. There are regular discussions on increasing or decreasing the speed limit by 10 km/h on this network. Based on the responses received, regarding the years to come, the trend is more in lowering the speed limit in countries with the highest limits (e.g. from 100 to 90 km/h).

The motorway network can be subject to frequent changes and political debates. In 2017, the general speed limits on non-urban motorways varied from 100 km/h (in Japan, New Zealand and Nigeria) to 140 km/h (in Poland). In Germany there is a recommended maximum speed of 130 km/h. There is usually a lower speed limit for urban motorways and lower limits for trucks and vehicles towing a trailer. In the past 20 years, nearly all countries have either increased or decreased their speed limits on the motorway network, without any clear direction. These changes are often pushed by political decisions. When the speed limit is reduced, the environmental benefits of reduced speed are often put forward.

Conclusion

Safe speeds and safe speed limits are on the global agenda today. In a safe system, three main strategies to eliminate fatalities and severe injuries due to road crashes can be identified: prevent people from exposure to the risks, reduce the risk level, and protect people from harmful energy in the event of a collision. Managing and controlling speed is therefore at the center of developing a Safe System. Setting speed limits according to safe system principles means that road users' vulnerability and tolerance against external forces should be the main design parameter for the speed. This requires that the speed limits be related to the infrastructure, human vulnerability, and best practices in vehicle design. The safer the roads and vehicles, the higher the speed that can be accepted.

Based on the human vulnerability, it has been suggested that the risk for different crash types should set the maximum speed. For example, in the situation where there are risks for crashes between cars and unprotected road users, the speed limit should not be higher than 30 km/h. If there is a risk for side-impacts, the speed limit should be maximum 50 km/h and if there is a risk for head-on collisions (i.e. cars to cars) the speed limit should not be higher than 70 km/h, Tingvall and Haworth (1999).

Looking at the speed limits systems used in Europe today (ITF, 2018), there seems to be a rather long way to go to Safe System speed limits within Europe. The default speed limit in urban areas in Europe are mainly 50 km/h and the compliance is sometimes low, ETSC, (2019). According to ITF, there is a discussion to lower the speed limits in urban areas in some countries and especially in areas where there are many vulnerable road users. On rural roads with no median barrier, the speed limit is often between 80 and 100 km/h. Here there are examples of countries going in the direction towards speed limits in line with safe system design principles. Sweden is one example where this change of direction for setting speed limits started in 2004 with a government commission whereby the Swedish Road Administration (SRA) were to present a strategy for gradual adjustment of the speed limits in line with the concept of Vision Zero but also consider accessibility requirements, good environment, regional development and a gender equal transport system. This has led to major changes of the speed limits on the Swedish roads, Vadeby and Forsman (2014, 2018). The process of adapting the speed limits in line with the concept of Vision Zero is still an ongoing process in Sweden. In France, following a government decision, speed limits on two-way rural roads without median barrier were decrease from 90 km/h to 80 km/h in mainland France on 1 July 2018.The main objective of the change was to reduce the number of deaths and injuries on the roads affected by the measure (Cerema, 2020).

In conclusion, the objective of managing speed and achieve safe speeds in a safe system involves, besides protecting road users from severe injuries and deaths, a desire to create a sustainable society addressing livable cities, health, security and equity among other things. Many countries have still a long way to go, but to be able to achieve a safe road system it is essential that the importance of speed as a design parameter is highlighted further.

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2.3 Measuring speeds

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1. Introduction

Speed as the **major cause of road accidents** constitutes one of the central issues in road safety. It has been found that excessive or inappropriate speed contributes to around 10% of all accidents and 30% of fatal accidents (TRB, 1998; OECD, 2006). Driving at higher speed than allowed affects both the risk of being involved in an accident, as well as the severity of an accident. In general: the higher the speed, the higher the accident risk and the more severe the accident consequences (EC, 2018a).

Speed does not only affect road safety, but also the environment and more precisely, the level of exhaust emissions, traffic noise, fuel consumption affecting thus, the quality of life of urban residents. However, both **authorities and road users underestimate largely the role of speed** in road accidents and environment, mainly due to the fact that the negative effects are mainly a societal problem which are overlooked by individual drivers, who on the other hand focus on the positive effects of speed on the travel time.

Today in road safety we work mostly in blind, as we have very **little knowledge about the frequency of speeding and its real role on accident occurrence and severity** and consequently no appropriate policies, programmes and measures can be designed and implemented, with major consequence that today the related road traffic safety measures are largely under-designed and even less accepted by the population. Fundamental data and corresponding analyses to support the necessary traffic safety decisions are missing. Traffic data necessary to combine with crash data in order to judge the size of the phenomenon are blatantly missing. And most importantly, reliable data and performance indicators on speeding, and any evaluation of traffic safety measures effectiveness are always largely piecemeal and with limited transferability in other places in the world.

Within this context, **speeding monitoring and accountability** both by the users and the Authorities could have a positive effect on the improvement of road safety performance. Data is the key support tool for developing evidence-based road safety policies. On that purpose, reliable and of high quality data are needed to be collected, which after their proper analysis will lead to the appropriate evidence-based speed measures and policies. The objective of this paper is to present the data requirements, data collection methodologies in order to properly measure speeds. Special focus is also given on the speed data needs of the involved road safety stakeholders in order to support their policies in dealing with speeding.

2. Why, What, When, Where and How to Measure

2.1 Speed measuring techniques

A variety of methods are today available to measure speeds. These methods differ by the equipment technology used as well as the installation location of the collection equipment.

Based on the **installation location of the equipment**, the methods are grouped into the three following categories (FHWA, 2012):

- manually-operated, handheld devices that are portable (e.g., stopwatch, radar gun, lidar gun),
- in-road devices that are installed into or on top of the roadway surface (e.g., pneumatic road tube).
- out-of-road devices that are installed overhead or to the side of the roadway surface (e.g. radar recorders).

Based on the **equipment technology**, the data collection methods could be grouped into the following categories (GRSP, 2008):

- methods involving timing,
- methods involving video,
- radar guns,
- laser guns,
- global positioning system (GPS).

Below, some of the most commonly used techniques of measuring speeds are presented:

Fixed cameras

The fixed cameras may either record the spot speed at which the vehicle passes them at a particular location or measure the time taken by a vehicle to travel over a fixed length of the road, and then calculate the vehicle's average speed for the journey.

Mobile cameras

Mobile cameras work like fixed cameras, but are moved from location to location. They may be hand-held, tripod mounted, or vehicle-mounted. In this category of speed measuring techniques, laser guns are also included, which rely on the measurement of the round-trip time of the infrared light beam to reach a vehicle and be reflected back.

Traffic counts

With this method, the passage time of a vehicle between two detectors is recorded. Detectors can be pairs of pneumatic tubes, tribo- and piezo-electric cables, switch tapes, inductive loops and photo-electric or electro-magnetic beams, but also traffic cameras.

Section control

Section control (also called average speed control) systems measure the average speed over a road section. The vehicle is identified when entering the enforcement section, and again when leaving it and the average speed is calculated based on the time interval between these two locations.

Smartphones / OBD

Sensors on smartphones and/or vehicles are fitted with receiver units that pick up signals from the Global Positioning System (GPS) satellite network. The accuracy of code-based differential GPS accuracy is about 2 - 3 m with a baseline distance of 100 - 200 km (GRSP, 2008).

In-depth investigation

The purpose of in-depth investigation is collecting all data describing the accident, including the road environment, the involved vehicles and road users in order to identify the causes and consequences of the crash. Vehicle crash profile measurements are also taken in order to calculate crash energy and speed change at impact (Sicinska & Zielinska, 2016). Thus, among data estimated from the in-depth investigation are the initial speed and collision speed of the vehicle.

Driver perception/attitudes

An alternative data collection method concerning the safety behaviour of road users is via questionnaires on perceptions and attitudes of drivers concerning speeding. Data on self-declared speeding can be collected as well as on acceptability of driving over speed limits. Such surveys have been conducted in the ERSA project (Yannis et al., 2016) which discusses speeding aspects, such as the acceptability of speeding, attitudes towards speeding, perceived likelihood of getting caught for speeding, etc.

2.2 Speed measurement types

The speeds that are most relevant for safety purposes are spot speeds measured at various locations on the road network. Several speed-crash studies have also looked at absolute speed, either at individual vehicle level or at road section level (Hakkert et al., 2007). Additionally, the average speed of vehicle(s) at a specific point in time either on a road axis or at a road network is essential to be measured, as well as the average speed of vehicles over time by road type or area type.

Different **purposes of speed data collection** imply different data and hence different methods of collection. For instance, Traffic Police collects data on speeding from enforcement controls in specific locations, while data on speeding from sample counts are collected for the estimation of speeding Key Performance Indicators (KPIs), such as the mean speed, the standard deviation, the 85th percentile speed and the percentage of drivers driving within the speed limits.

2.3 Data Sampling

In order to fully define the speeding problem, **reliable data** should be collected, representative of the size of the targeted population and unbiased by exogenous factors. On that purpose, data collection should include techniques that capture typical traffic behaviour without affecting it. More specifically, the vehicles checked should be only those in which drivers are choosing their own speed or are free-flowing (FHWA, 2012).

Speed data collection is also important for the estimation of the respective road safety performance indicators on speeding. On that purpose, the level of detail of the data collected should be compatible to that of road accident data to facilitate more detailed road safety analyses. Several **factors are associated with speeding**, which are related to the road environment, vehicle, traffic and other conditions, as well as the driver's characteristics. More specifically (Hakkert & Gitelman, 2007; Hakkert et al., 2007):

- The speed at which a vehicle is driven on a road is dependent on the **characteristics of this road**.
- Road design characteristics and the **surrounding environment** influence speeds. The locations at which speed measurements are carried must be chosen carefully, with the locations where vehicles are likely to stop, accelerate or brake being avoided.
- **Traffic and weather conditions** are two well-identified sources of temporal variations of speed. The vehicles in free flowing traffic conditions should be considered for the speed data collection. Speed data should be considered under weather conditions that have a small speed reduction effect.
- On a yearly basis, measurements should be taken in a month that is "neutral" as far as a **seasonal variation** in traffic is concerned, avoiding also the winter period (due to a risk of bad weather).
- Large variations also exist between **day and night** and to a lesser extent between **weekday and weekend**. Speed indicators should thus be disaggregated by weekday/ weekend and day/night.
- Different **types of vehicles** have different speed characteristics and show diverse shares in traffic between roads.
- **Driver’s profile** affects the speed at which a vehicle is driven.

Based on the above factors, the following disaggregation level of the speed data is recommended at least to be taken into account for estimating speed indicators:

- **Road type**: urban, interurban, motorways
- **Traffic conditions**: presence of a junction or not, weather conditions, week/weekend days, day/night
- **Vehicle type**: passenger cars, motorcycles, trucks, cycles (incl. e-scoters and e-cycles)

- **Driver type**: driver age, driver gender, distraction, drink-and-drive, trip purpose.

3. Data supported Measures against speeding

Speed data collection is essential in order to monitor the safety performance, associate the behaviour of road users with road safety outcomes and design the proper policies against speeding. Thus, the data collected as well as the analysis results should support the policy making process at all levels.

3.1 Data for policy making support

The collection and analysis of speed data aims to provide support during the policy making process by identifying properly the problem, so that the involved authorities are able to take **prompt and customized measures**. The involved authorities may be the related to road safety Ministries (i.e. Ministries of Transport, Health, Education), local authorities (e.g. municipalities), as well as public and private Road Authorities (e.g. Motorway concessionaires), who are responsible for designing and taking the proper measures for the reduction of speeding, such as engineering measures, legislative initiatives, traffic education measures, etc.

The collection of both macroscopic and microscopic data on speeding and the estimation of the related **performance indicators** can assist the decision makers not only to take the appropriate road safety measures, but also to **monitor the road safety performance** of the whole or specific parts of road network, specific types of drivers and vehicles, evaluate the effectiveness of the measures taken and **redefine their policies** with targeted measures at risk groups.

A successful example of the systematic collection and analysis of speed data, continuous monitoring of speeding and the implementation and evaluation of a measure with positive effects on road safety was the **reduction of speed limits on rural road in France**. On 1 July 2018, following a government decision, France implemented the measure to lower the speed limit from 90 km/h to 80 km/h on two-way rural roads without a central separator. The aim of this measure was to reduce the number of deaths and injuries on this type of roads.

An **in-depth assessment of the applied measure** was carried out in July 2020. Detailed data on crashes, speeds, exposure and socio-economic indicators were exploited and analysed around four themes: speeds, accident rates, acceptability and effects on society. Concerning the safety effects of the measure, the analysis led to significant conclusions. A 12% decrease in the number of deaths on the considered network was achieved compared to the rest of the French road network. For the 18 months after the implementation of the measure, a decrease of 331 deaths on the considered network was recorded compared to the reference period 2013-2017. On the contrary, on the remaining road network, the change differs; the number of deaths has remained stable compared to the reference level (CEREMA, 2020).

The collection of appropriate data alongside with dedicated data analysis methodologies for **predicting and benchmarking network's risk** can also contribute to the early detection of the problem and the selection of the optimum solution. In this case, spatial econometric models (e.g. Spatial error model, Spatial durbin model) can be used to the future short- and long-term predictions in time and space, while benchmarking techniques (e.g. stochastic frontier analysis and data envelopment analysis) can be used for the benchmarking and efficiency measurement of road risk for all existing levels (micro/ meso/ macro) and for all different dimensions (time/ space).

3.2 Data for driver support

Additionally, the data collection and analysis should also focus on driver support with aim to improve driver behaviour and develop better road safety culture at all road users. This could be achieved by collecting **real-time data from smartphone sensors** or vehicle OBDs and processing speed data in order to create microscopic driving behaviour metrics and KPIs. These KPIs and metrics could be used in two types of analysis: a) clustering algorithms in order to identify driving patterns, b) classification techniques for the pattern recognition of the dynamic driving behaviour. Based on the results of such analyses, recommendation systems algorithms can be developed, which will **provide feedback to drivers on their behaviour** (e.g. via knowledge graphs per trip, at all trips etc.).

Such an example of measuring driver behaviour is the experiment conducted within the context of the BeSmart project (besmart-project.gr) by the National Technical University of Athens and OSeven Telematics. The aim of the project is to develop measures by means of smartphone applications and a web-platform in order to inform, notify, motivate and train the drivers with upper aim to adopt a safer and eco-friendly driving behaviour. Among the various data collected, speed data are also collected for the assessment of the speeding behaviour and safety of drivers in every day drips. Then, personalised speeding feedback is communicated to drivers, allowing them to identify their critical deficits or unsafe behaviours. The first two phases of the experiment showed that the feedback the drivers received had a **positive impact on their driving behaviour**, resulting to a safer and within the speed limits driving. In fact, between the two phases of the experiment, speeding by car drivers was reduced by 28,39%.

3.3 Data for enforcement

Speed data are also important for the design and implementation of an **efficient speed enforcement plan**. The collection and analysis of the proper data and at the appropriate level of detail can support the policy makers and Traffic Police to design a road traffic enforcement plan with specific targets. Data analysis could assist in the selection of which groups of road users to be targeted by enforcement activity. Additionally, data analysis can also play a key role in the choice of locations and time of enforcement operations, considering the best mix between highly visible police checks and less visible controls for the increase of enforcement efficiency towards speeding reduction (EC, 2018b).

3.4 Data for campaigns

Publicity campaigns by public and private organizations can be used to raise awareness on the risk of speeding, inform road users about specific measures, their expected benefits and also about the realized effects (EC, 2018b). The collection and analysis of speed data can lead to **speed awareness campaigns** focused on specific driver groups, who present a risky driving behaviour or aiming at their social surroundings. However, the effect of publicity on driver behaviour is limited, while when combined with enforcement measures, campaigns are more effective.

3.5 Data for the vehicle industry

The development of in-vehicle systems that that supports drivers' compliance with the speed limits continues rapidly as large amounts of data are becoming available. Such a system is the **Intelligent Speed Adaptation** (ISA) is an in-vehicle system 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 (EC, 2018a). There are three types of ISA:

- informative: giving information to the driver
- voluntary supportive: driver can choose to set the maximum speed
- mandatory supportive: intervenes at all times when the vehicle exceeds the speed limit.

Additionally, the possibilities of vehicle - roadside communication offer new technologies that can support the reduction of speeding. For instance, **dynamic speed limits** can better reflect the safe speed, since they are based on real time traffic, road and weather conditions.

4. Future Challenges

Concluding, speed is highly misunderstood by all and this must change. In order to achieve this, **more data and knowledge** at a broader geographical and time coverage are needed to be collected. Additionally, new methodologies should be taken into account and new tools should be more broadly used in order to **better exploit both current and future data**. In order to face the speeding issue more efficiently, focus should be given on the collection of more and of high quality data, including more accurate road accident data, exposure data and performance indicators, while appropriate data are also needed for the evaluation of the effectiveness of the implemented measures and policies.

The **digitalization** (Artificial Intelligence, Machine Learning, etc.) and the wealth of (big) data being available by the wide range of new technologies and their applications open a totally new era to **support not only decision-makers but also road users** at their everyday strategic, operational and tactical decisions. Thus, a new great potential arises for seamless data driven procedures from the identification of road safety problems to the selection and implementation of the optimal solutions. New data offered by the emerging technologies offer increased net present value, since their analysis can contribute to the early (real-time) detection of the problem and the prompt and customized decision support.

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3. Speed in context: Vehicles and infrastructure

This section looks at speed both from the angle of the infrastructure and of the vehicle. How do we approach a road classification that better matches speed limits to road design and layout in a Safe System? What are the elements that make a road safe for vehicles and humans (particularly vulnerable road users)? And what does recent vehicle technology mean for speed policy?

3.1 Road function, safe speeds and credible speed limits

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Introduction

An efficient and effective transport system relies on the fast and safe movement of people and goods. Speed plays an important role and without some speed there is no mobility. However, speed has a large impact on safety. So, the challenge is to identify which speeds are appropriate for a given situation from a safety point of view and based on that, to set safe speed limits that road users consider as fair and credible. The next sections elaborate on this.

It should be kept in mind though, that, in the end, the choice of a safe or desirable speed is mainly a political decision that is directly related to the number of traffic fatalities deemed acceptable. But scientific knowledge and insights can help inform such choice. To this end, Sustainable Safety, the recently updated Dutch Safe Systems approach, offers a useful framework (SWOV, 2018).

A functional classification of the road network

A first step towards logical and safe speed limits is road network classification. In Sustainable Safety the number of road categories is limited and determined by two main functions:

1. The flow function: allowing efficient throughput of (long distance) motorised 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.
2. The access function: providing access to properties and specific destinations alongside a road or street - houses, shops, offices, factories, recreational areas, etc. Both intersections and road links can be used for traffic exchange, e.g. changing direction, crossing, turning.

Based on these two functions, the Netherlands distinguish just three road types (Figure 1):

- Through roads, which have a flow function.
- Access roads, which provide access.
- Distributor roads, linking the access roads to the through roads and which allow traffic to flow on the road links and to exchange at intersections.

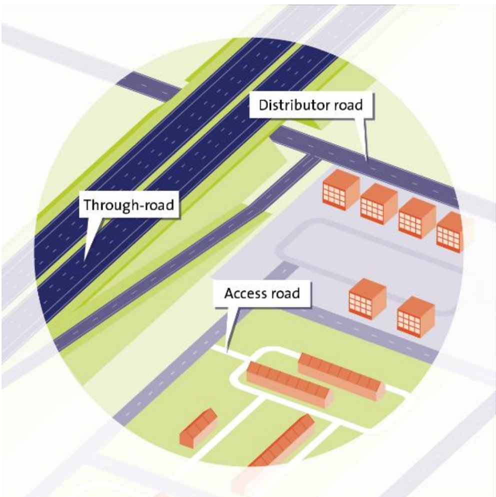

Figure 1. Functional classification of roads (From: SWOV, 2018)

From a safety point of view (lowest crash risk), but also from an efficiency point of view (minimising travel times), it is desirable that a travelled route, from origin to destination, is primarily undertaken on the highest order roads with the smallest proportion of the trip on the access and distributor roads (Figure 2). Obviously, this requires a fairly dense network of motorways and principal urban and interurban roads.

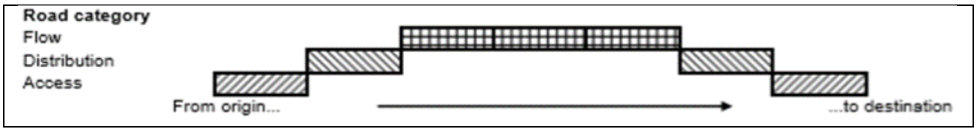

Figure 2. Diagram of an optimal route composition using different road functions. (From: Dijkstra, 2011)

Sustainable Safety strives for monofunctionality: roads should ideally have only one of the earlier described functions. However, in practice this is not always easy to realise. For example, currently through roads in villages often combine a flow function, catering for motorised through traffic, and an access function, with shops and houses alongside the road, resulting in a mix of fast driving cars, crossing pedestrians, and people getting on and off their bicycle. In these situations where roads have a combined flow and access function with limited options to redirect through traffic away from the village, the road would be assigned the lowest function, namely that of access and with that operate at an appropriate low speed limit (see next paragraph).

Road function and safe speeds

Road function and road category determine how traffic is managed on a road: which road users can make use of that road and which manoeuvres and interactions are allowed, and hence, what conflicts can occur. These features, in turn, determine which driving speed would be 'safe'[1] on a specific road. Generally, the higher the road category, the higher the speed limit and the more segregated the different traffic types, thereby limiting conflicts resulting from large speed, directional and mass differences. Each road category is preferably characterised by a unique set of design features in order to make the intended use recognisable for road users.

In a Safe Systems approach, speed restrictions are largely based on biomechanical principles or injury minimization: people are physically vulnerable and can endure only a limited amount of external forces. Impact speed, impact mass, impact direction, and the level of protection provided by, for example, the car body or a helmet determine the injury consequences of a collision. Higher speeds, larger differences in mass between the colliding objects, frontal and right-angle collision, and insufficient physical protection lead to more severe injuries.

In situations where there is a need for higher speed, i.e., when the road has a flow function and people and goods need to be moved fast and efficiently, large differences in speed, mass and direction must be prevented, and road users must be well protected. If these differences cannot be minimised and there is, for example, a risk of interaction between unprotected road users and motorised traffic, speeds must be low. Additional criteria for determining a safe speed are stopping sight distance and a forgiving roadside, i.e., the presence of a (semi) hard shoulder and a sufficiently wide clear zone next to the road (or appropriate barrier systems to prevent run-off road incidents).

Table 1 below lists the potential conflicts given various road and traffic characteristics, the related road category, and the recommended safe speed (limit). The characteristics listed in Table 1 are all relatively static features. However, safe speeds are also dependant on dynamic features such as traffic volumes, traffic composition, congestion, and weather conditions. Taking these features into account would require a real-time roadside or in-vehicle information and communication system, such as dynamic intelligent speed assistance (ISA).

Table 1. Safe speeds in different road and traffic conditions (changes with row above indicated in bold)[2]. (Based on: SWOV, 2018)

Road and traffic characteristics and possible conflicts	Road category	'Safe' speed (km/h)
Possible conflicts with vulnerable road users in residential zones (no foot paths and pedestrians using the carriageway)	Access	15
Possible conflicts with vulnerable road users **on roads and at intersections,** including situations with bicycle lanes that are not physically separated from the carriageway.	Access	30

[1] Obviously, a one hundred per cent safe speed does not exist. Even at very low speeds, crashes can have serious consequences. Here, we use the concept of 'safe' speed for readability purposes. 'Safe speed' must be considered as the optimum between enabling mobility and optimising road safety.

[2] Potential conflict situations demanding a maximum speed of 15km/h are based on Ministry of Transport (1985). Potential conflict situations and design requirements linked to a desirable speed between 30 and 120 km/h are based on Tingvall & Haworth (1999) and Aarts et al. (2009). Design requirements for safe travel on roads of 130 km/h have provisionally been specified but require further study.

No conflicts with vulnerable road users, except with helmet-protected riders of motorised two-wheelers. Possible right-angle conflicts between motorised vehicles, possible frontal conflicts between motorised vehicles. **Stopping sight distance ≥ 47 m**	Distributor	50
No conflicts with vulnerable road users **No right-angle conflicts between motorised vehicles,** possible frontal conflicts between motorised vehicles **Obstacles shielded or clear zone ≥ 2.5 m, (semi)hard shoulder** **Stopping sight distance ≥ 64 m**	Distributor	60
No conflicts with vulnerable road users No right-angle conflicts between motorised vehicles, possible frontal conflicts between motorised vehicles Obstacles shielded or **clear zone ≥ 4.5 m,** (semi)hard shoulder **Stopping sight distance ≥ 82 m**	Distributor	70
No conflicts with vulnerable road users **No right-angle or frontal conflicts between motorised vehicles** Obstacles shielded or **clear zone ≥ 6 m,** (semi)hard shoulder **Stopping sight distance ≥ 105 m**	Distributor	80
No conflicts with vulnerable road users No right-angle or frontal conflicts between motorised vehicles Obstacles shielded or clear **zone ≥ 10 m, hard shoulder** **Stopping sight distance ≥ 170 m**	Through road	100
No conflicts with vulnerable road users No right-angle or frontal conflicts between motorised vehicles Obstacles shielded or clear **zone ≥ 13 m**, hard shoulder **Stopping sight distance ≥ 260 m**	Through road	120
No conflicts with vulnerable road users No right-angle or frontal conflicts between motorised vehicles Obstacles shielded or clear **zone ≥ 14.5 m**, hard shoulder **Stopping sight distance ≥ 315 m**	Through road	130

Credible speed limits

In the foregoing section we have tried to demonstrate how a functional classification of roads in a road network can prescribe the mix of road users and road use. This, in turn, would determine which speeds are safe, given the vulnerability of the human body and several related traffic engineering criteria. These safe speeds would then be the basis for setting appropriate speed limits. However, the next challenge is that these speed limits are respected. A first step is that all road users need to be made aware of the prevailing speed limits by informing them about general speed limits for different road types, by applying recognisable road design characteristics in a consistent way on these different road types, and by placing speed limit signs alongside the road (or as is becoming commonplace, providing in-vehicle speed limit information) to reinforce the message.

Although these actions will have a positive effect on driven speeds, they do not guarantee that road users will actually comply with the speed limits. Until all vehicles are fitted with some form of mandatory ISA, drivers can choose their own driving speed. Furthermore, it is not realistic to assume that (traffic) police can enforce speed limits on all roads. The challenge therefore is to find ways with which to 'seduce' road users to choose the desired speed. This brings in the psychological dimension.

An important psychological aspect is the credibility or perceived fairness of the speed limits. It does not make sense, for example, to re-classify an existing 50km/h urban distributor road as an access road and then simply placing a 30km/h sign without physically changing the look and feel of the road. Similarly, if a road has an 80 km/h limit, it should not look like a road that would normally have a limit of 100 km/h. A speed limit can also be perceived as not credible when the limit is seen as too high. For example, having a speed limit of 80km/h on a winding, narrow road in the mountains might seem inappropriate to many motorists.

In other words, speed limits need to match the image that is evoked by the road itself and by the immediate surroundings. If a limit is not credible, drivers will be more inclined to choose the speed they themselves consider appropriate. If too many situations occur where limits are perceived to be not credible, it might even damage the trust in the speed limit system as a whole.

Table 2 lists the features that are important in guiding speed choice. Figure 3 provides an illustration of one of these features, namely the openness of the surroundings. For newly built roads these features can be considered relatively easily. For existing roads there are several options as well, though some solutions will be more costly than other. Furthermore, it must be realised that the credibility of a speed limit is not an absolute measure. Credibility is a sliding scale that varies from 'very credible' to 'not credible at all', and people are likely to differ in the extent to which they will be guided by credible speed limits.

Table 2. Road and roadside features influencing speed limit credibility. (Based on: Aarts et al., 2011)

Feature	Effect on speed choice
Number of lanes	More lanes → higher speeds
Lane width	Wider lanes → higher speeds
Median	Median present → higher speeds
Hard shoulders	Hard shoulder present → higher speeds
Road markings	Edge lines and central lines → higher speeds
Type of pavement	Even surface (asphalt) → higher speeds
Openness of surroundings	Open surroundings → higher speeds

Figure 3: An example of a main urban road with an open (right) and closed (left) environment of Dutch rural roads. (From: Goldenbeld & Van Schagen, 2007)

The ultimate high-speed road is of course a motorway with high geometric standards and features. A high standard motorway is one of the most recognisable road types, with a well-known, unambiguous function, and featuring all elements (such as full grade separation, separate carriageways, etc.) that support higher driving speeds. Nevertheless, in certain situations, for instance, near built-up areas and protected nature reserves noise or air pollution can be a reason to reduce the speed limit permanently or temporarily (e.g. certain hours of the day). In these cases, it is advisable that the reason of the locally reduced speed limit is effectively communicated in order to make the reduced speed limit credible for road users (Figure 4).

Figure 4. Communicating the reason for a reduced speed limit during nighttime in Germany increases speed limit credibility.

In conclusion

Speed is an indispensable aspect of road mobility. At the same time, speed leads to crashes and injuries. An absolute safe speed does not exist, but there are circumstances in which higher speeds are safer than in other circumstances. In general, higher speeds are safer if differences in mass, direction and driving speeds are small. If these conditions cannot be met, speeds must be kept (very) low. This is certainly the case when unprotected road users such as pedestrians and cyclists must share the traffic space with motorised traffic or when there is a possibility of frontal or right-angle collisions between motorised traffic.

A systematic classification of roads based on the two traffic functions (providing access or facilitating traffic flow) defines the mix of road users, the traffic space in which road users can meet, which manoeuvres can be expected, and consequently which traffic conflicts to expect. These features, supplemented with some specific geometric design criteria, are the main determinants of the 'safe' driving speed on a specific road.

These safe driving speeds are the basis for setting appropriate speed limits. In order to help road users to comply with these speed limits, it is important that they consider the speed limits as fair and credible. That implies that the speed limit matches the view of the road and its immediate surroundings, so that drivers automatically are prompted to choose the desired driving speed.

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3.2 The Impact of Operating Speeds on the Risk of Road Traffic Accident Occurrence and Road Infrastructure Star Rating Scores

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Speed of vehicles is one of the most important factors that significantly contributes to the probability of road traffic accident occurrence and severity of their consequences. Previous researches [1], [2], [3] have already shown that there is strong correlation between the number of fatal and serious road traffic accidents and the Operating Speed of vehicles in traffic flow, both in urban and rural areas. In urban areas, due to the presence of higher number of pedestrian and bicyclist crossings, intersections and property access points, there is much higher risk of collisions between motorized vehicles and Vulnerable Road Users, whereby in cases where pedestrians or cyclists are struck by vehicle at speeds higher than 30 kph, there is a very high probability that they will be killed or seriously injured. About 90% of pedestrians will be killed in the case of an impact from a vehicle travelling at 80km/h and above.

On the other hand, in rural areas, the Operating Speed of vehicles is usually much higher than in urban areas and therefore in cases when the driver loses control over the vehicle and collides with the vehicle from opposite direction or if the vehicle runs-off road and/or hits any rigid roadside object, there is also a very high probability that fatal or serious road traffic accidents will occur. Due to these reasons, a large number of countermeasures used for increasing road safety primarily include the implementation of various regulatory and traffic calming methods, based on which the Operating speed of vehicle in traffic flow is reduced, which then also decreases the probability of road traffic accident occurrence and the severity of its consequences.

Vehicle speed influences both the likelihood of a crash occurring and its severity. Speed is therefore a critical aspect of managing a safe road system, and influences iRAPs Star Rating Scores and Safer Roads Investment Plans [4]. In essence, the safety of a road cannot be understood without the knowledge of the traffic speeds.

Speed management is a complex area of policy for any country. The setting and enforcement of speed limits compatible with the road use at a location is an essential component of a safe road system. Roads should be engineered to reflect the road use and desired speed environment. This involves political leadership, community engagement, enforcement and engineering to achieve the best outcomes. iRAP assessments typically focus on the high-risk sections of the road network where the risk of fatalities and serious injuries is greatest. This primarily includes higher speed rural roads and urban arterials, and roads where vulnerable road users are not adequately provided for. The iRAP models and theory therefore focus on the influence of speed in these environments. iRAP models recognise the important role of speed in understanding the safety of a road. Vehicle speeds play a major role in the likelihood of a crash and in the severity of a crash [5].

Excessive and inappropriate speed is the number one road safety problem in many countries, often contributing to as much as one third of fatal accidents and an aggravating factor in all accidents [6]. Speed has been identified as a key risk factor in road traffic injuries. Higher speeds lead to a greater risk of a crash and a greater probability of serious injury if one occurs.

This is because, as speed increases, so does the distance travelled during the driver's reaction time and the distance needed to stop. Also, at speed, the effects of failing to anticipate oncoming hazards in good time and of vehicle handling errors are magnified. In addition, higher speeds can cause others to misjudge closing speed. Most research now provides clear evidence of the relationship between higher vehicle speeds and crash involvement [1], [2], [7], [8].

The relationship between travel speed and injury severity is even more strongly demonstrated by the research [9], [10], [11]. The probability of injury, and the severity of injuries that occur in a crash increases, not linearly, but exponentially with vehicle speed – by a factor of four for fatalities, three for serious injuries, and two for casualty crashes. Even small increases in travel and impact speed results in a great increase in the forces experienced by vehicle occupants and other road users.

The kinetic energy to be absorbed in a crash equals one half of mass multiplied by the square of velocity – illustrating that the effect of velocity is greatly enhanced as velocity increases. The level of damage to the body will depend on the shape and rigidity of the colliding surface or object, but velocity usually plays the most critical role [12].

Vulnerable road users such as pedestrians, cyclists, moped riders and motorcyclists have a high risk of severe or fatal injury when motor vehicles collide with them. This is because they are often completely unprotected or, in the case of a motorcyclist, have very limited protection. The probability that a pedestrian will be killed if hit by a motor vehicle increases dramatically with speed.

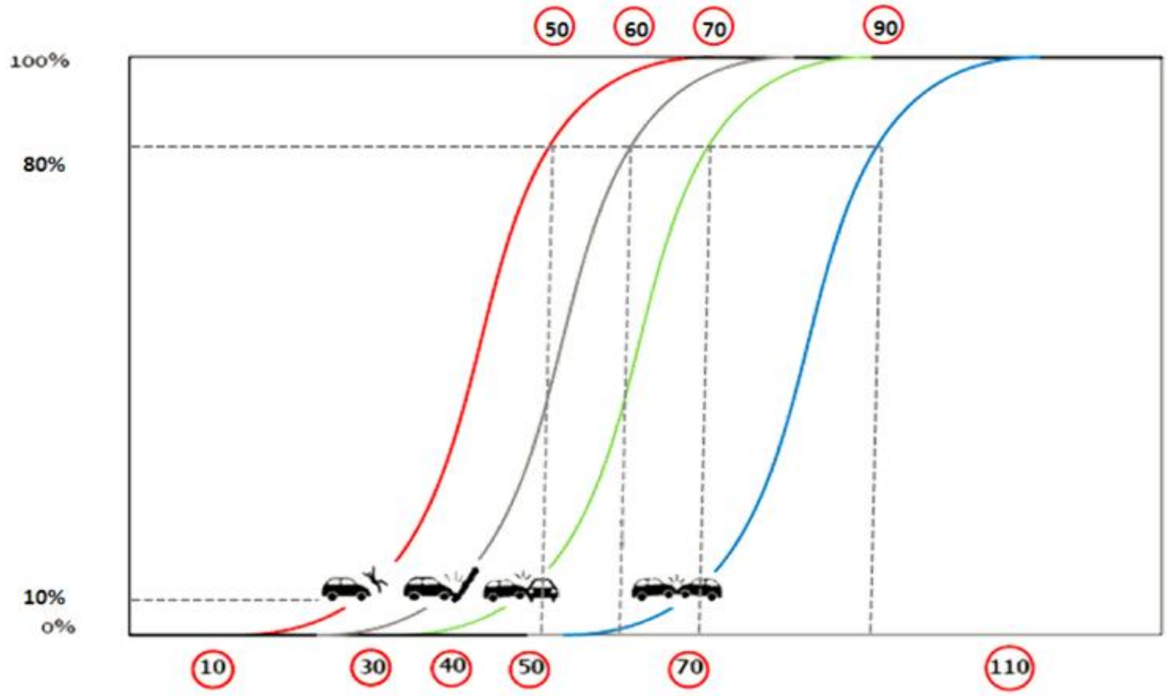


Figure 1. The relations between the risk of road fatalities and operating speed of vehicles for four main types of road crashes.

The importance of reducing the operating speed is clearly visible from Figure 1, which shows the risk of fatal injuries to road users depending on the operating speed of vehicle immediately before road traffic accident occurrence. Four percentile curves are related to four main types of road crashes, including (1) crashes between vehicles and pedestrians, (2) run-off type of crashes, (3) side collisions and (4) head-on collisions.

Based on the risk curves shown in Figure 1, it is evident that at operating speeds of 60 kph, the risk of death for the most vulnerable road users (pedestrians) is greater than 90%, while at operating speeds of 50 kph, 40 kph and 30 kph this risk is reduced to 80%, 40% and 20%, respectively. The risk of vehicle occupant fatalities in case when vehicle collides with dangerous roadside objects at operating speed of 60 kph is 80%. At lower operating speeds the risk of fatal injuries to vehicle occupants is significantly reduced (to 35% and 10% at operating speeds of 50 and 40 kph, respectively).

In the event of a side collisions, the risk of fatal injuries to road users is about 50% at operating speeds of 60 kph. This risk can be reduced to 20%, 5% and even 1% if operating speed of vehicles is reduced to 50, 40 and 30 kph, respectively. In the case of a head-on collision at an operating speed of 60 kph, the probability of the death of a vehicle occupant is 5%, while on the other hand at operating speed of 90 kph this probability increases to 80%.

Speed Limit and Operating speed of vehicles in the traffic flow are one of the most important attributes, used by iRAP SRS model in order to produce the Star Rating Scores and determine the number of Stars which will be assigned to each of the 100-meter road segment on the observed road network. Operating Speed used in calculation of Star Ratings is usually greater than the posted (or official) speed limit, i.e. it can be defined as the speed at which 85 percent of drivers will drive at or below under conditions of free traffic flow. The operating speed of the road is a large factor in determining what the Star Rating will be.

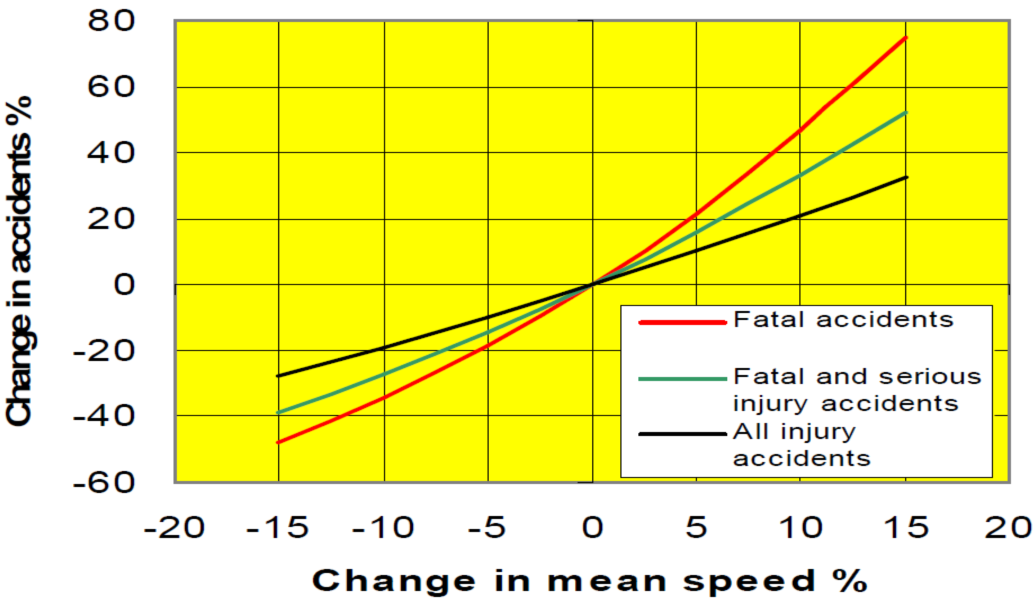


Figure 2. Illustration of the Power model and the relationship between % change in speed and the % change in accidents [9].

Small percentage increases in speed lead to much greater percentage increases in fatalities. Figure 2 indicates the increase in crashes of varying severity for small increase in travel speed. Relatively small mean speed reductions lead to major fatal (and to a lesser extent, other injury) crash reductions.

Research by [8] shows that:

- Travelling at speeds just 5km/h above a speed limit of 60km/h in urban areas and 10km/h above a speed limit of 100 km/h in rural areas – doubles the casualty crash risk
- This increase in risk is comparable to driving with a blood alcohol concentration of 0.05 g/100 ml compared to a zero level.

So, higher travel speeds increase crash risk and “moderate” speeding (within 10 or 15 km/h of the posted limit) makes a large contribution to serious road crashes – comparable to the contribution of more extreme speeds - because it is so common.

The Figures 3 to 5 show the relationship of speed with Star Rating for different scenarios and illustrate the speeds at which typical motorway and undivided road sections may achieve 3-star or 4-star rating. Figure 3 shows a functional dependency between Operating Speed of vehicles in traffic flow and resulting Vehicle Star Rating Scores obtained based on the iRAP Star Rating model for motorway road section type A with following road infrastructure and traffic flow characteristics: (1) Three traffic lanes and one stopping lane are present in each direction; (2) metal barrier is present in the median, placed 0-1 meter from the edge of the carriageways; (3) metal roadside barriers are present at distance 1 to 5 meters along the passenger side of the road on each carriageway; (4) AADT volume is 35,000 vehicles per day and (5) all intersections are merge lanes.

The functional dependency between Operating Speed and Star Rating scores is shown in the form of family of curves, whereby each curve represents the specific functional relation for selected sample values of intersection densities. This means that if we assume the intersection density of 1 intersection per 1 kilometers and Operating Speed of vehicles in traffic flow of 90 kph this road section would be rated with 4 stars. The same road section would be rated with 3 stars, when Operating Speed is increased to 107 kph and with only 2 stars in cases when Operating Speed is higher than 145 kph. On the other hand, if we assume that there are no intersections, the same motorway section would be rated with 5, 4 or 3 stars at Operating Speed of 90, 95 and 120 kph, respectively.

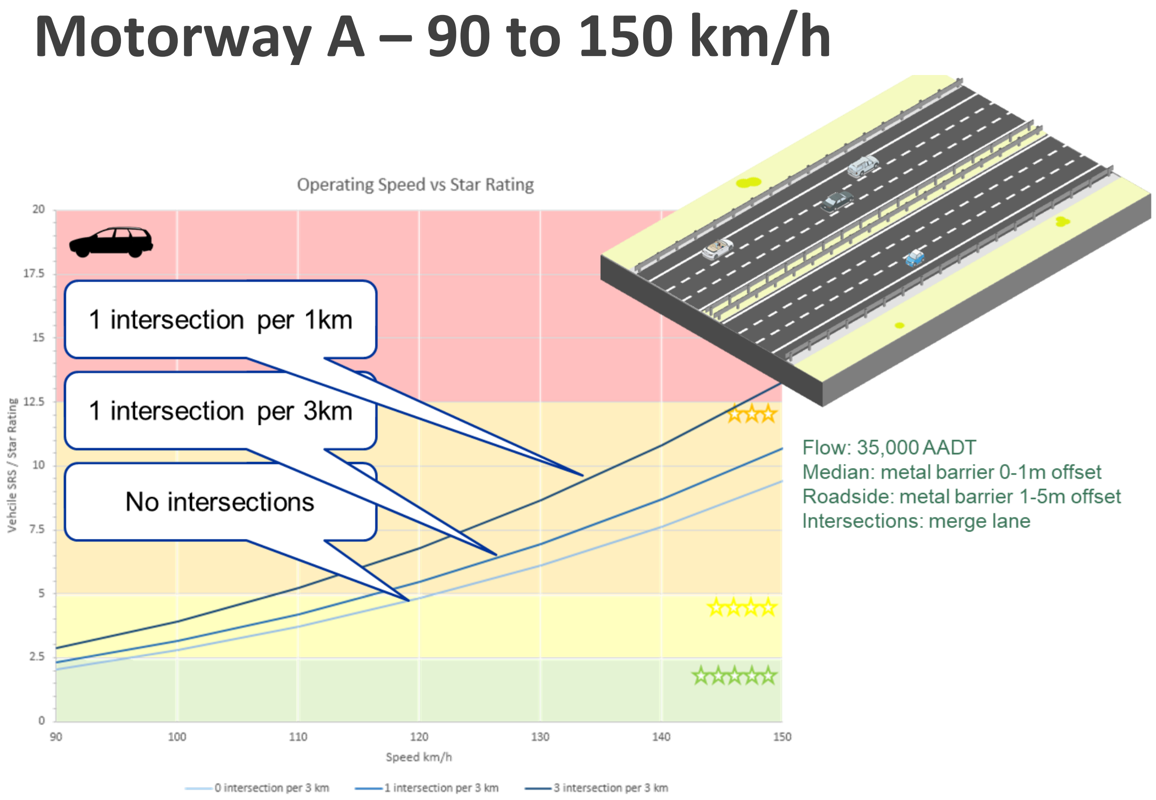


Figure 3: Motorway A - Common scenarios of the relationship between speed and Star Rating [13].

Figure 4 shows a functional dependency between Operating Speed of vehicles in traffic flow and resulting Vehicle Star Rating Scores produced based on the iRAP Star Rating model for motorway section type B with following road infrastructure and traffic flow characteristics: (1) Two traffic lanes and one stopping lane are present in each direction; (2) Metal barrier is present in the median, placed at distance 0-1 meters from the edge lines; (3) Traffic signs poles, wider than 10 cm in diameter, are present at distance 1 to 5 meters along the passenger side of the road on each carriageway; (4) AADT volume is 35,000 vehicles per day and (5) all intersections are merge lanes. In this case, if we assume the intersection density of 1 intersections per 1 km, at Operating Speed of 90 kph, this motorway section would be rated with 3 stars, unlike motorway section type A, which would obtain 4 stars. On the other hand, at higher Operating Speeds, from 107 to 114 kph, both motorway sections type A and B would be rated with 3 stars. The motorway section A would obtain only 2 stars for Operating Speeds higher than 145 kph, while motorway section B would gain 2 stars at significantly lower speeds (at 114 kph). This means that the representative curves for motorway section type B have lower slope than curves for motorway section A, and therefore comparatively higher SRS scores (lower number of stars) can be obtained at same Operating Speeds. This can be explained by the fact that motorway section type B has unprotected traffic sign poles present along passenger side of the road on each carriageway and therefore vehicles are exposed to higher risk of being involved in run-off collisions than vehicles travelling on motorway section type A where metal roadside barriers are present at distance 1 to 5 meters along the passenger side of the road on each carriageway.

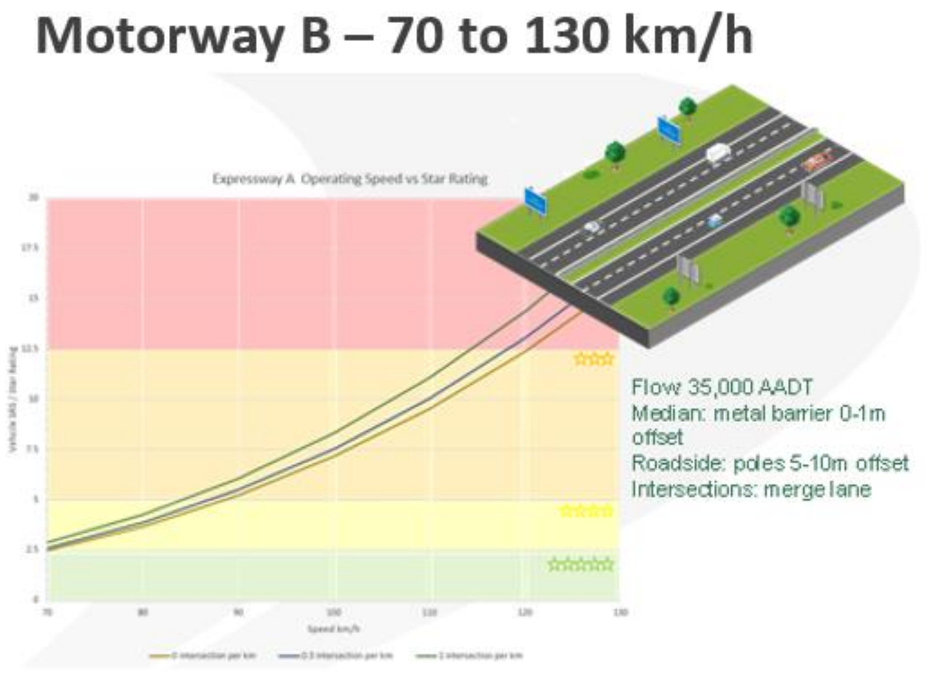


Figure 4: Motorway B - Common scenarios of the relationship between speed and Star Rating [13].

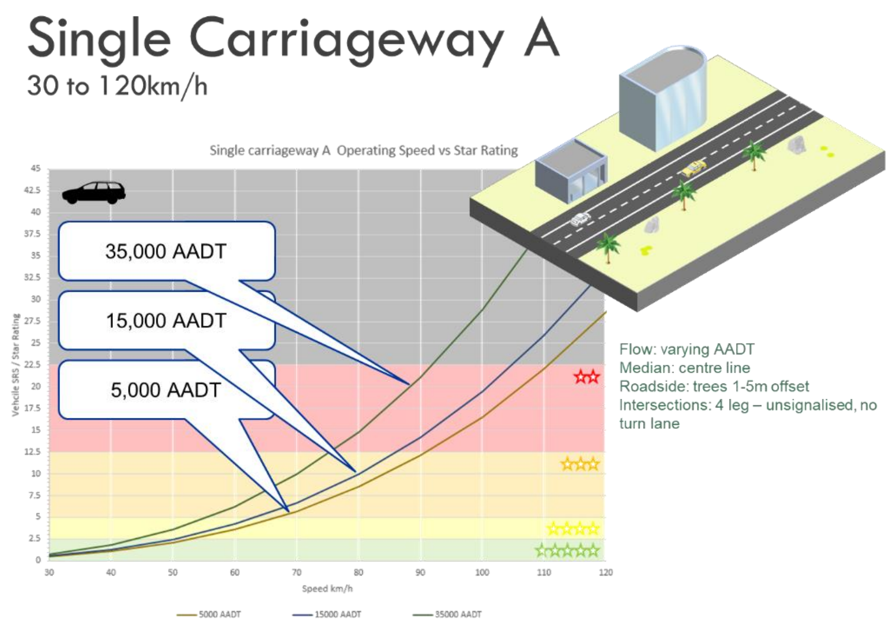
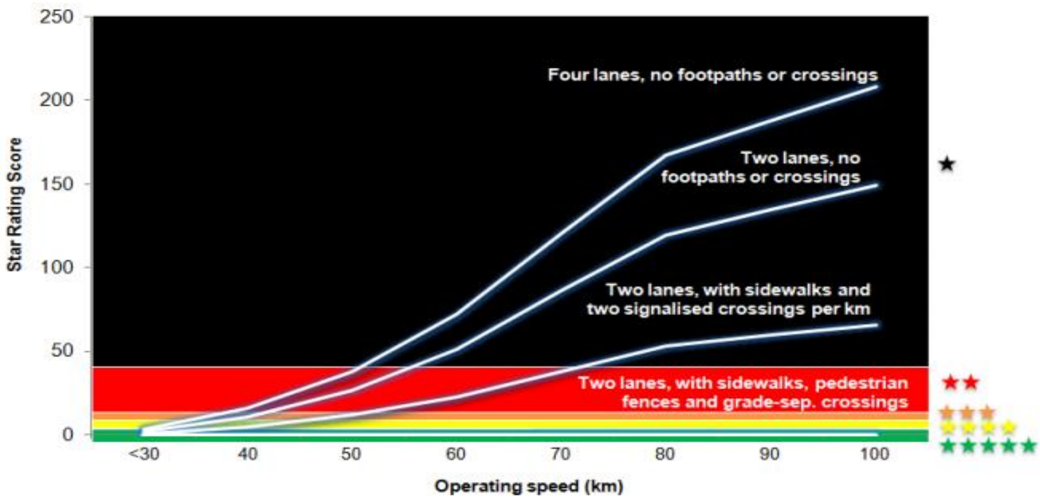


Figure 5: Undivided road (Road section type C) - Common scenarios of the relationship between speed and Star Rating [13].

The functional dependency between Star Rating scores produced by iRAP model and Operating speed for typical undivided road section is shown on Figure 5. The typical undivided road section has following road infrastructure and traffic flow characteristics: (1) One traffic lane in each direction; (2) opposite traffic flows are divided only by centreline; (3) Dangerous roadside objects are present at 1 to 5 meters along the passenger side of the road; (4) AADT volume is between 5,000 and 35,000 vehicles per day and (5) all intersections are 4-leg unsignalized intersections without turn lanes. It is clear that in this case the slope of the curves used to describe the mathematical relation between Operating speed values and resulting Star Rating Scores are significantly steeper than in the previous two examples (motorway sections – type A and B). This means that at same Operating Speeds, undivided road will obtain comparatively lower number of Stars than motorway sections type A and B. The lower Star Rating Scores in this case are caused by the lack of physical median and lack off roadside barriers on the both sides of the road. Since in this case there is no roadside barriers which can prevent vehicles from running-off road and hitting directly into dangerous objects present along the road, and there is no physical median which would divide the opposing traffic flow and reduce the probability of head-on collisions, the risk of fatal and serious injuries to road users in this case if road traffic accident does occur is much higher than on motorway sections type A and B.

The Figure 6. shows the way in which the SRS and Star Ratings for pedestrians vary with changes in design and speed [14]. It shows the degree to which the SRS increase as speed does, which results in the Star Ratings declining. It also shows that the increase in risk associated with an increase in speed can be offset by road attributes. For example, a road is rated 5-stars at all speeds when pedestrian movements are fully managed through the use footpaths, pedestrian fences and grade-separated crossings. At the other end of the spectrum, a four-lane road (two lanes in each direction) with no footpaths or crossings road will be rated 1-star at speeds above 50km/h. However, if the road has only one lane in each direction, footpaths and well-spaced signalized crossings, it will be rated 3-stars. Further, if the speed reduces to 40km/h, then the road would be rated 4-stars. When speeds are 30km/h or less, all roads are rated 5-stars for pedestrians.



Assumes: traffic volume = 10,000 vpd; there are pedestrian flows along and across the entire road; no vehicle parking; sight distance good; grade is flat; delineation good; no shoulder rumble strips; road condition good; skid resistance good; street lighting not present; and no curves.

Figure 6. Star Rating Scores (SRS), Star Rating and selected pedestrian facility options [14].

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3.3 Vehicles and Technology

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Introduction

With speed being the number one road safety problem (e.g. Elvik, 2009), the system that directly addresses driver speed choice, Intelligent Speed Assistance (ISA), is the number one safety system. ISA is the in-vehicle system that (1) provides the driver with information on the current speed limit and on changes in the speed limit and (2) actively assists the driver in keeping speed below the speed limit. In the review by the EU of the vehicle-based safety systems that could be adopted in the revision of the EU General Safety Regulation, which specifies the minimum safety equipment that must be fitted to all road vehicles, ISA came out as the top performing candidate (Hynd et al., 2014) and it was duly part of the package of measures that was legislated in 2019. The specification adopted in that legislation is that ISA defaults to being on at vehicle startup, in contrast to the current optional systems which default to being off and require driver activation. New vehicle models will have ISA from 2022 and all new vehicles, even those that are existing models will have to be equipped not long after.

This is a radical change. For the first time all vehicles, apart from motorcycles and older vehicles, will have a system that promotes driver awareness of the prevailing speed limit (not always an easy task) and compliance with those limits. But we cannot just afford to sit back and say “job done”. The introduction of ISA into the European fleet entails various responsibilities and provides new opportunities for road safety. In addition, there may be ways in which the mandated ISA specification can be enhanced to deliver further safety benefits.

Responsibilities: what is needed to ensure that ISA delivers on its promise

The specification for the new ISA system, being prepared by DG GROW, is still in draft, but is clear that it will be performance-based for speed limit identification. Manufacturers are likely to be able to reach the required level of performance with camera (image processing) technology alone. In other words, they will not be required to supplement the reading of speed limit signs (both explicit and implicit) with an on-board digital road map that is encoded with speed limit information. There is nothing to stop them using a map, but there is also nothing to require it.

Signage

The use of camera-based technology imposes responsibilities on ***road infrastructure owners***. They need to:

1. Ensure that signage is present, e.g. replaced when knocked down or otherwise damaged
2. Ensure that the camera technology can recognise any special signs (that can be done by engagement with the technology providers such as Mobileye)
3. Ensure that signage is visible (e.g. not faded and with retro-reflectivity maintained)
4. Ensure that signage is not obscured by foliage or other obstruction

It should be noted that these points apply not just to fixed signs but also to VMS signage of speed limits, which the cameras are also supposed to recognise.

Of course, that does not mean that the map-based technology can be ignored. Some OEMs may choose to use that technology and Euro NCAP is promoting it through the scoring of Safety Assist systems. There is already a process in place for road authorities to share information on infrastructure features (and in particular changes in those features), such as speed limits, with digital map providers such as HERE and TomTom. The process is managed by TN-ITS (https://tn-its.eu/), and the more that infrastructure owners participate in that process, the better will be the quality of the digital road maps. With vehicle automation, that process of digitalisation will become mission-critical.

Appropriate speed limits

With ISA discouraging drivers from speeding, it becomes even more important that speed limits are credible (see the contribution from Ingrid van Schagen and Letty Aarts). An ISA system that tries to prevent drivers from exceeding a speed limit that lacks credibility will be annoying. This will have the potential to bring the system into disrepute. This applies not just to permanent speed limits, but also to temporary ones. A temporary speed limit sign on a 110 km/h motorway informing drivers that the speed limit is lowered to 30 km/h because of roadworks should not be present on a Sunday when no road works are being undertaken. Furthermore, one can ask whether a 30 km/h limit for roadworks on a motorway is ever appropriate or whether it has just been posted because having the sign there, while still not enforcing the lower speed, is considered an adequate way to deliver safety in construction zones. In such a situation the presence of vehicles with ISA could make things worse, by lowering the speed of the equipped vehicles while the drivers of non-equipped vehicles continue to ignore the lower speed limit.

Thus a thorough review of the speed limits on each road section should be undertaken by road authorities. Such a review is to be recommended anyhow, but the coming introduction of vehicles with ISA makes it even more imperative.

Opportunities

ISA is of course directly targeted at addressing excess speed — discouraging drivers from driving above the speed limit. But ISA also has the potential to assist in addressing inappropriate speed — driving too fast for the conditions — and also assisting in more traditional forms of speed management.

Rural roads

The introduction of ISA into the vehicle fleet provides new opportunities to address speed-related safety problems. On rural roads, loss of control crashes related to horizontal curvature are a major problem. In the EU over 60% of fatalities in single-vehicle crashes occur on rural roads, with horizontal road curvature being a major factor in such crashes (Road Safety Observatory, 2012). ISA proves road authorities with a new tool to address such crashes. Many countries typically post lower mandatory speed limits on the approach to sharp curves on rural roads, with some jurisdictions even posting lower speed limits in sequence on curve approach, e.g. 60, 50, 40, 30. With an ISA system reading those signs and then passing feedback to the driver, the practise of lower mandatory speed limits on the approach to sharp curves should become much more widespread.

Another problem location on rural roads is at-grade intersections. Accident prediction modelling has shown that injury accidents on such roads go up with proportional changes in the mean of main road traffic speed to the 5th power, so that small reductions in through traffic speed will have a dramatic benefit in serious injury and fatality reduction (Taylor et al., 2002). ISA provides the opportunity to post lower speed limits on the approach to junctions and thereby to deliver real reductions in traffic speed and consequent injuries and fatalities. It should not be forgotten that protection of occupants from serious injury when vehicles are struck at high speed is very challenging.

Urban areas

Traffic calming is expensive and results in unpleasant side effects such as increased noise, from vehicles travelling over humps, cushions and rumble strips, and extra emissions and energy consumption from drivers slowing down to negotiate vertical and horizontal features and then speeding up again. Once ISA-equipped vehicles predominate, then many aspects of physical traffic calming, i.e. those oriented mainly at curtailing speed, should become unnecessary. Thirty km/h zones should become self-enforcing and therefore it will be practical to introduce them on a citywide basis at low cost.

Equally compliance with school zone speed limit should become high and, since the ISA cameras can read and interpret time of day and day of week rules, the higher local speed limit will prevail at non-school times.

Dynamic speed limits

Both weather conditions and traffic incidents create a need for lowering traffic speed. Road authorities are increasingly looking to speed management as a way to address vehicle emissions and pollution hotspots. Speed management thus becomes a dynamic activity, where in real time speed limits are adjusted to fit the prevailing conditions. C-ITS (Cooperative Intelligent Transport Systems), providing connectivity between infrastructure and vehicles, is the enabler for dynamic traffic services, of which the setting and broadcast of speed limits should be one of the most obvious functionalities — although for some reason it has not been included in the European "Day 1 Services". Here too ISA has potential to deliver by promoting driver compliance with speed limits set in real time.

The Intelligent Transport Systems Directive (2010/40/EU) is the relevant EU legislation. Article 3 lays out a set of priority actions of which action (c) is: "***data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users***." It is hard to think of any information which is more safety-related and more required by users than information on speed limits. On can only wonder why, when the ITS Directive gives the Commission the authority to require provision of this information, no action has been taken on creating a universal service to provide and broadcast targeted dynamic speed limits.

If the obstacle is the lack of a set of protocols to geocode and time code those speed limits, then surely that is not a very hard problem to crack. If the obstacle is the lack of a universal pan-European broadcast service, then again it is hard to believe that this is an insuperable problem. We are not talking here of high bandwidth very low latency communications as with some of the more elaborate C-ITS functions. It is likely that 2.5G transmission, as used for many traffic services, would suffice. Almost certainly, the lack of action is a result of a lack of vision on what should be the most important C-ITS services and a lack of political will to address some of the paramount problems in road safety.

Would dynamic speed limits deliver large benefits? The empirical evidence is that they would. Dynamic management of speeds on the motorway network, with overhead VMS as the mean of information transmission to drivers, is increasingly the norm on heavily trafficked roads. Such dynamic management limits — with lower speed limits implemented when traffic builds up to capacity, when an incident occurs, when the road surface becomes slippery or visibility poor, and more recently when there is a need to manage air quality — has been shown to bring benefits in terms of smoother flows, reduced crashes and reduced journey time. But VMS is a very expensive and arguably rather outdated and crude technology. It is not feasible to manage the whole road network through VMS. Broadcast is the sensible, low-cost option. Carsten and Tate (2005) estimated that dynamic ISA could deliver an injury crash reduction that was 80% greater than a "fixed" ISA system, that merely incorporated current static speed limits.

Conclusions

The compulsory fitment of new vehicles with ISA is to be greatly welcomed. Europe is a world leader here. To maximise the benefits of that fitment, the road authorities will have to play their part, particularly in sign maintenance. But ISA fitment also opens up new potential for addressing crashes cause by inappropriate speed, particularly in high-risk locations on rural roads. It can also greatly assist in urban speed management. Finally, with connectivity to the infrastructure, we could move to a new dynamic regime in which speed limits are no longer indicated by signs mounted on posts anchored into the ground, but rather by broadcast over the airwaves.

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4. Managing speed: Enforcement and links to other policy areas

This section looks at successful enforcement strategies and how enforcement within and across EU borders can be improved. It explores links between speed and other policy areas, including public health, sustainable mobility and tourism. Lastly, it approaches speed from the angle of psychology: What is behind the attraction of speed and the emotional reactions when speed limits are lowered? How can speed policy and speed management achieve broad acceptance?

4.1 Speed and Enforcement

Ellen Townsend, European Transport Safety Council

Introduction

Excessive speed is a major problem in all EU countries and speed limit enforcement remains a challenge for all governments.

This short section includes an overview of speed enforcement and tries to cover these topics suggested by the EC:

- Speed (cross-border) enforcement
- Speeding as the most common and one of the most dangerous traffic offences
- Which enforcement strategies are successful and how can enforcement within and across EU borders be improved?

The section gathers up to date research findings (from academia and surveys), it presents the EU policy framework and presents the findings of two recent ETSC PIN reports, including an overview of speed data and enforcement levels among Member States who collect such information. Country examples can be found in Annex I to the paper.

What is speed enforcement and why it is so important for road safety?

While education and engineering improve safety in the longer term, effective enforcement can lead to a rapid reduction in deaths and injuries. Excessive and inappropriate speed is accountable for about one third of fatal collisions and is an aggravating factor in most collisions. 2,100 lives could be saved each year if the average speed dropped by only 1 km/h on all roads across the EU.[3] ETSC's research shows that in the EU countries that monitor speed levels countrywide, cases of speeding are widespread. For example on urban roads, between 35% and 75% of vehicle speed observations are higher than the speed limit.[4]

Sustained intensive enforcement that is well explained and publicised also has a long-lasting effect on driver behaviour. Traffic law enforcement is a very cost-effective means of enhancing road safety and forms a fundamental part of achieving the new EU 2030 road safety targets.

Speed enforcement is also part of the Vision Zero philosophy and the Safe System approach as set out in the EU Road Safety Strategy: "The core elements are ensuring safe vehicles, safe infrastructure, safe road use (speed, sober driving, wearing safety belts and helmets) and better post-crash care[5]". As part of the 'shared responsibility' in reaching road safety goals included in the EU Road Safety Strategy and Safe System approach[6], law enforcement officers and the justice system need to work to reduce speeds as do drivers by complying with speed limits.

[3] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/3iG0zw8
[4] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/3iG0zw8
[5] European Commission (2019) EU Road Safety Policy Framework 2021-2030 -Next steps towards "Vision Zero" https://bit.ly/3mxQKm7
[6] ibid

Speed limit enforcement will remain essential as long as the speed problem is not solved in a structural way by implementing safe and credible speed limits, self-explaining, forgiving and self-enforcing roads, as well as self-complying vehicles with Intelligent Speed Assistance (ISA)[7].

The new General Safety Regulation[8] requires, as of July 2022, that all new vehicle types have to be fitted with Intelligent Speed Assistance (ISA) and all new vehicles as of July 2024. Besides a handful of high-level requirements, the new GSR however does not specify exactly how ISA is supposed to function and perform. These technical requirements are instead to be set out in a delegated act, currently under preparation by the European Commission. The number of lives saved in the real world will depend on the standard defined in the delegated act (see Oliver Carsten's paper)[9].

Speed limit enforcement aims to deter drivers from exceeding the speed limit by penalising those that do. This not only affects the speed of those that actually get caught (specific deterrence), but also those who see or hear that others have been caught (general deterrence)[10]. Apprehension and deterrence are generally held as the two main functions of police officers tasked with policing the roads. This includes a range of overt and covert operations including automation and more traditional human enforcement methods[11].

Tools and methods for non-automatic speed enforcement[12]:

- 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: time-over-distance cameras (control between two points)

In Elvik's 2001 ESCAPE Project, speed law enforcement is reported to have the most substantial effect on road deaths[13]. The PEPPER project from 2008, which systematically reviewed meta-analysis results, showed a significant reduction of 18% in the number of collisions in the case of speeding enforcement [14].

A combination of mobile roadside police checks together with automated stationary enforcement, including fixed and average speed or time-over distance cameras, has proved to be an effective tool in addressing speeding[15].

Speed limit enforcement is most appropriate on specific road stretches where collisions are concentrated. Such targeted action brings road safety benefits in the most dangerous road sections

[7] European Commission, Speed limits, http://goo.gl/q3eFFq
[8] Regulation (EU) 2019/2144 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users https://bit.ly/2FOJIJ6
[9] ETSC (2020) Response to Draft Delegated Act on Intelligent Speed Assistance https://bit.ly/2FG8zPt
[10] ETSC PIN Flash (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/3iG0zw8
[11] Bates L. Soole D. Watson B. (2012) The effectiveness of Traffic Policing in Reducing Traffic Crashes. In: Prenzler T. (eds.) Policing and Security in Practice. Crime Prevention and Security Management series. Palgrave Macmillan: London in PACTS (2020) Roads policing and its contribution to road safety https://bit.ly/35Fsh8C
[12] ibid
[13] ESCAPE (2001) in PACTS Roads policing and its contribution to road safety (2020) https://bit.ly/35Fsh8C
[14] PEPPER (2008) in PACTS Roads policing and its contribution to road safety (2020) https://bit.ly/35Fsh8C
[15] SWOV Fact Sheet (2009), Speed cameras: how they work and what effect they have, http://goo.gl/PYtqd0, and PACTS (2003), Speed cameras. 10 criticisms and why they are flawed, http://goo.gl/NJvUUt

and makes it easier to explain the reasons for enforcement to the general public. It is important that enforcement is perceived as a necessary road safety measure, not a fund raising activity[16].

Whereas enforcement should focus on roads with a poor safety record, it should not be limited to one road category. It is important that drivers become aware that surveillance exists everywhere, especially on roads with high traffic volumes so that enforcement is visible for many road users[17].

Academic research has found that, whilst safety cameras can reduce both the number and severity of road collisions, their effect is localised. One study found that the ‘halo' effects were limited to within 500 metres of the camera sites; and that, moving away from the camera, there was a slight increase in collisions. Overall, the study points to a net reduction in collisions and injuries as a result of the cameras[18]. 'Halo effects' are changes in driver behaviour observed over periods of time and distance due to an enforcement measure. For safety cameras, TRL found the minimum distance halo associated with physical policing to be around five times larger than for safety cameras alone.[19] Showing how important it is to have both automatic and physical speed enforcement.

The importance of effective follow up of offences

The systems in place to follow up a traffic offence are crucial. The existing EC Recommendation on Enforcement stresses that the follow-up of detected offences should be “effective, proportionate and dissuasive”[20].

Research has found that long-term behavioural effects from speed enforcement are only achieved if the detection of a violation is followed by immediate feedback or sanction21. To make this possible, ‘low-level' speeding offences detected by cameras should be followed up by simplified procedures. In these procedures, detection, prosecution and sanctioning are essentially combined into one stage, and a small range of fixed sanctions apply. In cases of very serious speeding offences or repeated offences, the application of penal law is of course still possible[22].

It is however important that the level of sanctions is proportionate to the risk related to non-compliance. Although research has found that higher sanctions have less of an impact on safety than the level of enforcement[23]. With moderate levels of enforcement but a high perceived chance of being caught thanks to good communication, a Demerit Point System is also likely to have an effect on driver behaviour that is stronger than the effect of enforcement alone[24].

Efficiency is further enhanced if the handling of fines for detected violations is largely automated and if the vehicle owner and not the vehicle driver is held liable, or is required to identify the driver,

[16] Tang, Cheng Keat (2017) Do speed cameras save lives? SERC Discussion Papers (SERCDP221). Spatial Economics Research Centre, London School of Economics and Political Science, London, UK.
In PACTS (2020) Roads policing and its contribution to road safety https://bit.ly/35Fsh8C
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[21] ESCAPE (2001) In PACTS (2020) Roads policing and its contribution to road safety https://bit.ly/35Fsh8C
[22] ibid
[23] Koornstra, M. et al (2002) SUNflower: A comparative study of the development of road safety in Sweden, the United Kingdom, and the Netherlands https://bit.ly/2ZLZv2c
[24] Ibid

since it is easier and faster to identify the owner than the driver[25]. As reported by the ITF, several countries have recently strengthened their sanctions and penalties regimes for speeding violations. This has been accompanied when needed by a change in legislation to allow the principle of "owner's liability", i.e. that the owner of the vehicle is by default responsible for the violation[26].

The importance of Communication

Despite speed limit enforcement efforts in the EU, drivers' perception of being detected for a speeding offence remains. According to an ESRA survey, only 38% of respondents, on average, think there is a chance of being checked by the police for not respecting the speed limit[27].

To raise people's awareness that their compliance is being checked, enforcement must be highly visible and publicised. Research indicates that it is the drivers' subjective risk of being caught that must be increased if enforcement is to be successful[28]. This is why changes in the enforcement policy should be widely communicated. Research also finds that, unless enforcement and publicity levels are maintained over a long period, their effect is usually only short term[29]. Road users adapt their behaviour according to their own experiences as well as those of others, and a publicity campaign may not be so effective if individuals do not see that it is clearly matched by the appropriate enforcement measures[30].

The PEPPER 2008 report found in relation to all speed enforcement methods (including automated methods) that, on average, larger collision reductions were achieved when the enforcement was clearly signposted and when there was local publicity of the enforcement, compared to when there was no publicity at all[31]. Police should also report the results of these activities to the media. Collecting and communicating data illustrating the success is crucial to ensure public support for this measure.

Speed limit enforcement levels by country

The methods and levels of speed limit enforcement differ greatly between EU Member States. The 2019 ETSC PIN Report on Speed finds that there appears to be an overall increase in speed offences detected throughout the EU, mainly due to the extension of safety camera networks[32]. This finding is in line with responses to a recent survey for the OECD/ITF Report 'Speed and Crash Risk' which also found that in the past decade most speed management measures have focused on the enforcement side, and even that: 'there has been less effort in adapting the road infrastructure and the road environment to promote lower speeds'.[33] Nevertheless, there are big discrepancies regarding the

25 ETSC PIN Flash (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c
26 OECD-ITF (2018) Speed and Crash Risk https://bit.ly/2RzK9t9
27 Holocher, S., & Holte, H. (2019) Speeding. ESRA2 Thematic report Nr. 2. ESRA project (E-Survey of Road users' Attitudes). Bergisch Gladbach, Germany: Federal Highway Research Institute. https://bit.ly/3hErirD
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32 ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c
33 OECD-ITF (2018) Speed and Crash Risk https://www.itf-oecd.org/speed-crash-risk

levels of speed enforcement in the different Member States (See Fig.1[34]). The ETSC report found that the proportion of offences detected by a safety camera varies greatly in the PIN countries but has been increasing since 2010[35]. According to the ITF Report, many countries have now implemented automated enforcement of speed limits, including in some countries the section control system.[36]

Levels of Enforcement

Out of the 27 countries that could provide data on the number of speeding tickets issued over the period 2010-2017, the figure went up in 18 countries while 9 registered a decrease (Fig.1)[37]. Table 1 below shows the levels of speed enforcement across the EU.

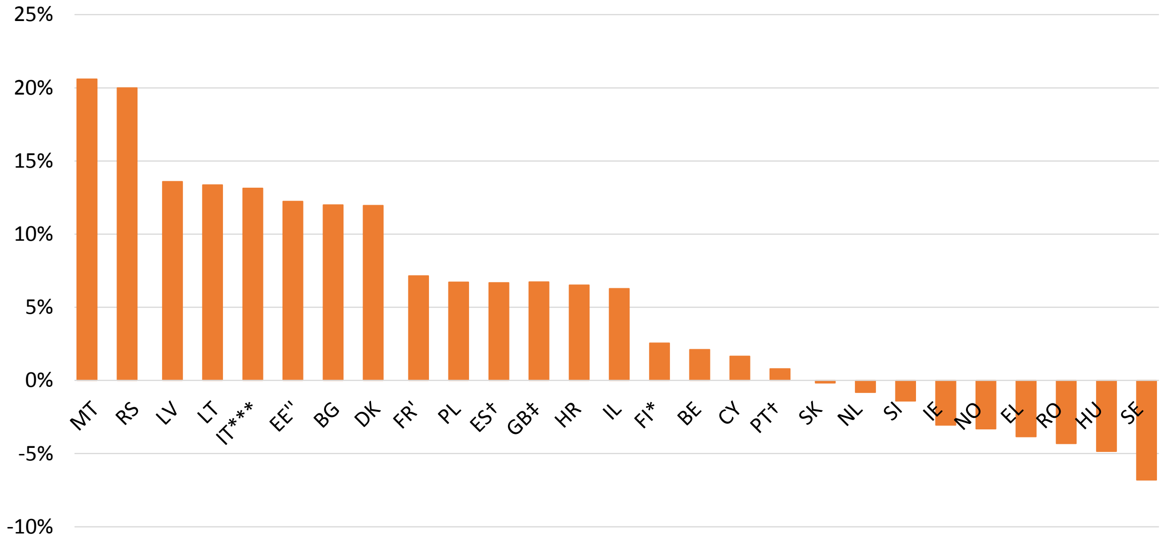

Figure 1. Annual change (in %) in the number of speeding tickets over the period 2010-2017. *FI* - written warning letters and fines, petty fines and crime reports are included. IT*** - speed tickets following checks by national police, Carabinieri and police in main cities (provincial capitals). ES† - data on number of tickets following checks on roads in urban areas and in the region of the Basque country and Catalonia are not available. FR' – 2010-2016. GB‡ - total number of speeding tickets and sanctions imposed as an alternative to a speeding ticket in England and Wales over the period 2011-2015. EE'' – 2012-2017 data.*

The number of speeding tickets issued is not available countrywide in the Czech Republic and Germany. This deprives policymakers of a key indicator of the effectiveness of measures to enforce speed limits.

[34] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c
[35] ibid
[36] ibid
[37] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36). The ideal indicator on how to assess the level of enforcement of speed limits would be to compare countries on the basis of the time spent on speed limit enforcement or the number of checks performed both by the police and by safety camera. Unfortunately this indicator is not available in most countries. Thus, ETSC 2019 report uses the number of tickets per thousand inhabitants, assuming that they are broadly proportionate to the level of enforcement activity. https://bit.ly/2ZLZv2c

Levels of Speed Limit Enforcement ETSC (2019) PIN Report[38]

	2017		2016		2015		2014		2013		2012	
	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)	Number of speeding tickets per 1000 inhabitants	Proportion by fixed or time-over-distance safety camera (in %)
NL	457	77%	470	79%	393	n/a	400	n/a	503	n/a	454	n/a
LU	428	95%	470	94%	n/a							
BE	299	n/a	292	n/a	n/a		301	n/a	286	n/a	272	n/a
FR	n/a		253	95%	212	94%	200	93%	181	92%	199	92%
LV	186	65%	116	43%	75	29%	54	0%	64	1%	201	84%
MT¥	171	99.9%	163	99.8%	169	99.8%	145	99.8%	37	98.5%	56	98.4%
CY	121	6%	124	9%	108	29%	89	14%	84	0%	133	0%
EE	116	78%	126	73%	102	66%	95	65%	76	58%	71	47%
FI*	111	66%	111	64%	93	55%	76	70%	83	64%	80	68%
DK	97	n/a	98	n/a	82	n/a	44	n/a	63	n/a	47	n/a
LT	94	92%	58	98%	50	98%	51	98%	40	98%	30	98%
HR	71	n/a	77	n/a	66	n/a	62	n/a	51	n/a	51	n/a
SI	57	n/a	37	n/a	44	n/a	48	n/a	42	n/a	35	n/a
PL	56	20%	55	21%	50	17%	55	20%	46	15%	43	8%
BG	54	n/a	47	n/a	29	n/a	12	n/a	41	n/a	36	n/a
RS	52	n/a	47	n/a	38	n/a	25	n/a	20	n/a	16	n/a
HU	51	n/a	28	n/a	28	n/a	29	n/a	30	n/a	46	n/a
NO	45	39%	50	36%	48	36%	50	36%	54	35%	56	35%
SK	45	3%	47	2%	55	2%	63	2%	60	0%	56	0%
PT†	43	70%	10	0%	n/a		25	0%	23	0%	25	0%
IL	42	77%	18	67%	17	73%	12	65%	17	72%	13	57%
RO	36	0%	42	0%	38	0%	39	1%	44	2%	37	3%
IE	31	n/a	36	n/a	47	n/a	49	n/a	45	n/a	49	n/a
EL	20	n/a	16	n/a	16	n/a	14	n/a	16	n/a	17	n/a
SE	14	51%	15	51%	17	48%	19	39%	21	31%	23	34%
AT* **	n/a	87%	n/a	87%	n/a	86%	n/a	84%	n/a	84%	n/a	84%
Data available for speeding tickets on part of the road network only												
IT''	13	78%	15	82%	13	88%	12	85%	12	85%	13	86%
IT'	47	n/a	44	n/a	44	n/a	46	n/a	25	n/a	24	n/a
ES‡	n/a	78%	n/a	73%	n/a	66%	n/a	85%	n/a	82%	n/a	86%
GB'''	n/a		37	n/a	33	n/a	34	n/a	29	n/a	29	n/a
Data on the number of speeding tickets not available												
CZ	n/a											
DE	n/a											
CH	n/a											

Table 1. Total number of speeding tickets per 1000 inhabitants (by both police roadside checks and safety cameras) and the proportion (in %) of those speeding tickets that were sent after an offence was detected by fixed or time-over distance safety camera between 2012 and 2017. *FI* - warning letters, fines, petty fines and crime reports are included. AT*** - % of fixed or time-over-distance safety camera refers to offences detected but not the number of speeding tickets. MT¥ - speeding tickets issued by national police. PT† – data on % of offences detected by safety camera in 2017 refers to July-December 2017. ES‡ – speeding tickets from offences detected by mobile speed cameras are included in the % of offences detected automatically if the driver was not pulled over and the ticket was issued automatically, data on number of tickets following checks on roads in urban areas and in the region of the Basque country and Catalonia are not available. IT'' - speeding tickets following checks by national police only. IT' - speeding tickets following checks by national police, Carabinieri and police in main cities (provincial capitals). GB‡ - the figures of those attending the NDORS courses (see below) in England, Wales and Northern Ireland are added to the speeding tickets to give a true reflection of the enforcement activity within the UK.*

[38] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c

The EU Enforcement Policy Framework

At EU level the Cross-Border Enforcement Directive 2015/413 covers the main offences causing death and serious injury in the EU: speeding, drink/drug driving, non-use of seat belts and mobile phone use at the wheel.[39] This instrument puts in place an important missing link in the enforcement chain thus enabling the information exchange needed to follow through police and enforcement authority efforts to achieve fuller compliance with traffic law and improve road safety. For better implementation of the Directive, improved EU tools are needed to enable cross border cooperation on road traffic offence investigations and mutual recognition of financial penalties specifically for traffic offences[40].

This instrument is due for revision in the near future and there are a number of barriers which need to be addressed, such as updating the camera specifications, a lack of human resources in case of manual follow up and that following up these offences is not seen as a political priority.[41]

The EC Recommendation 2004/345[42] on enforcement asks EU Member States to apply in a national enforcement plan what is known to be best practice in the enforcement of speed, alcohol and seat belt legislation. In the years immediately after its publication the Recommendation stimulated discussion and best practice exchange. Member States should continue the implementation of the Recommendation.

The Recommendation also stresses that the follow-up of detected offences should be “effective, proportionate and dissuasive”. Finally, the Recommendation includes the need to “combine enforcement with information of the public, which will be given in the form of publicity campaigns aiming at making the public conscious of road safety”. These recommendations could also be included in a new EC Speed Recommendation.

As well as addressing the cross-border aspects of enforcement, the EC Recommendation on Speed should also define a common EU-wide approach to speed enforcement based on best practice.

Joint enforcement actions on the speed enforcement, such as the Europe-wide Roadpol run “Road Safety Days” and “Speed Marathon,” should also be encouraged as this helps foster political will and helps exchange best practice.[43] EU funds for infrastructure (Cohesion and Connecting Europe Funds) should also be more widely used to support the EU Member States’ use of recognised enforcement best practices[44].

Motorcycle Speed Enforcement

One particular road user group with a high risk that also deserves extra attention in speed enforcement are motorcyclists. According to data gathered by ETSC there are high levels of non-compliance and in some cases they can escape speed enforcement[45].

[39] Directive 413/2015 facilitating cross-border exchange of information on road-safety-related traffic offences, https://goo.gl/WnFrtQ
[40] Grimaldi (2016) Evaluation Study of the CBE Directive 2011/82, https://goo.gl/2xSXH2
[41] ETSC PIN Flash on Enforcement Can Contribute to Safer Roads (2016) P. 42, https://goo.gl/GVwmf5
[42] EC Recommendation 2004/345 on Enforcement in the Field of Road Safety https://bit.ly/2H06SMX
[43] ETSC (2015), Enforcement in the EU – Vision 2020, http://goo.gl/5NFGNW
[44] ibid
[45] ETSC (2019) Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c

Both traditional and automated enforcement are more complex for PTWs. Their manoeuvrability and speed means that they are difficult to catch and stop when an offence is detected by traditional enforcement[46]. Motorcycles are not required to have a licence plate in front and therefore remain unidentified by safety cameras that photograph from the front. Moreover the identity of the rider is hard to establish in jurisdictions where this is required with 'driver liability'. The PTW license plate is smaller than that of cars, which makes them unreadable for certain camera systems. These technical issues in relation to enforcement should be resolved[47]. Otherwise, enforcement activities are more effective if police officers are well trained to detect dangerous manoeuvres and equipped to intercept the riders quickly and safely[48]. This often means that the traffic police should be riding a PTW[49].

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4.2 Managing speed and links with other policy areas

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Introduction

Road traffic injury clearly has many societal impacts. The scale of the road safety challenge, the diversity of the effects of road traffic injury and the increasing ambition for road safety results at global, European Union and national levels underline the importance of fully exploring synergies with other societal goals and priorities. When directed and assisted by accountable national road safety lead agencies working to a robust safety performance framework, national road safety coordination arrangements and bilateral partnerships provide valuable platforms for integrating road safety into other government policies to increase coverage and resourcing levels. In addition, the top management of organisations can play a key role in ensuring that safety goals are fully embedded into management systems and operations.

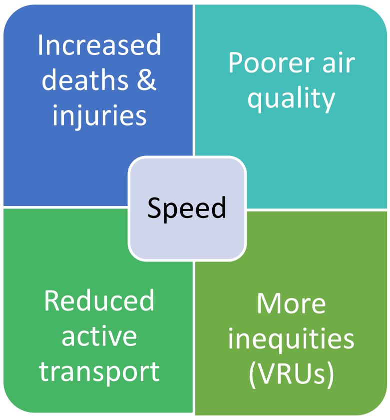
Road traffic crashes and injuries are multi-factorial and therefore road safety should be delivered in a multi-sectoral context because co-benefits with other sectors are obvious. Addressing speed in the planning, design, operation and use of the road traffic system is at the core of road safety management and there are win-wins for aligning road safety strategy with a range of societal objectives.

This contribution seeks to explore how to identify these benefits more visibly and realise these synergies in policy terms. Its content draws heavily on publications by the European Road Safety Observatory [1], World Health Organization and World Bank [2] [3] and the World Road Association Road Safety Manual [4].

What societal objectives benefit from successful speed management?

Speed and public health

Transportation is an important factor influencing individual's health and the health of communities. Five interacting dimensions have been identified between transport and public health, these are safety, active transport, clean air, connectivity/access and equity [5]. In order to have a healthy and safe system there needs to be balance with equity taking a central role, so that all people have adequate access irrespective of age, sex, ability, or income. Inequities in the transport system can lead to reduced access to health-related destinations such as hospitals, rehabilitation centres, food, fitness and recreation facilities which can further interact with other risk factors to cause morbidity and premature mortality. The *World report on road traffic injury prevention* identified road safety as a social equity issue with vulnerable road users benefiting the least from policies designed for motorised travel but bearing a disproportionate share of the disadvantages of motorisation in terms of injury, ill health from pollution, reduced active travel and the separation of communities [2].



Speed management cuts across all these public health impacts. While it is argued that speed may have a positive effect on mobility in terms of reducing journey times, it impacts negatively on road safety, air quality and other aspects of public health. Speed is a central design parameter for safe mobility, as reflected in the setting of Vision Zero goals and targets which embody the public health eradication principle.

Speed affects both the likelihood of a road traffic crash and the severity of its consequences. "Speed is the pathogen" in public health [6] insofar as kinetic energy is the causative agent of injury. Excessive speed and inappropriate speed, the latter often due to allowable speed limits which are too high, are at the core of the road traffic injury problem. As average speeds rise so too does the likelihood of a crash resulting in injury. An increase of 1 km/h in mean vehicle speed results in an increase of 4¬5% of fatal crashes [7].

Lower speeds reduce the risk of road traffic collisions, and when they occur, the severity of the injuries sustained. This has a significant impact on trauma care systems in terms of reduced numbers of injured patients, reduced surgical interventions, reduced hospital stays and ultimately reduced health spending. Furthermore, pedestrians and cyclists – who are most vulnerable to high speeds – often cite safety as a major barrier to regular active transport. Reduced speeds will alleviate these barriers and thus encourage more regular exercise good for physical and mental health and has been shown to improve more than 25 chronic diseases (including obesity) and increase longevity [8]. Improving road safety by reducing traffic volumes and speeds by a range of planning, infrastructure, in-vehicle and enforcement measures are thus important ways to both help prevent injury and also to encourage healthy physical activity.

Speed and sustainable transport, urban mobility and active travel objectives

Significant co-benefits can be achieved for sustainable transport by taking speed into account in planning and design and managing speed levels. For example, land use and transportation planning, the provision of safe infrastructure facilities to promote increased walking and cycling, and measures to reduce vehicle speeds, will also result in less greenhouse gas emissions and local air pollution, greater energy security, and improved physical wellbeing [3].

Other means include reducing the volume of motor vehicle traffic by providing for public transport and pursuing liveable city policies; providing efficient networks where the shortest or quickest routes coincide with the safest routes; and encouraging road users and freight to switch from higher risk to lower risk modes of transport [9].

Some 60% of the global population will live in urban areas by 2030. A population's health and well-being is greatly influenced by having liveable places – which are both safe and healthy – in which to live, work and stay active. Consequently, many governments now have a vested interest in making their cities safer by reducing vehicle traffic, e.g. car-free days, reducing urban speeds and improving urban street design to encourage safe walking and cycling [10].

Speed and environmental objectives

There are no global systematic reviews on transport's contribution to urban air pollution, but available data suggests that in rapidly developing cities transport does play a significant role – up to 30% of PM_{25} in some European cities. Furthermore, an assessment of the burden of disease from environmental noise concluded that traffic-related noise accounts for over 1 million healthy years of life lost annually to ill health, disability or early death in the Western Europe countries [10]. In addition to addressing road traffic injury, reducing speed will reduce both air and noise pollution.

Road safety and environmental considerations are high priority areas for transport. However, they are more often considered separately rather than in a coordinated manner [1]. One good practice example is Sweden's recent reclassification of its rural road network which has sought to address safety, the environment and other goals. New speed limits based on injury criteria and the available protection offered by infrastructure and vehicles were introduced to balance safety, environment, accessibility, navigability, favourable regional development and equality. Full compliance with these was estimated by the Swedish Transport Administration to save around 150 lives annually and reduce carbon dioxide emissions by @ 700,000 tonnes (equivalent to emissions from 240,000 passenger cars).

In addition to infrastructural measures, research shows that in-vehicle Intelligent Speed Assistance (ISA) systems to be implemented in the 2022 GSR vehicle safety package not only have the potential to prevent many deaths and serious injuries but can also be an effective instrument in mitigating climate change. Carsten et al demonstrated that in the UK on 70 mph roads, there was a substantial reduction of 3.4% in CO_2 with voluntary ISA and 5.8% with mandatory ISA [11]. In urban contexts, London, for example, requires the fitment of ISA on buses in their network to address a range of objectives.

Speed and occupational health and safety

Work-related motor vehicle crashes are a leading cause of death and long-term injury in the workplace and in driving associated with work. While systematic monitoring of work-related road deaths and serious injuries for the EU as a whole is lacking, it is estimated that between 40-60% of <u>all</u> work accidents resulting in death are road crashes while using the road for work and while commuting. Both a public and private sector issue, a UK study found that more than three quarters of work-related road deaths involve users other than the driver [12]. Joint country strategies developed by road safety lead agencies and the occupational health sector are being increasingly produced. The ISO 39001:2012 standard on road safety management systems in organisations was developed to provide key advice to employers towards these ends [13]. Governmental public procurement policies which include safety and speed management requirements for transport services and car buying are also providing a useful tool for private sector engagement.

Work-related road safety can contribute to substantial reductions in employers' costs, and impact on national and organisational goals for occupational health and safety. Managing speed has positive results for safety, fuel efficiency, reduced vehicle wear and tear, and reduced air and noise pollution. For example, the use of new geofencing and in-vehicle technologies, which can monitor and record speed, provides employers with an opportunity to continuously assess their employees driving and speed behaviour, so identifying speeding offences that may go undetected by national enforcers. Using such data an organisation can identify the prevalent risks, then target, record and monitor relevant interventions [14].

Speed and tourism

The risks of road traffic injuries are appreciably higher for tourists than health risks such as epidemics (e.g. AIDS); illnesses (such as malaria and cholera); personal security risks associated with international terrorism, violence and crime; travel injury risks on modes other than road transport modes (e.g. aviation); and other personal injury risks such as drowning [15]. Globally, international tourist road fatalities are forecast to increase three-fold to around 75,000 per annum in 2030, with implications for developing and mature economies alike [16]. Managing high speeds on rural and urban networks, promoting safe car rentals with high safety ratings and advising on allowable speed limits are key issues for joint safety and tourism bilateral partnerships.

Speed and policing objectives

Speed limit enforcement by the police combined with publicity to deter potential offenders is a key facet of speed management. At the same time, undertaking enforcement work can also work to deter and detect criminal activities. Research indicates that about 25% of motoring offences are committed by drivers who have also committed non-motoring offences. A Europe-wide TISPOL week-long seat belt check during March 2012 resulted in 125,000 seat-belt offences but also uncovered 3,256 criminal offences including fire arms, stolen goods, drugs, illegal immigration and for human trafficking [1, 17]. However, countries are increasingly moving to automated speed enforcement and so there will be less opportunities to pick up other offences as this becomes the norm.

Speed and economic objectives

Last but by no means least, speed management and road safety contribute economic benefits in a variety of ways. Globally, the socio-economic costs of road traffic injury represent between 1 and 7% of GDP [4]. Notwithstanding the availability of many cost-effective interventions, a high price is being paid for unsafe mobility. In addition, road safety can contribute to poverty reduction goals given the scale of loss of GDP from road crashes. Crash victims typically involve the most economically active of citizens, often with adverse impacts on their dependants [2]. Many evidence-based interventions represent large benefits to cost including those on speed management. For example, a recent study found that interventions targeting road traffic injuries (including speed management) for adolescents, had a benefit to cost ratio of 5·9 (95% CI 5·8–6·0) on investment of $0·6 per capita each year [18].

It is often argued that reducing speeding adversely affects economic objectives in increasing journey times. However, research indicates that travellers value journey time reliability (small variance) even more highly than small amounts of journey time. Reducing speeding improves reliability of traffic by reducing speed variance. Evaluation of motorway safety in the UK shows that lower speeds when flows are high can benefit throughput. Here lower speeds result in *reduced* journey times. Calculations also often substantially under-estimate the cost of crashes by failing to include congestion costs dues to crashes (speed will be a key factor), or environmental costs. Fatal crashes can result in huge disruption, with roads closed for investigation even for a whole day.

What tools and mechanisms will aid alignment?

Key road safety performance targets can provide useful focus for multi-sectoral working and aligning with a range of societal objectives. These include the two Sustainable Development Goal targets which relate to road safety, viz.

- Target 3.6 to decrease by 50% the number of road traffic deaths and injuries by 2020 (now extended to 2030 by new UN GA resolution) - indicator is road traffic deaths per 100,000 population;
- Target 11.2 to provide safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons - indicator is road traffic deaths per 100,000 population.

In addition the 12 Voluntary road safety performance targets endorsed by the UN General Assembly in 2018 include a specific target (6) on speed which encourages countries to "halve the proportion of vehicles travelling over the posted speed limit and achieve a reduction in speed-related injuries and fatalities" by 2030 [19]. There are four associated indicators for this target, viz.

- Number of countries that have reduced by half the number of vehicles travelling over the posted speed limit and achieved reductions in speed-related injuries and fatalities;
- Number of countries having legislation setting appropriate speed limits in accordance with safe system principles;
- Number of countries that enforce speed limits; and
- Number of countries that collect data on speeding violations.
- most countries have national safety performance objectives.

Most EU countries have set headline targets for deaths and serious injury reduction and at a regional level new 2030 EU targets and a range of KPI, including one on speed, will encourage new attention to the need to measure and manage this important area of safety performance. As a next step, the Commission plans to work with Member States on outcome targets based on KPIs in as far as this is possible. Results conferences will take place every two years open to all public and private stakeholders to take stock of progress achieved and offer participants a forum for analysis and exchange [20].

The outcome document – Stockholm Declaration – from the recent 3rd Global Ministerial Conference held in Sweden in February 2020, specifically resolves to "Focus on speed management, including the strengthening of law enforcement to prevent speeding and mandate a maximum road travel speed of 30 km/h in areas where vulnerable road users and vehicles mix in a frequent and planned manner, except where strong evidence exists that higher speeds are safe, noting that efforts to reduce speed in general will have a beneficial impact on air quality and climate change as well as being vital to reduce road traffic deaths and injuries" [21]. Furthermore, the Academic Expert Group to the Ministerial Conference encouraged strong coordination mechanisms, specific funding allocations and public procurement in addition to the two speed-related recommendations on limits and enforcement [22].

Finally, most recently, the UN General Assembly resolution adopted a new resolution on the Global Road Safety Crisis in August 2020, invites Member States that have not already done so to put in place comprehensive legislation around the key behavioural risk factors including speed [23]. Sadly, the strong recommendations on speed made by the Ministers in Stockholm were not translated into this new UN resolution.

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4.3 The Psychology and Politics of Speed

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Introduction

The management of speed delivers powerful irrefutable benefits in road safety, as well as co-benefits for reduced climate change, air pollution, noise pollution, and fuel efficiency (Carsten et al., 2008; Job & Sakashita, 2016). Lower speeds in urban settings also facilitate active transport (addressing a growing obesity problem in high income countries) and more equitable access for those who cannot afford personalized motor transport. In addition to these synergistic benefits, management of speed has lower costs than many other safety interventions, proven cost-benefit ratios, and many well established interventions to deliver improvements across behaviour change, road design/engineering, and vehicle design/engineering (Howard et al., 2008; Job & Sakashita, 2016).

Road safety is long recognized to be a political issue (e.g., Job et al., 1989). Despite all the above benefits, speed management is commonly resisted by the community (or at least presented as commonly resisted in the media) (Job, 2018; Job et al., 2013; Litras & Spits, 2010) and thus also by political decision makers and road system managers. This commonly obviates adoption of effective speed management interventions and effective (safe) settings for travel speeds. Lower speed limits work and higher speed limits generate sometimes huge increases in deaths and serious injuries (Sliogeris, 1992; Job & Sakashita, 2016). Irrefutable evidence demonstrates the live-saving value of speed enforcement including various forms of speed camera (Goldenbeld & van Schagen, 2005; Keall, et al., 2001; OECD, 2006; Howard et al., 2008).

Factors contributing to the Positive Emotional Associations and Perceived Value of Speed

A nested set of multiple social and psychological factors promote speed, and thus resistance to its management.

Higher speed is better: Most fundamentally, faster is better: Races are pervasively watched competitions won through speed, and there is no fundamental sense to a competition on who is the slowest. Usain Bolt is a household name because he is the fastest. Few among us even recall who came second in his races, and no one is a household name because s/he is the slowest.

In relation to road use, faster is also seen as better from an economic perspective, and indeed for many companies this is true because they reap the cost savings on higher speeds through faster delivering (who wants a slower delivery?), reduced driver time to pay, etc. and externalize the costs of speed. Pervasively transport companies do not pay the true costs of speed (though they may be paying more than is appreciated in increased fuel costs): the community and the Government (using the community's money) pay for emergency and hospital costs, suffer the lost revenue of deaths, sustain the disabled, and pay for the more hidden mental and physical health effects of air pollution and noise pollution (WHO, 2012; Job, 1996) as well as increased climate impacts– all broadly increased by higher speeds. Thus, for low- and middle-income countries (LMICs) the costs of crashes are typically several percent of GDP each year (World Bank, 2019) and these costs are proven to retard the economic development of LMICs (World Bank, 2017). Other economic assessments taking into account the many costs of higher speeds show that economically ideal speeds are significantly lower than the speed limits typically set (e.g., Cameron, 2012; Hosseinlou et al., 2015). The results of these studies, showing the high economic costs of higher speed, are themselves resisted in the blinding faith of many that 'faster is better.'

Again closely related to road safety, motor sports (again, predominantly races) create the same impacts. In addition, motor sports have an extraordinary safety record of survival of major crashes in both F1 car and F1 motorcycle racing. Unfortunately, the road safety lessons most people take from this record are in error. Many see the safety of motor sports as being due to driver skill and this promotes the maintenance of the last 80 years of largely inadequate attempts to fix the driver, rather than fixing the road transport system to accommodate inevitable human error (i.e., the highly successful Safe System approach). It is noteworthy that a classic study of race and rally car drivers revealed that they have a much <u>higher</u> crash rate than the average driver on public roads (Evans, 2002). The correct, but largely overlooked, lessons from motor sport safety achievements are consistent with safe system. Motor sports (especially F1) have achieved significant safety improvements through system change. Race tracks have forgiving roadsides – with well-designed barriers and clear zones not drop-offs, trees, poles and parked cars; motorcycle tracks have wide spaces to skid and slide; racetracks are one-way minimising head on crash risk; fences and barriers prevent spectators from crossing the raceway as pedestrians; cars and motorcycles do not mix, let alone mix with trucks and buses; the drivers of cars as well as the motorcycle riders must wear protective clothing and helmets; F1 cars offer dramatically greater protection in a crash – an impressive achievement at the speeds of impact survived.

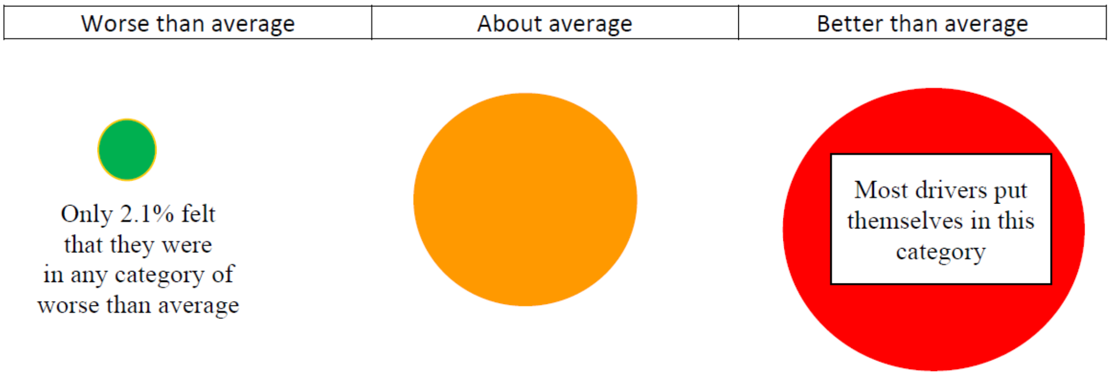
Finally, to close the loop directly connecting the promotion of speed to road use, cars are commonly advertised and promoted to the motoring public on the basis of their speed, power, and acceleration: this is the clear meaning of 'sports cars' and 'performance cars' (e.g., see: Bober, 2017) though the promotion of speed goes well beyond these specific car types. A google search of the fastest street cars reveals many lists and reviews of the fastest and most powerful cars available and, parenthetically, a search of the slowest street cars still pulls up mostly lists of the fastest cars – surely what any red blooded male would have intended to search. In many countries, cars are still advertised by showing high speed, referring directly to their 'racing heritage' with comparisons of race and street cars (for example, recent Audi advertising: see Green, 2020), and are compared on the basis of their acceleration and top speed. Adding to all this promotion of speed, risk-taking including speeding has positive value especially for young drivers (Prabhakar, et al., 1996).

<u>*Psychological misjudgement of risk*</u>: On the other hand, we may expect the rush to speed to be significantly countered by the risk of a serious crash. However, the internal dismissal of personal risk operates powerfully against this balancing force. Thus, this dismissal of personal risk constitutes the psychosocial wall which forms the second key structure sustaining unsafe speed as a cultural norm. Even those who stick to the speed limit are driving above safe system speed levels in most countries, with speed limits of 50, 60 and 70kmh in urban environments where pedestrians can access the road and of 90 and 100 on undivided non-urban roads where head on crashes are possible. The safe system limits for these contexts are 30 and 70kmh.

Three closely related psychological mechanisms constitute this wall: optimism bias, driver over-confidence, and the focus on personal experience in judging risk. Optimism bias and over-confidence are part of a larger set of 'self-serving' biases (Forsyth, 2008) which also include the illusion of control (human misjudgement -overestimation- in the extent to which we control what happens).

Optimism bias refers to the systematic bias where we generally expect to have better lives than our peers: we expect that our futures contain more good events (being successful, winning an award, having a long happy relationship) and less bad events (cancer, fired from work, early heart attack, causing a serious car crash) than average for our peers (Weinstein, 1980, 1984; Chua & Job, 1999). Driver over-confidence is the related phenomenon that most drivers believe that they are better than average: better, more skilled, safer. This has been identified in many studies and countries (See Figure 1 for an example, and see Dalziel & Job, 1997; Job, 1990; Jonah, 1988; Prabhakar, et al., 1999; Svenson, 1980). Clearly these are psychological biases; almost all of us cannot be better, safer, healthier and happier than average- somehow the average for the community has to be, well, average.

Figure 1: Driver Over-confidence in a large survey of Australian drivers asked if they were various categories of worse than, equal to, or better than average drivers (Results from Job, 1990)



The relevant impact of these biases is that they powerfully influence precaution-adoption versus risk-taking (Weinstein, 1988). These are relative judgements of risk, which carry the weight of survival whereas absolute judgements are much more difficult to make[50] and have less practical impact in part because people are strikingly bad at estimating actual probabilities especially small probabilities (Job, 2000). Drivers seeing themselves as better than others, more skilled, and less likely to cause a serious crash are less likely to see speeding as a risk, or the chance of causing a serious crash as being a significant issue for them. The risk of speeding (and many other behaviours) is not personalized.

Part of the basis of optimism lies in making estimates of the future from person experience. In the case of driving, the errors of drivers around us are visible and often noted, whereas our own errors are excused or even undetected by ourselves. Thus, we see ourselves as making less errors than others. Our personal experience also dismisses personal risk: in defence of speeding many drivers will say that they have been speeding regularly for xxx years (or months for young drivers) of driving and have not killed themselves or anyone else. Therefore, either the risks are exaggerated by road safety advocates leading to disbelief in the risks of speeding or the risk does not apply to them.

The above factors are the reason for the threat of enforcement being more effective in changing behaviour than the threat of a serious crash and death. People just do not believe that the latter will happen to them even if they speed (unless another 'bad' driver causes it), but they do believe that if

[50] Consider the difficulty of judging the height of an object in front of you in cm, versus judging which of two objects in front of you is higher. The latter is easy even when the objects only differ by small amounts.

they speed they may be caught. This difference and the importance of optimism/overconfidence to general deterrence was brought into sharp focus by the extraordinary life-saving success of Random Breath Testing for alcohol. This was much more effective than Police detecting impaired drivers and testing them, in significant part because the latter type of enforcement did not create general deterrence for drink-drivers most of whom were confident that that their driving would not be impaired by their drinking and so they would not be detected by police (due to continuing superior skills even when drink-driving: Job, 1990). Random testing highlights that no matter how good you think you are at drink-driving, police may still stop and test you. The general deterrence impact was profound, saving many thousands of lives (Job et al., 1997). Similarly, speed enforcement works as referenced earlier.

The Culture of Road User Control and Victim Blaming: This situation is allowed to continue through victim blaming operating as a powerful mechanism by which politicians and system operators avoid responsibility and accountability, sometimes cynically, sometimes naively (Deborah, 2007; Job, 2020). Despite the apparent adoption of safe system principles in many countries, the popularist focus on road user behavior as the element to be fixed (not the system itself) continues largely unabated, allowing victim blaming to flourish. Victim blaming not only supports avoidance of system responsibility in road safety, but also supports optimism bias and over-confidence. The pervasive media presentation of the errors made by people leading to fatal crashes (e.g., Anonymous, 2013; Flint, 2013) reinforces the view that not having had such a fatal crash further demonstrates superiority. This is exacerbated by the newsworthiness of extreme behaviors. The horror crash at really high speed is more likely to make the news, and highlighting that the crash was caused by a driver travelling at 60 or 80kph above the limit, simply normalizes the lower levels of speeding and reinforces the view that even if I speed I do not do it as extremely or poorly as others.

In addition, there is a deeply held cultural faith in education and training as a core means of behavior change including for drivers. This faith sustains the view that road safety is still the problem of the 'nut behind the wheel'. These views and media stories also reinforce the belief that superior car handling skill, attained through training, is critical to safety. Nothing could be further from the truth: even with a focus on the human error contribution, rather than the lack of system protection (such as a barrier to avoid the injury) the claim is still wrong and disastrously misleading. Crash injuries and deaths are caused most commonly by lapses such as micro-sleeps and behaviours which are motivation-related (speeding, drink-driving, not wearing a seatbelt or helmet, etc.) not car handling skill related. More confidence leads to more risk-taking which leads to more serious crashes, explaining why the most skilled drivers (licensed race and rally car drivers) have the most crashes on public roads. This also explains why most driver training either causes an increase in crashes or does no good. This is such a controversial claim flying in the face of our deep cultural faith in training, that it is still strongly resisted despite the abundant evidence. Thus, the evidence is briefly presented in the Annex to this paper.

Managing the Psychology and Politics of Speed

Despite the deep cultural, social, and psychological factors described above aligned to resist speed management, a great deal can be done to address these and succeed in the management of speed. In the interests of space these are presented in lists:

1. The most important action is to *genuinely adopt a Safe System approach*, increasing the focus of road safety resources on providing a system which forgives human error rather than imagining road users will ever be perfect.

2. *Communications with the community including school education* need to explain safe system and facilitate community demand for it, allowing stronger support for actions which deliver safety.
3. *Training of the journalists in understanding road safety and safe system* may have value and does appear to be generating better reporting in some LMICs.

In the interim, in the absence of a safe system, management of speed through influencing road user behaviour offers powerful cost-effective road safety opportunities. Perhaps the most politically viable effective opportunities are:

4. *Road engineering to control speeds (speed humps, roundabouts, chicanes, raised platform crossings),* which are extremely effective and politically less challenging in most jurisdictions than enforcement.
5. *Vehicle engineering* (ISA, speed limiting, continuous speed monitoring), which are also effective, and the EU is to be applauded for the commitment to ISA.
6. S*peed enforcement works, and the evidence for the safety value of speed cameras is irrefutable (as above).*
7. *Optimism bias can be countered* (Hatfield & Job, 2000), though this has not been broadly adopted.

However, in many circumstances enforcement of speed is required and many countries need substantial increases in general deterrence of speeding through stronger enforcement including lower enforcement tolerances, and automated enforcement. The required ramp up of enforcement to achieve road safety is politically fraught. Thus, recommendations are made for methods which have been used successfully to address the political risks:

1. *Strongly advertised advance warnings (in time not location)* of coming increases in speed enforcement are vital. The tendency of police to want to catch people through minimal warnings to the community demonstrates an unhelpful focus on specific deterrence rather than the required focus on general deterrence. Advance warnings increase the perception of fairness and support better behaviour change by generating changes in habits before people are caught, and reduce the perception that more speed enforcement is just for revenue raising.
2. *Issuing warning letter instead of penalties for the first* month of new enforcement operations manages political concerns and increases perceived fairness.
3. *Tversky's anchoring heuristic (*Rottenstreich & Tversky, 1997) is a useful psychological phenomenon in persuasion. Tversky demonstrated that offering a particular value as an answer for people to consider anchors their thinking closer to the posited answer. For example, people first asked whether the distance between Singapore and London is greater or less than 10,000 km and then asked to give an exact estimate of the distance, will give answers closer to 10,000km than without the first question. People given the same sequence by with the initial figure of 5,000km will subsequently give answers closer to 5,000km. Their judgements are anchored by the first number considered. This offers an important means of persuasion, for example by presenting to the community that the introduction of 10,000 speed cameras has been recommended, before introducing a much smaller number of cameras.
4. *Communicate to facilitate the normalization of sticking to the speed limit*, rather than highlighting the extremes. The common tendency is to justify enforcement by referring to the extreme cases. Thus, police will justify a speed enforcement operation by pointing to the most extreme speeder (or highest blood alcohol level, etc.). Listeners who hear of a

driver caught at 100kmh over the speed limit can have many unwanted reactions to this: Yes that person should be caught not me at a mere 15kmh over; so with the right skill someone drove 100kmh above the speed limit and did not crash but was caught - speeding is not so dangerous; the rest of us are quite normal at 10 to 20kmh over the limit, and relatively safe compared with this guy. Finally, noting Tversky's anchoring heuristic, this anchors the debate around whether it is reasonable to infringe drivers at this excessive speed, and so the debate on low levels of speeding can be lost in one miss-step. The ideal answer to a media enquiry on an enforcement operation is something along these lines: 'We are immensely pleased that most drivers are doing the right thing. 99% of those passing the cameras were not infringed. We need to get this to 100%.' This normalizes not speeding, leaves speeders feeling unsupported by most drivers, and anchors the debate on what should be infringed around not speeding at all.

A counterargument may be mounted, by suggesting that the focus on high-level speeding is warranted by the substantially greater risk of extreme speeding. While the claim of much greater risk is warranted by the evidence, extreme speeding is much rarer than the sadly common behaviour of lower level speeding (say up to 10kmh above the speed limit) in most countries. Thus, counter-intuitively, low-level speeders still contribute more speeding-related deaths and injuries than do extreme speeders. As an example, Table 1, presents the data on levels of speeding from a large scale on-road automated survey in New South Wales, Australia (Gavin et a., 2010). Table 1 shows that around 75% to 80% of speeding is by 1-10kmh above the speed limit compared with 0.01% of speeding at 46kmh or more. These survey data allow for another step in assessing the relative importance of different levels of speeding: by multiplying the proportions of speeding at each level by the known relative risk created it is possible to determine the contributions of each level to deaths and injuries from speeding. For example, if 1600 drivers are speeding by around 10kmh and this adds around 40% to each drivers risk of a fatal crash, compared with two speeders (around the ratios Table 1 shows) at 50kmh above the limit and this adds 250% to those drivers risks of a fatal crash (applying a power model), the low level speeding still contributes many times more risk of fatality than the extreme speeding. This analysis is presented in Table 2, showing that 67% of speeding fatalities are contributed by those speeding up to 10kmh above the limit compared with only 1% contributed by extreme speeders. Without a strong focus on low level speeding, the majority of the speeding problem is left unaddressed.

Table 1: Proportions of drivers speeding by speed offence band in NSW, Australia (Source: Gavin et al., 2010)

Speed band (over speed limit)	Speed limit						
	50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h
1-10 km/h	74.2%	81.6%	78.5%	77.4%	75.9%	81.6%	79.9%
11-20 km/h	22.2%	15.8%	18.1%	18.4%	19.7%	15.3%	17.3%
21-30 km/h	3.1%	2.2%	2.7%	3.3%	3.5%	2.4%	2.3%
31-45 km/h	0.5%	0.4%	0.5%	0.7%	0.8%	0.6%	0.4%
46 km/h +	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%

Table 2: Population risk of a fatal crash by speeding offence band in NSW, Australia (Source: Gavin et al., 2010)

Speed band (over speed limit)	Speed limit							Total risk (fatal)
	50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	
1-10 km/h	55%	68%	65%	65%	64%	73%	72%	67%
11-20 km/h	33%	24%	26%	25%	26%	20%	22%	25%
21-30 km/h	9%	6%	6%	7%	7%	5%	4%	6%
31-45 km/h	3%	2%	2%	3%	3%	2%	1%	2%
46 km/h +	1%	0%	1%	1%	1%	0%	0%	1%
Fatal crashes % (2008)	19%	18%	9%	14%	2%	32%	6%	

5. *Refined use of paid mass media can help generate community support.* For example, a paid advertisement heralding the introduction of mobile speed cameras in NSW, Australia, showed the community holding up their hands like a mock camera at cars seen speeding expressing a desire to see them caught, thus supporting community disapproval of speeding as well as giving advance warning of the coming camera program before it started. The camera program and the advertisement were extremely well received and effective in reducing deaths and injuries.
6. *Announcements of speed enforcement programs should be accompanied by talks from victims of the families of victims.* These generate all-important emotional support for the programs.
7. *Cognitive dissonance, a classic psychological phenomenon (Festinger, 1957), is vital to appreciate and use*. The common view that we must change attitudes in order to change behaviour is naïve and fundamentally mistaken. In road safety (and in many areas of life) forcing a change in behaviour will lead to a change in attitude to match the behaviour. Thus, random breath testing forced most previous (uncaught) offenders to change their behaviour and stop drink-driving, and this caused a gradual change in attitude: increased disapproval of drink-driving (Job et al., 1997). Similar studies are needed for speed enforcement.
8. *Promoting the community-wide economic costs of crashes* will reduce the perceived value of high speed.
9. *Independent surveys of community views on speed and enforcement* commonly show more support for enforcement than the media presents (as ESRA, E-Survey of Road Users Attitude show: https://www.esranet.eu/), and thus these can be valuable news in themselves.
10. *Government commitment to dedicate all speed camera revenue directly back into road safety* has calmed accusations of revenue raising in several instances in states of Australia and elsewhere.
11. *Commitment to evaluation of the program along with publication of results* also eases concerns and allows for a demonstration of the road safety success of increased enforcement. Camera locations should be legitimately chosen on the basis of crash data to ensure that this is possible. The first locations for camera instillation will be the most carefully scrutinized and should be chosen based on serious crash rates as well as levels of speeding, to ensure early wins.
12. *Consultation with the community including sharing the opportunity to nominate camera locations* has proven most helpful in the state of New South Wales, Australia. This reduced concerns with location choices.
13. *Regular calibration of the accuracy of cameras* is essential for credibility.

With precise planning of announcements, sound use of the psychological evidence, victim support, careful sequencing of advertising, staged implementation, and considered policy power road safety gains are possible without political cost and the demonstration of these gains further supports the political decisions taken.

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Annexes

Annex I: Speed enforcement – country examples

France – Automatic Speed Enforcement by Presidential Decree

Automated safety cameras were introduced in France in 2003 following a decision by President Chirac in 2002 to make road safety one of the three major nation priorities during his mandate. Between 2003 and 2009, 1 661 fixed safety cameras were implemented, supplemented by 932 mobile cameras. The network of fixed and mobile safety cameras continue to be implemented progressively[51]. The first cameras were installed by central decision at points in the network with most traffic. Then, the locations were decided at local level taking into account the characteristics of the infrastructure and levels of crash risk[52].

Between 2002 and 2005, the mean speeds fell by 8.9 km/h on secondary roads and by 7.7 km/h on two or three lanes highways (two-way roads)[53].

Research has shown that the French safety camera programme reduced the proportion of fatal collisions attributable to high-level speeding (>20 km/h over the limit) from 25% to 6% over the period 2001-2010 and increased the proportion attributable to low-level speeding from 7% to 13%[54]. The French authorities apply a 'Zero Tolerance' approach for drivers exceeding speed limits beyond the estimated technical error margin for speed checks: 5km/h or 5% of the speed if it is above 100 km/h.

France maintains one of the highest levels of automated speed enforcement activities in the EU (Fig.1)[55]. Due to high level of automation, the procedures for issuing fines after a speeding offence has been detected by safety camera are very efficient and fast, tickets for speeding offences are sent within 8 days after the offence was detected. The National Processing Centre of Road Traffic Offences (CNT) in Rennes is under the responsibility of the French Minister of the Interior[56].

A combination of owner liability, administrative law, clear license plates, high quality enforcement cameras and effective software allows France to annually process millions of violations from automated enforcement systems with limited human intervention from one national processing and fine collection centre. The funds resulting from the traffic fines go to a separate account in the national budget and are reinvested exclusively in road safety measures including new equipment for traffic violations detection and infrastructure.

Italy – Section Control

Section control of speed (known in Italy as Safety Tutor) was introduced on the Italian motorway network in December 2005[57]. In 2014, it totalled 320 camera sites which covered more than 2900 km of the motorway network (about 40% of the Italian motorway network managed by Autostrade per l'Italia). It has since been extended to other national expressways[58].

The evaluation conducted showed a clear decrease in the mean speed and also an impressive reduction in the speed variability. On the A56 urban motorway, mean speed of light vehicles decreased by 10% and the number of collisions decreased by 32%[59]. One of the most important effects of the system is an impressive reduction of the speed variability. The standard deviation of average speeds of light vehicles over the study sections

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[51] ibid
[52] Case Study from OECD/ITF (2018) Speed and Crash Risk https://bit.ly/2ZO3ewh
[53] ibid
[54] Viallon, V, and Laumon, B (2013), 'Fractions of fatal crashes attributable to speeding: Evolution for the period 2001-2010 in France'. Accident Analysis and Prevention, Vol. 52. In OECD/ITF Speed and Crash Risk (2018) https://bit.ly/2ZO3ewh
[55] ETSC (2019), Reducing Speeding in Europe (PIN Flash Report 36) https://bit.ly/2ZLZv2c
[56] ETSC (2020) EU Road Safety Exchange France Study Visit https://bit.ly/2RCf0Fq
[57] Summary of Case Study from OECD/ITF Speed and Crash Risk (2018) https://bit.ly/2ZO3ewh
[58] ibid
[59] ibid

decreased from 16.5 to 12.2 km/h (from 13.1 to 10.5 km/h for heavy vehicles), i.e. a 26% reduction (20% for heavy vehicles)[60].

Austria – Section Control

Section control has been used as a road safety measure in Austria since 2003. Permanent section control installations were initially only used in Austria on motorways and highways (ASFINAG road network). A recent study has also evaluated the use of section control in Austria[61]. There are currently five permanent section control installations on the ASFINAG road network and three permanent installations on the secondary road network (the first one was introduced in 2012). The majority of the permanent section controls in Austria are located in road tunnels. For the purposes of the ITF study, five permanent section control installations were studied in detail, four of which are located on the ASFINAG road network and one on the secondary road network. Collision trends for the studied sections were compared with those for the complete ASFINAG road network and for all ASFINAG tunnels[62].

The recent study found that for Austria section control installations generally have a positive effect from a collision perspective, especially when the full section of road is considered (including the approach and exit). The effect is particularly evident for collision severity and thus also collision cost rates. This, in turn, can be attributed to the harmonisation of driving speeds and the reduced number of vehicles being driven at a speeds that "far exceed" the maximum speed limit. Given the positive effect of section control installations in reducing collision cost rates in particular, their use is especially beneficial on sections of road with high collision rates – and above all severe collision consequences – as well as on sections of the road where high numbers of collisions are the result of "inappropriate driving speeds"[63].

France – Cameras to detect Speeding Powered Two Wheelers

In France, where road safety efforts in the early 2000s focused on moderating driving speeds, motorcyclists reduced their speed since 2002 but not to the same extent as other road users[64]. In 2006 as least 30% of motorcyclists were still riding 10 km over the legal speed limit, against 15% for cars and heavy good vehicles. Starting in 2006, the French government acknowledged the specific problem of overrepresentation of motorcyclists in fatal collisions compared to the rest of Europe and adopted a new set of measures. Safety cameras have progressively been replaced by new ones capable of detecting speeding motorcyclists from the rear and thereby allowing their identification based on registration plates. The number of mobile speed controls targeting motorcyclists also increased. However, data from 2012 show that in France, 100% of PTWs speeding were not caught by devices with front cameras and it is estimated that only 15% of PTW speeding were caught by devices with rear cameras, because their plates could not be read[65].

Finland – Means Tested fines

Finland has a 'day fine' system, with penalties linked to an offender's wages, Finnish 'day fine' system, in place since the 1920s, links fines to net income. In a widely-reported case in 2016, Reima Kuisla, a wealthy businessman was fined EUR 54,024 for travelling at 103km/h in an 80km/h zone. The fine was calculated based on his 2013 tax return which showed a EUR 6.5 million income for that year.[66]

There are several other examples of fines linked to income around Europe, in particular for speeding offences. In the United Kingdom judges can also impose higher fines linked to weekly income, but these are capped at £2,500, or £1,000 for offences committed on non-motorway roads. Sweden and Switzerland also have this

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[60] ibid
[61] Austrian Road Safety Council (KfV) (2018)Section Control Effectiveness and Implementation Recommendations https://bit.ly/32APLK6
[62] ibid
[63] ibid
[64] ETSC PIN Flash (2008) Reducing Motorcyclist Deaths in Europe https://bit.ly/3iIKC8y
[65] CNSR, 2013 cited in OECD/ITF (2014) Working Group Safety of Powered Two Wheelers Final Report https://bit.ly/3iIKC8y
[66] ETSC (2016) Ireland Considers Higher Fines for Wealthier Speeders https://bit.ly/2RxlA00

approach. Ireland is also considering a similar scheme[67].

Ireland – Mobile Safety Camera Scheme on low traffic density roads

Ireland has set a target of 100% compliance with the speed limits for all vehicles on all roads in its Road Safety Strategy 2013-2020[68]. Recent data collected on 'free speed' show levels of speeding of up to 52% average on urban roads and 25% average on rural roads[69]. Ireland has an interesting approach to traffic law enforcement. Because of its' relatively low traffic density, it has introduced mobile cameras housed in vans instead of fixed cameras. The vans are driven by a private company but the tickets are processed by the police. The contractor operating the cameras has to provide at least 6000 hours of speed enforcement each month. The payment is based on the number of hours, not on the number of detected violations.

In 2010, the Irish police launched a mobile safety camera scheme and identified a large number of road sections with a history of collisions where speed was a contributing factor. Currently 1322 sections of road are identified as speed enforcement zones with safety cameras housed in marked vans[70]. A 2014 study by the Department of Economics at Trinity College Dublin, carried out for the Irish Department of Transport, revealed that the benefits of the safety cameras outweighed the costs by more than five to one, generating a benefit to Irish society of over 70 million Euro each year, with almost 92% being delivered in the form of reduced collision levels[71].

The operational costs of running safety cameras in Ireland (16 million Euro a year) are more than double the fine income they generate (6.9 million Euro a year). Comparing "before" (2005-2010) and "after" (2011-2013) periods, it was estimated that the mobile camera scheme has prevented on average 24 deaths, 41 serious injuries and 319 slight injuries each year[72]. The research factored in the effects of reduced traffic volumes caused by the recent Irish recession and of national trends in collision reduction following greater efforts in enforcement, road engineering and safety education. There is also strong evidence of public support: 85% of drivers support the use of safety cameras, while 66% believe they have an effect on safety. 75% of motorists consider that it is 'likely' they would encounter a safety camera on a long distance journey[73].

Netherlands – innovation

A recent report from the Netherlands has examined the 'possibilities for innovative (both existing and new) technologies and methods for effective speed enforcement, such as section control on the secondary road network, unmanned mobile safety cameras and higher fines for excessive offenders[74].

Concerning speed enforcement by the police, the following innovations seem the most promising to explore further:

• Using dashcam footage collected by citizens in the detection of speed offenders. This is now done sporadically, but the UK has good experience with this.
• Detection by police cars with in-built radar systems. This is already done in France. However, it needs to be investigated whether this method is sufficiently cost-effective.
• Before-and-after warnings on the road at speed checks to increase the subjective risk of being caught.

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[67] ibid
[68] Road Safety Authority (2013) Ireland Road Safety Strategy, Ireland https://bit.ly/2RE2nda
[69] 'Free speed' Free speed is defined as the speed at which drivers choose to travel when unconstrained by road geometry (e.g. sharp bends, intersections or hills), weather conditions (e.g. rain) or traffic conditions (e.g. congestion). Survey of Driver Free Speed (2018) Road Safety Authority, Ireland https://bit.ly/33CyMGt
[70] An Garda Síochána Website (February 2020) https://bit.ly/2RBtkOw
[71] Cited in ETSC PIN Flash How Traffic Law Enforcement Can Contribute to Safer Roads (2016) P. 42, https://goo.gl/GVwmf5
[72] ibid
[73] ibid
[74] Goldenbeld, Ch. et al (2018) SWOV Speed enforcement on 60 and 80 km/h roads; Exploratory research on developments and possibilities for the future https://bit.ly/35QlMA1

Research shows that speed control has a greater speed reduction effect on the V-85 speed with a pre-warning sign resulting in a 4.5km/h reduction than without pre-warning sign which only results in a 2.5km/h reduction[75]. Showing a warning immediately after the control was shown to be effective. In a simulator study of Marciano (2015) it was found that drivers kept to the limit and a more consistent speed when the controls were not visible and when they would receive immediately a signal at the moment their vehicle was signed. For the post-warning method the necessary ICT has a higher cost[76]. Thus Goldenbeld (2018) concludes that best effects can be achieved by using them simultaneously. This requires good cooperation between enforcement authorities and road authorities.

More recently it has been reported that Police will deploy of unobtrusive radar cars across the country to target speeders[77].

Other new methods currently in preparation are facing further legal barriers before they can be fully introduced. These include for example establishing new tasks for special investigators *'buitengewoon opsporingsambtenaren'* (BOAs) who also have traffic enforcement tasks. Also 'de-anonymizing the offenders by sending personal letters after violations'. Automatic Number Plate Recognition (ANPR) is also coming to the Netherlands thus increasing the risk of being caught for multiple-offenders. The fine system for speed could be changed to enable higher sanctions linked to the severity or offence repetition. One of the existing barriers to, for example sending personalised letters is the difference between fining a person and fining a vehicle registration number. Also for ANPR and repeat offenders, the current legislation does not allow the storage and use of information about traffic violations.

UK National Driver Offender Retraining Scheme (NDORS)

The National Driver Offender Retraining Scheme (NDORS) is an education scheme launched in England, Wales and Northern Ireland in 2010 when safety camera schemes were under criticism[78]. It allows a motorist who has been caught committing a 'low level' speed offence (exceeding the speed link by few miles per hour), not wearing a seat belt or driving while using a mobile phone to attend an education course instead of paying a fine. When a person has attended and completed a course, their details are kept on a national database. This ensures that if a person is caught committing the same type of offence within three years from the date of the original offence they cannot be offered another course. Since 2010 the numbers taking the National Speed Awareness Courses has increased from 447,000 a year to 1.282 million in 2019[79].

Automated enforcement and safety camera network in Poland - Use of EU funding

Poland continues to benefit from EU co-funds for its automatic speed enforcement network[80]. First launched in 2011, the project was called "Construction of the central automatic road supervision system" (CANARD) and its first phase was implemented in 2011-2015 under the EU Operational Program Infrastructure and Environment 2007-2013[81]. The project aimed to increase the efficiency and streamline the CANARD activities (including through the use of more technologically advanced recording devices), increase the coverage of automatic enforcement and thus improve road safety. Phase II of the project continues with further EU funding thus enabling Poland to further update its safety camera network introducing for example section control. This includes a study carried out by ITS Motor Institute to select high risk sites for the placement of new safety cameras[82]. As well as the continuous improvement of the ICT infrastructure and, for example, the processing of the data from the safety cameras[83].

[75] Wilmot (2016) in Goldenbeld, Ch. et al (2018) SWOV Speed enforcement on 60 and 80 km/h roads; Exploratory research on developments and possibilities for the future
https://bit.ly/35QlMA1
[76] Marciano (2015) in Goldenbeld (2018)
[77] Article in NOS Netherlands August 2020 https://bit.ly/2HbcNPx
[78] ETSC PIN Flash How Traffic Law Enforcement Can Contribute to Safer Roads (2016) P. 42, https://goo.gl/GVwmf5
[79] NDORS Statistics https://bit.ly/3kq2jKj
[80] CANARD Calendar https://bit.ly/3hGsgU2
[81] https://bit.ly/3fhuIAe
[82] CANARD Calendar https://bit.ly/3hGsgU2
[83] TVN 24/PL https://bit.ly/2H39QQQ

This table overview shows the positive impact of the introduction of fixed safety cameras in Poland.

Data on the state of fixed safety cameras (for the period January 2008- September 2014)

Fixed equipment	Collisions/month	Deaths/month	Injured/month
Years 2008-2012 (before installation of equipment)	17,3	2,7	22,9
Years 2013-08/2016 (after installation of equipment)	10.3	1.2	12.5
Reduction	**-36.%**	**-52%**	**-42.1%**

Data on the state of fixed speed cameras (for the period January 2008-September 2014)[84]
Data on impact 2023-08/2016[85]

Another more recent study (2019) looked at ten safety camera locations and their effectiveness in reducing speeds between 2016-2018. The results showed reductions in speed seven out ten of the chosen locations. These locations were chosen because the safety camera had been activated for at least 5 months and where there had been no the speed camera for at least 5 months[86].

In another recent move on information to citizens regarding speeding, ahead of actually sanctioning, Poland has introduced new digital speed signs showing actual speed, this is not new, what is new is that the signs also show the possible fine and penalty points that would be incurred.[87]

[84] https://bit.ly/3hCrnvJ
[85]CANARD https://bit.ly/3c6gS2E
[86] Świderski A., Dąbrowska-Loranc M., Łopata E., et al. (2019) Zwiększenie skuteczności i efektywności systemu automatycznego nadzoru nad ruchem drogowym Analiza stanu bezpieczeństwa na potrzeby instalacji nowych urządzeń rejestrujących Motor Transport Institute & Heller Consult, Warsaw
[87] Polish Radio 24/PL https://bit.ly/33FmuwW

Annex II: Driver and motorcycle rider training

Despite our faith in education and training, driver training is repeatedly proven to be ineffective, or event harmful, for road safety in the vast majority of circumstances. The highly credible Cochrane Library have published expert methodologically rigorous reviews of the evidence which have shown no safety benefits of driver training. For example, the review of post-license driver training concluded: “This systematic review provides no evidence that post-licence driver education is effective in preventing road traffic injuries or crashes. …. Because of the large number of participants included in the meta-analysis (close to 300,000 for some outcomes) we can exclude, with reasonable precision, the possibility of even modest benefits.” (Ker et al., 2003). The analysis of the evidence also found that: “No one form of education … was found to be substantially more effective than another, nor was a significant difference found between advanced driver education and remedial driver education.” More recent reviews have demonstrated increases in crash rates from vehicle handling skills-based training such as skid training (Elvik et al., 2009).

In addition, the same pattern of no road safety benefits of training applies for motorcycle riding: with benefits absent in systematic reviews of the evidence (Kardamanidis et al., 2010) and in a recent well controlled evaluation of post-license training (Ivers et al., 2016).

School-based driver education is important to consider because there is a common view that this will assist with road safety. The evidence suggests the contrary, mainly because young people start driving earlier. A comprehensive review of evaluations of school-based driver training produced negative results, concluding as follows: “The results show that driver education leads to early licensing. They provide no evidence that driver education reduces road crash involvement, and suggest that it may lead to a modest but potentially important increase in the proportion of teenagers involved in traffic crashes.” (Roberts & Kwan, 2001). Licensing and thus driving at a younger age is harmful because the adolescent brain areas responsible for impulse control are for many individuals not fully developed until around the ages of 20 to 25 years (Johnson & Jones, 2011; Casey, et al., 2008).

However, there are claimed successes in road safety education. These generally have one or more of several limiting features for genuinely demonstrating the claimed benefits:

1. The measures of success used are self-reports by participants that they feel better or safer drivers (which we will see below is actually evidence for road safety harm, not help)
2. The outcome measures are of knowledge or skill improvements not real safety outcomes such as less serious crashes
3. The studies lack proper control groups, and are thus confounded by various other factors such as age or self-selection bias
4. The interventions are a combination of driver training, organizational culture change, and/or contingencies placed on drivers to improve safety behaviours, and the benefits observed may thus arise from the latter components not the training
5. The evaluations are undertaken by people with a vested interest in the program’s success.

There are a number of factors behind these consistent and surprising failures, including that driving is a self-paced task, that road safety risk is primarily a motivation problem not a skill or knowledge problem (Job, 1999), with more skill creating more confidence and thus more risk-taking (Katila, et al., 2004).

There is some positive news. Many hours of on-road supervised practice by novice appears to reduce subsequent crash risk (Gregersen et al., 2003). This may be related to entrenching safe habits rather than skills.