

PROPOSED SPEED LIMITS FOR THE 2030 MOTOR VEHICLE

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ABSTRACT

Vision Zero builds on the aspiration to keep kinetic energy below human tolerance to prevent fatalities and serious injuries. In this work, a Swedish expert group within the SAFER arena estimated the maximum safe speed limits for the 2030 motor vehicle based on the boundary conditions of vehicles, road infrastructure and human crash tolerance to achieve close to zero road fatalities and serious injuries.

The present work was based on expert consensus, rather than a retrospective quantitative analysis of crash data. Different load cases were discussed separately, with the involvement of a passenger car being the common denominator. The passenger car and its collision partner were assumed to be of model year 2030, thus reflecting the base safety level of the Swedish car fleet by approximately 2050.

The boundary conditions were set based on pre-crash autonomous braking ability and the maximum acceptable impact speeds that would result in a very low risk of death or serious injury among the car occupants and the car's collision partner. In the case of car to pedestrian impacts, the acceptable impact speed was set to zero, as any impact with pedestrians can lead to serious injuries as a result of ground impacts. It was expected that the responsibility to comply with speed limits will move from the driver to the car itself, and that travel speeds will be autonomously reduced when low road friction, sight obstructions, and other challenges in the traffic environment are detected. This function was expected to be non-overridable. Lateral control was also expected to be further enhanced with lane support technologies, although it was assumed that it will be still possible to override such technologies.

Over time, increased performance of vehicle safety technologies will likely be able to prevent an increasingly large proportion of crashes in all load cases. However, in line with Vision Zero design principles, human crash tolerance will always be the ultimate boundary condition to guarantee a safe outcome in a crash. As a result, the recommended maximum travel speeds in the road transport system containing motor vehicles only of model year 2030 and beyond are:

- 5-7 km/h in pedestrian priority areas,
- 40 km/h in mixed traffic urban areas, if there are no obstructed sensor sightlines, e.g. due to parked vehicles along the sidewalk,
- 50 to 80 km/h on roads without mid- and roadside barriers,
- 100+ km/h on roads with continuous mid- and roadside barriers,
- 40 to 60 km/h in intersections, depending on vehicle mass differences.

The results from this work can be used to inform the development and amendment of transport planning guidelines when moving away from the economical paradigm into Safe System boundary conditions in the setting of speed limits.

INTRODUCTION

Vision Zero, the policy framework for traffic safety introduced in 1995, builds on the aspiration to control kinetic energy and keep the amount of kinetic energy below the threshold of human biomechanics tolerance for severe injuries (Tingvall and Haworth, 1999). In the introduction of Vision Zero, kinetic energy was simply a function of travel speed, but was later defined as impact speed. The strong relationship and the high sensitivity of speed versus injuries has been known for a long time. The early works by Nilsson presented in 1981 (Nilsson 1981, 2004) and later by Elvik (2009) show that travel speed versus fatalities and serious injuries are non-linear relationships and are sometimes described as power functions (Elvik et al., 2019). The relationship between impact speed, or sometimes delta V (change of velocity), and injury risk has been described using many methods.

Injury probabilities are typically quantified with regression models applied to large representative samples of real-world crashes (McMurry et al., 2021; Lubbe et al., 2022). Of particular importance is a good estimation of delta V, for example available from on-board crash recorders (Kullgren et al., 1995; Funk et al., 2008), to show a clear and strong relationship between delta V and serious injury as demonstrated by Doecke et al. (2021). Studies have clearly shown that the relationships are non-linear, but that the threshold for an injury and the slope of the non-linear relationships are complex to estimate by statistical methods (Kullgren and Stigson 2010; Rosén and Sander 2009).

The first attempt to estimate the maximum travel speed and associated speed limits to fit with an aspiration of zero fatalities was done in 1996 (Tingvall et al., 1996). This was later followed up in a paper by Tingvall and Haworth in 1999, with a focus on pedestrians and car occupants.

Table 1.

Possible long-term maximum travel speeds related to the infrastructure, given best practice in vehicle design and 100% seat belt use. Source: Tingvall and Haworth (1999)

Type of infrastructure and traffic	possible travel speed (km/h)
Locations with possible conflicts between pedestrians and cars	30
Intersections with possible side impacts between cars	50
Roads with possible frontal impacts between cars	70
Roads with no possibility of a side impact or frontal impact (only impacts with the infrastructure)	100+

The indicative speed limits were based on a few boundary conditions; car occupants using seat belts and complying with speed limits, and the car being rated four stars at the time Euro NCAP presented the results (at the time, the maximum Euro NCAP rating was just four stars). Even though road user age was known to strongly influence injury outcome, this aspect was not explicitly considered. The limits were said to be relevant long-term. Given the boundary conditions, empirical data to validate the result of the chosen boundary conditions were not available at the time; rather they were seen as aspirations of a number of desired safety performance factors and how they can interact to allow for a certain speed limit. There have been a few attempts to investigate the effect of fulfilling these boundary conditions but they failed due to incomplete speed data and the fact that the safety of individual car models can vary substantially (Stigson 2009).

Later, more boundary conditions were set up, in line with the development of vehicle technologies. Eugensson et al. (2011) presented a speed limit chart based on the fitment and performance of safety technologies on a car of model year (MY) 2020 and beyond (Figure 1).

In contrast to the earlier boundary conditions set by Tingvall and Haworth (1999) which assumed travel speed and impact speed being identical, the new boundary conditions set by Eugensson et al. (2011) took into consideration pre-impact braking. This resulted in lower impact velocities but higher acceptable travel speeds due to the availability of pre-impact braking. The other boundary conditions, like using seat belts and not exceeding posted speed limits, were identical between the two studies. Frailty of elderly road users was not specifically addressed. The safety performance of the car would be in line with the expected safety level for a five stars car of MY 2020 - without precisely knowing what safety features five stars car of MY 2020 would have.

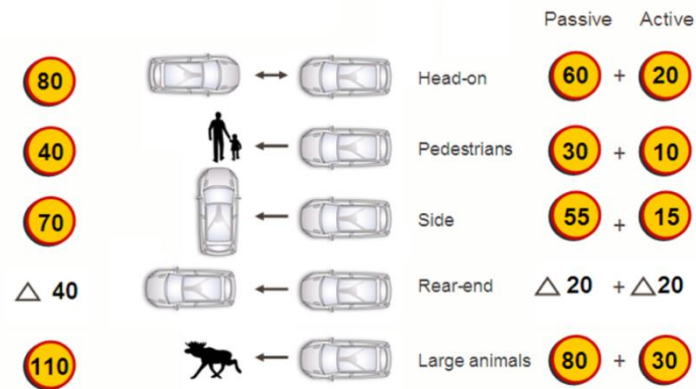


Figure 1. Examples on how the responsibilities can be divided between vehicles (active and passive safety) and requirements for infrastructure (speed limits). Source: Eugensson et al., 2011.

Apart from pre-impact braking, there are other pre-crash technologies intervening prior to crashes, such as Lane Keep Assist (LKA) and Emergency Lane Keeping (ELK), that have been shown in a number of studies to be effective for safety (Leslie et al., 2022). Utilizing a technique to predict the future outcome of technologies, Strandroth (2015) showed that such technologies would substantially reduce the number of fatalities in car crashes and change the pattern of crash types. In research of motorcycle crashes, Rizzi (2016) showed that combinations of safety technologies can interact to produce a higher level of safety where one safety technology is dependent on another safety technology. Leg protection was dependent on an upright crash configuration, which in turn was provided by Antilock Braking Systems (ABS). Similarly, Fredriksson has shown in several studies the benefit of combining active/auto-brake and passive/deployable countermeasures for both pedestrians and bicyclists (Fredriksson and Rosén 2014, Fredriksson et al., 2015). In all, there are many examples of technologies that can not only protect a road user at a given crash severity or change the crash severity by pre-impact braking, and also reduce the risk of a crash or an injury. Therefore, it could be argued that there is a need to update the results shown in Eugensson et al. (2011) to consider the increasing potential of vehicle safety technologies to reduce the risk of death and injury.

The aim of the present study is to update the boundary conditions of vehicles and road infrastructure and to estimate speed limits that would result in a very low risk of death or serious injury. The boundary conditions would mirror the expected safety technologies and performance of a car of MY 2030 and beyond. It would also involve a number of other requirements explained in the next section.

GENERAL APPROACH AND MAIN ASSUMPTIONS

Similar to Eugensson et al. (2011), the general approach of the present work was to form a consensus group to discuss boundary conditions for a number of load cases involving passenger cars. It is therefore important to stress that the present work was mostly based on a rationale using logical deduction, rather than the analysis of crash data. A working group was formed including seven road safety experts with different backgrounds and associations. Most participants were selected within the SAFER arena (www.saferresearch.com) and agreed to be a part of the working group on a voluntary basis and without any monetary compensation. The process was facilitated by discussing different load cases separately, with the involvement of a passenger car being the

common denominator between the cases. The car's collision partner was also assumed to be of MY 2030, thus reflecting the base safety level of the Swedish car fleet by approximately 2050. Similar to Eugensson et al. (2011), the boundary conditions were set based on pre-crash autonomous braking and maximum acceptable impact speed to make long-term injuries and fatalities unlikely among the car occupants and the car's collision partner. The group agreed to not include pre-crash autonomous emergency steering in the boundary conditions as its reliability and relation to injury outcome is still unclear (Robinson et al., 2020).

In this work, it was acknowledged that striking a pedestrian with a passenger car will always be associated with a risk of long-term injury or fatality, since hitting a pedestrian can result in serious injuries as the pedestrian hit the road surface. Therefore, in the boundary conditions for pedestrian impacts, the acceptable impact speed was set to zero km/h.

It was also acknowledged that the maintenance of the road infrastructure has become more relevant with advanced pre-crash technologies like Electronic Stability Control (ESC), Autonomous Emergency Braking (AEB) and lane support technologies. It was therefore anticipated that the road maintenance will be kept to a standard where the vehicle's Advanced Driving-Assistance Systems (ADAS) can operate with no reduction in functionality. It was also anticipated that the road friction would either be at the optimum level, or that the vehicle can detect the available road friction and consequently adjust its travel speed. Accurate and instantaneous road friction estimation is a current topic in research and development (Sander et al., 2019). Hence, we acknowledged that road conditions will not always be optimal, but we expect the vehicle to be able to adjust to them. Basically, it is up to the infrastructure provider to guarantee good maintenance and road friction to deliver the intended mobility on the road.

Vehicles' ability to detect other road users was anticipated to be improved compared to the present performance. The average time between detection and full autonomous braking was assumed to be about 0.5 seconds, which the working group believed to be reasonable based on the current sensor performance. The development of pre-impact safety technologies also includes connectivity and the vehicle's ability to adapt to factors that influence safety. The gradual introduction of ADAS nowadays also includes support for not exceeding the posted speed limit (e.g. Intelligent Speed Assistance, ISA). In general terms, it is anticipated that by 2030, a new car will not allow the driver to travel above the speed at which the car would be able to stop within its sensor horizon with maximum autonomous braking (based on available friction). More specifically, it is anticipated that cars will detect objects and potential crash partners in the sensor horizon and predict potential and possible maneuvers and crash risks. However, sudden, hard-to-predict maneuvers and sensor imperfections might still lead to collisions. Here, the sensor horizon was considered to be about three seconds headway distance, which seems feasible due to the "ground rule" in a car-following situation.

Similarly, we expect vehicle crashworthiness to improve further, with improved structural integrity at high speeds and softer, more forgiving responses at low speeds. This would be enabled, for example, by adaptive front-end structures (Wågström et al., 2005), adaptive occupant restraints (Mackay et al., 1994; Zhao et al., 2019) and better protection of road users outside the vehicle (Fredriksson and Rosén 2014, Fredriksson et al., 2015).

The main assumptions of the present work can be summarized as follows:

- Compared to Eugensson et al. (2011), a new main assumption was added; a passenger car of MY 2030 cannot be driven faster than the speed at which it can stop using maximum braking within its sensor horizon (3 seconds headway distance). It would not be possible to override this functionality. Therefore, the boundary condition of not exceeding the speed limit is moved from the driver to the car itself, and it is a function of the road environment, available road friction, sight conditions etc. Lateral control is enhanced with lane support technologies, although it will be possible to override such technologies.
- Based on that assumption, the boundary conditions are given by pre-crash autonomous braking and maximum acceptable impact speeds that would pose a very low risk of death or serious injury. In the case of pedestrians hit by cars, the acceptable impact speed is set to zero km/h.
- The other boundary conditions, i.e. proper use of seat belts and other protective equipment, is unchanged compared to Eugensson et al. (2021).
- When the passenger car's counterpart is another motor vehicle, it is assumed that that vehicle is also of MY 2030. This is expected to reflect the lowest safety performance of the Swedish vehicle fleet by approximately 2050.

The chain of events leading to a crash (Rizzi 2016) can be used to further illustrate the main differences between Eugensson et al. (2011) and the present work (see Figures 2 and 3). The potential contribution of ADAS in

reducing the number of crashes was also considered in the present work, and conceptually illustrated by a “funnel” between the safe driving phase and the actual crash. The size of such a funnel varies across different load cases, as further described in later sections.

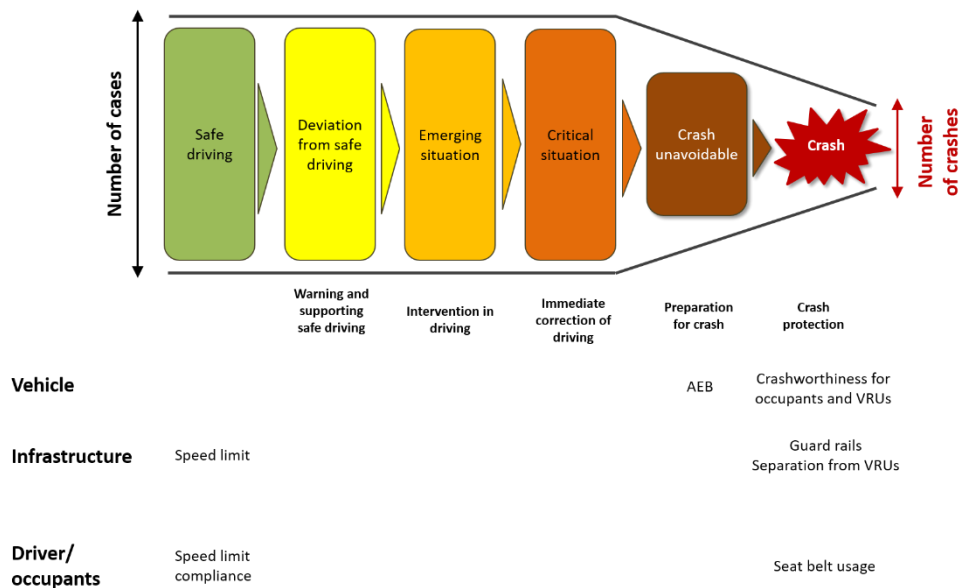


Figure 2. Previous work (Eugensson et al., 2011) illustrated with the chain of events leading to a crash.

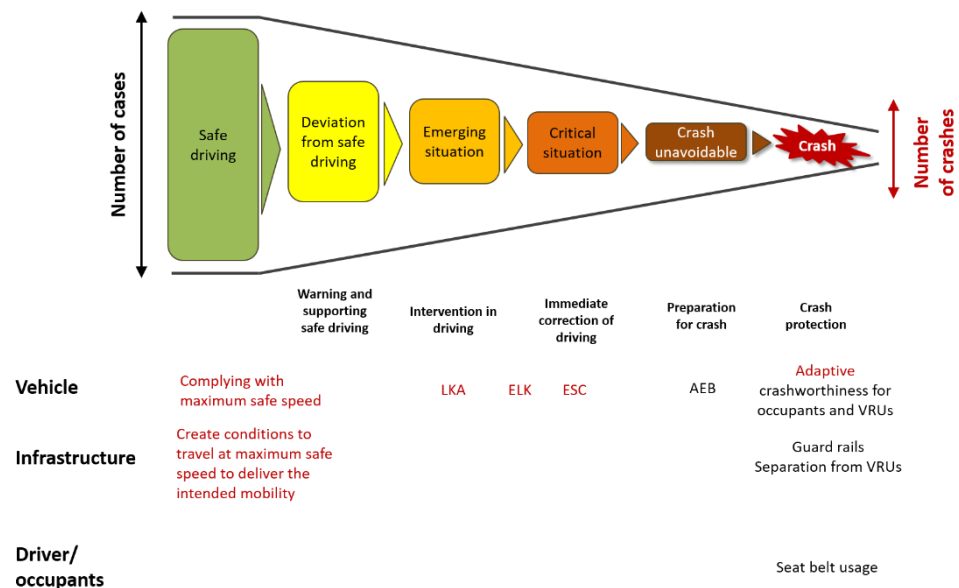


Figure 3. Present work illustrated with the chain of events leading to a crash. Differences with Eugensson et al. (2011) are highlighted with red text.

LOAD CASES

Rear-end collisions

The vast majority of rear-end crashes occur between an approaching vehicle and a still standing or a moving vehicle. In order to study the ability of vehicle seats to prevent long-term whiplash symptoms, rear-end crash tests are conducted by Euro NCAP at a delta V of 16 km/h using a triangular pulse shape. Most vehicle models perform well in these tests. Studies of real-world crashes have shown that the majority of rear-end crashes occur at relatively low speeds and with a low resulting delta V, below 10 km/h (Kullgren and Stigson, 2011). It has also been shown that crashes resulting in long-term whiplash symptoms among the occupants of the struck vehicle usually occur at a delta V above 15 km/h. Also, 15 km/h has been reported to correspond to a 10% risk of long-term symptoms (Kullgren and Stigson, 2011). If the threshold for acceptable risk is set at 10%, the

relative speed between vehicles (of the same mass) in rear-end crashes should be kept below 30 km/h. However, it should be noted that the mentioned results show average risks for the population. The literature shows that many variables may influence the risk of sustaining long-term symptoms after rear-end crashes such as age, gender, stature, weight, seating position, vehicle or seat type, occupant head orientation etc. (Jakobson 2004, 2005; Krafft et al., 1996; Kullgren and Stigson, 2011).

In addition to seats designed to prevent whiplash symptoms, AEB systems fitted to the striking vehicles are expected to be the most important safety technology to avoid injuries in rear-end crashes, either by preventing the crash or by mitigating the crash severity. In 2030 all new passenger cars in Europe are expected to be fitted with AEB technologies aimed to avoid or mitigate crashes with other vehicles travelling in the same direction, both for low-speed and high-speed crashes. The AEB systems can detect both still standing and moving vehicles in the same direction. In 2030, new heavy vehicles (HV) and buses are also expected to have better detection of stationary and moving vehicles compared to the situation today. Studies have shown that first generation AEB technologies, implemented in the last decade, reduce the risk to strike the rear of another vehicle by 38% (Fildes et al., 2015; Rizzi et al., 2014).

An important aspect regarding avoiding rear-end crashes between vehicles travelling in the same direction is that the approaching vehicle must keep the distance of at least the sensor horizon of three seconds to give the AEB system a possibility to react if an unexpected hazardous situation should occur. It is expected that cars of MY 2030 will also have digital maps and GPS positioning that provide the possibility to have a three second headway distance, even in the case of sharp road curvatures and road crests. Cars are also expected to have radar sensors in the vehicle corners.

Hereby, predictable rear-end collisions are expected to be prevented leaving only a very small number of unpredictable rear-end crashes, e.g. scenarios with sudden maneuvers due to system override and sensor errors. A study based on the performance of current advanced vehicle safety technology showed that after full implementation, rear-end crashes will approximately account for 5-10 % of all crashes leading to an injury (Östling et al., 2019a; Östling et al., 2019b). Even though it is expected that this residual will be even further reduced by 2030, the relative velocity in case of a hazardous situation should be kept within the effective envelope of whiplash protections, not exceeding 30 km/h.

Frontal car-car and car-HV collisions

Head-on collisions are expected to occur with MY 2030 vehicles. Narrow undivided roads without mid-separation will allow for sudden and unforeseeable lane departures into opposing traffic, even with advanced lane support and AEB systems, for example on icy roads, as a consequence of technical failures or drivers overriding lateral control systems.

Recent studies estimating residual crashes confirm the expectation of the persistence of head-on collisions. Östling et al. (2019b) found head-on collisions to currently account for 10-12% of crashes leading to AIS2+ injuries; after introduction of ADAS including Driver initiated Evasive Steering Assist (ESA) and Lane Keep Assist (LKA), head-on collisions are still expected to account for 7-12%. Östling et al. (2019a) similarly estimated AIS 2+ injuries occurring in lane departure - opposite direction crashes to reduce from 11% to 6% with ADAS, but not be eliminated.

While steering is in principle more effective in avoiding head-on crashes at high speeds (Brännström et al., 2014), the available road space may not always be sufficient. Roads may simply not be wide enough to avoid an oncoming vehicle on either side. With emergency steering not always being effective, emergency braking appears the avoidance maneuver of choice, which is expected to mitigate crash severity rather than avoid head-on collisions altogether.

Full width frontal impacts against a rigid barrier in consumer ratings are conducted at 50 to 56 km/h. Offset deformable barrier tests are commonly conducted at 64 km/h, replicating a head-on collision at 50 km/h impact speed for both collision partners (Euro NCAP, 2022) and the Insurance Institute for Highway Safety (IIHS) small overlap test is also conducted at 64 km/h. Many passenger cars get good to excellent safety ratings in the IIHS tests. Higher test speeds in IIHS crash tests correspond to an increase in injury risk, with a 15% risk of AIS3+ injury at 64 km/h impact speed and increasing to 59% at 80 km/h and 78% at 90 km/h (Kim et al., 2021).

Doecke et al. (2021) suggest a 10% risk of serious injury at 53 km/h impact speed (calculated as half the closing speed between the two vehicles meeting head-on) based on US field data, and a 1% risk at 28 km/h and a 50%

risk at 76 km/h. Stigson et al. (2012) estimated a 10% MAIS2+ injury risk at a delta V of 28 km/h based on analysis of Swedish on-board crash recorder.

It is anticipated that crashworthiness and restraint systems will get better (Kullgren et al., 2019), to the level where we believe that an impact speed of 60 km/h (a closing speed of 120 km/h) in a head-on collision with an equivalent and compatible passenger car of MY 2030 will be safe enough to avoid serious injuries.

AEB is expected to reduce impact speeds in imminent head-on crashes. However, trajectories can change suddenly and turn a harmless passing scenario into a crash scenario very quickly, especially considering small overlap crashes. The TTC at which a collision becomes unavoidable and triggers AEB, if detected correctly, can be very small even for the simpler rear-end crashes (Spitzhüttl and Liers, 2019). Short TTCs at activation translate into small speed reductions. It was expected that a reasonable performance for head-on AEB in vehicles of MY 2030 is a 20 km/h speed reduction, for reasonably large overlaps and as assuming a TTC judgment of 1.0 second in average (Hasegawea et al., 2017). Aggressive AEB systems with sensitive threat assessment and performance brakes may very well reduce more speed in large overlap situations. For small overlaps and systems optimized to prevent false positive activations, substantial speed reductions will be hard to achieve.

Therefore, we suggest a travel speed of up to 80 km/h (60 km/h allowable impact speed + 20 km/h speed reduction by AEB) on roads without mid-separation where passenger cars could crash head-on. Optimal road friction needs to be provided, AEB systems need to be developed and tested for small-overlap head-on collisions to prove their ability to reliably reduce speed by 20 km/h, and crashworthiness and occupant protection needs to improve particularly in small overlap crashes to provide protection at speeds of 60 km/h and above in case AEB fails to sufficiently mitigate or avoid the collision.

Head-on crashes with incompatible and divergent vehicles, such as heavy vehicles (HV), remain challenging. In crashes with HV, a delta V of 60 km/h for the passenger car is assumed manageable; therefore, both the HV and the car can be allowed to impact at 30 km/h each, only. Strandroth et al. (2012) analyzed car-to-HV crashes in Sweden concluding that an average delta V reduction for the passenger car of 18 km/h with braking only on the HV and 30 km/h with braking also on the passenger car can be achieved. The performance is expected to increase to a speed reduction of 20 km/h before impact for both the car and the HV. We suggest a travel speed of 50 km/h for both the passenger cars and HV where they can meet in opposing traffic without suitable mid-separation given that both are equipped with performant AEB.

Side collisions

Side collisions car-car and car-HV: in Sweden crashes at intersections are the third most common crash type for passenger car fatalities (Trafikanalys 2020). In the European Union, 18% of fatal crashes occur in intersections (ERSO 2021). In the United States, side impacts accounted for 23% of all passenger vehicle fatalities in 2020 (IIHS 2021).

Due to the basic design of a car, today and for the foreseeable future, an occupant is least protected when the car is impacted from the side. Theoretically, with infrastructure measures such as roundabouts, traffic-signs or signal controls at intersections, and with vehicles designed to obey the signals (i.e. connected vehicles) and not lose control due to ESC, vehicles would only impact in the longitudinal direction. However, in situations where vehicles need to leave or enter a main road without the safety measure of a roundabout, further development of ADAS is needed and the sensor set needs to monitor 360 degrees. Side impacts occur typically in intersections (straight crossing path, SCP), in left turns across path (LTAP) and in loss of control.

Loss of control (LOC) crashes have decreased dramatically with ESC systems, and especially the LOC type where the vehicle oversteers, and the side is exposed to other vehicles (Lie 2012). When we move towards more assisted driving and connected vehicles (vehicle to vehicle - V2V, vehicle to infrastructure - V2I) where unsafe speeds due to a mismatch between speed and road friction can be avoided, it is believed that LOC crashes with other vehicles can more or less be eliminated.

In LTAP crashes, the struck vehicle typically decelerates close to or to a full stop on a rural road, before initiating a left turn. If drivers fail to recognize the oncoming vehicle, they may proceed the left turn from this low speed to expose the right side to the oncoming car. There are already systems in production that can detect an oncoming vehicle (including Powered Two Wheelers, PTW) up to 60 km/h for a still standing ego vehicle and brake the car to prevent the turn. This is also driven by AEB test protocols in Euro NCAP.

The SCP is the remaining scenario and likely the most challenging one in the future. Straight crossing path will be difficult even with advanced sensors due to limited sight lines and also because of the large sensor field of view necessary. Besides, vehicles obeying a stop sign, for example, will still have a risk entering an intersection exposed for an oncoming vehicle from either side. From a timing perspective it is challenging for the oncoming vehicle to reduce the speed automatically to a large extent (AEB with forward looking sensors). On the other hand, it is less challenging for the straight crossing vehicle to be automatically stopped from entering the intersection due to sensors looking to the sides. It seems this technology is possible to scale at least for speeds up to 60 km/h of the oncoming vehicles. This is also supported by a new upcoming test in Euro NCAP with this scenario and speed range.

Regarding the maximum impact speeds, it seems that a delta V of 30-40 km/h may be acceptable, based on crash data with modern cars with high NCAP adult occupant rating (Lubbe et al., 2022). In today's best cars it seems that a delta V of 40 km/h is not feasible, but with almost ten more years of development and increased test requirements in NCAP, it is reasonable to believe that this should be achievable for car-to-car impacts. With an acceptable delta V of 40 km/h and the fact that the cars being considered here are ranging in weight from 1500 to 3500 kg, it seems feasible that a 60 km/h travel speed for cars could be managed. As for HVs the weight difference to cars means that they can never travel faster than 40 km/h through a 3 or 4-way intersection.

Side collisions PTW-to-car: worldwide at least half of the 1.35 million traffic fatalities yearly are vulnerable road users. The largest group of these are Powered-Two-Wheeler (PTW) riders, which make up 28% of all road traffic fatalities (WHO 2018). In Europe, this group makes up 15% of fatalities in road traffic, and although there has been a reduction in PTW fatalities in Europe, it has been a slower decline than for overall traffic fatalities (ERSO 2021). Sweden has a similar trend to Europe (STA 2021).

Crashes at intersections are among the most common scenarios with severe and fatal injuries (Fredriksson and Sui 2015, 2016; Puthan et al., 2021). Impact speed, alongside other factors, has been shown to strongly influence injury and fatality outcomes for motorcyclists (Ding et al., 2019). With regard to car-to-PTW collisions in Sweden, crashes at intersections are the most common crash type. In 85% of these, a car crosses the PTWs path in the SCP or LTAP scenarios (STA 2016a).

Compared to other vehicle types, it is more difficult to predict potential new safety systems for PTWs implemented by 2030. Although the implementation of airbags on PTWs is still very limited, the technology seems to be mature (Aikyo et al., 2015) for full-scale implementation. Similarly, research on rear-end AEB for PTWs has been ongoing for several years (Savino et al., 2020; Lucci et al., 2021). We do not expect non-overridable Intelligent Speed Assist will be standard by natural evolution. We foresee that PTWs of MY 2030 may be equipped with a frontal airbag and AEB for rear-end scenarios, but the implementation rate remains unclear.

In intersection crashes, the PTW typically impacts the side of a crossing vehicle. Using risk curves based on traditional motorcycles (Ding et al., 2019) with a helmeted PTW rider, and even with the best-case added protection from a PTW airbag we estimate that 40 km/h is the maximum acceptable impact speed. It is therefore suggested that maximum speed for a PTW through an intersection should be 40 km/h, although this may not confer a very low fatality and injury risk.

Collisions with pedestrians and bicyclists

Collisions between cars and pedestrians are to be avoided altogether. Injuries and even fatalities can occur at very low collision speeds (Hussain et al., 2019) and it appears necessary to emphasize the need to guarantee the freedom from danger for pedestrians. Pedestrians pose very little hazard to other road users, and in collisions between cars and pedestrians it is typically the pedestrian that gets injured, not the car occupant. Thus, the need for pedestrians to be protected from cars over the demand for mobility of cars must be emphasized.

In areas where cars and pedestrians mix, inner city streets or pedestrian streets, and the movements of pedestrians cannot be predicted with certainty, walking speed, i.e. 5 to 7 km/h, appears suitable to guarantee that a driver, or alternatively an automated collision avoidance system, can detect and react to suddenly manifesting collision threats.

Mixed traffic not only includes intentionally mixed traffic on the same surface areas, but also areas where pedestrians can remain undetected while in close proximity to a motor vehicle lane and may suddenly appear when attempting to cross the lane. Besides obstructed sight lines, pedestrian collisions also occur in conditions such as night with glare from streetlights and other participants or rain may impair detection (Wisch et al., 2013).

These sudden appearances may leave very little time to react, with a substantial number of detections below one second TTC and exceeding AEB ability to prevent a collision (Jeppsson et al., 2018). Therefore, in areas with pedestrian traffic and view obstacles such as parked cars along the curb, the car speed must remain at 5-7 km/h to enable the driver or the automated emergency braking system to avoid a collision.

If there is a clear separation between motor vehicle traffic and the view is not obstructed, travel speed may be allowed to increase. If it can be predicted with certainty that pedestrian movements cannot lead to collisions within one to two seconds, a driving speed of 40 km/h should be manageable. That could mean in practice, if the absence of pedestrians within a sufficiently large sensor horizon is guaranteed, then cars can travel at 40 km/h. If the absence cannot be guaranteed, the driving speed needs to decrease proportionally to the possibility of a pedestrian to reach the driving path, and in the end, again to 5-7 km/h.

Collisions between cars and cyclists are more challenging as cyclists can move faster and more often share the same road space with cars. Guaranteeing no cyclist being able to reach the driving path of a car in crossing and turning scenarios requires larger sensor detection areas. When interactions between cyclists and car drivers can occur in longitudinal traffic, lateral distances become crucial. If sufficient lateral distance is not ensured, sudden lateral movements of the bicycle (sudden side winds, the rider attempting to avoid sudden obstacles on the road or starting to turn left not noticing the car) can bring the bicycle quickly in front of the car or directly cause collisions with the side of the car. Guaranteeing absence of collisions appears not feasible; therefore, a mix between speed reduction and injury reduction measures are needed.

We expect that at 20 km/h closing speed, appropriate measures on the car (softened front and side structures; external airbags) (Hu and Klinich, 2012; Fredriksson et al., 2015), and protective equipment for the cyclists (e.g. helmets; Oliver and Creighton (2017)), ideally in combination, can prevent serious injuries (Pipkorn et al., 2020). Forgiving road surfaces for secondary impacts may also be needed. Euro NCAP assesses AEB for cyclists up to a car speed of 60 km/h in straight-crossing scenarios and up to 20 km/h in turning scenarios. We expect that AEB on cars can reliably reduce crash speed by 20 km/h in all intersection scenarios if visibility is assured. Therefore, a 40 km/h traveling speed for cars (and no limit for cyclists) in intersections with good visibility appears suitable also to protect cyclists.

In longitudinal scenarios, pre-impact kinematics appear more complex, and collisions are perhaps harder to predict. While Euro NCAP assesses AEB in longitudinal scenarios where the cyclist is lined up to be hit by the center of the car front, smaller overlaps (i.e., the cyclist more on the side) are not assessed for AEB, but Forward Collision Warning (FCW) only. In line with the complexity assumed for head-on collision between cars, a speed reduction of 20 km/h appears to be a realistic performance for AEB in longitudinal car and bicycle encounters. Therefore, car speed should be limited to 40 km/h if absence of a cyclist on the road cannot be reliably concluded by the car's sensors.

Lateral control systems may further alleviate risks but require sufficient lateral space to be available to steer away from collisions. It appears impossible to guarantee sufficient space, especially on narrow roads with oncoming traffic. If speeds higher than 40 km/h are desired, it appears necessary to physically separate car and cycle lanes.

There is no safe speed for HVs running over vulnerable road users in a first or subsequent impact; collisions must either be avoided altogether or the vehicle geometry must be altered, with gaps either closed permanently or with deployable structures on impact (TRL 2018). With automated collision avoidance systems, for longitudinal and turning scenarios, and run-over protection implemented for HVs, walking speed, i.e. 5-7 km/h, is expected to be manageable.

Collisions with fixed objects/run off road crashes

Single vehicle run off road crashes are, together with head-on crashes, the most common crash scenario involving passenger cars. The proportion of fatal single vehicle crashes varies in the EU countries between 22% and 41% with an average of 31%, while the proportion of single vehicle crashes with MAIS 3+ injuries vary between 22% and 49% (ERSO 2018). While the absolute number of severe single vehicle crashes has decreased over the last 10 years in the EU, the proportion has been rather constant (ERSO 2018). Predictive analysis undertaken in the review of the Swedish road safety targets also suggests that single vehicle crashes will continue to represent a majority of the overall road trauma in the coming decades, even when considering the benefit realization of current and emerging vehicle safety technologies (STA 2016b).

Single vehicle crashes normally start in a lane departure due to loss of control, an evasive maneuver, a vehicle failure, or just an unintentional deviation from the lane. Given the fitment of LKA, Emergency Lane Keeping (ELK) and ESC, the conservative approach would be to assume that scenarios with evasive maneuvers, vehicle failures and unreadable road edge lines would still be in the residual. Following the lane departure, single vehicle crashes come with a variety of crash scenarios including rollovers as well as front and side collisions with frangible and fixed objects. Hence, it is challenging to reproduce a representable single vehicle crash due to the large variation. The unpredictable nature of single vehicle crashes is also depicted by the comparatively flat risk curve in Doecke et al. (2021), that seeks to illustrate the relationship between travel speed and risk for a fatal or serious injury (MAIS 3+).

The safe travel speed with regards to single vehicle crashes will depend on two aspects primarily.

First, the availability of infrastructure elements aimed at preventing run off road crashes. Paved shoulders in combination with line markings and Audio Tactile Line Markings (ATLM) have shown to be effective in reducing run off road crashes by 20-30% (Turner et al., 2010). However, to effectively reduce the majority of all run off road crashes, including those involving loss of control, flexible roadside barriers may be the only viable option with a reduction of serious injuries in this crash type on high-speed rural roads of approximately 90% (Candappa et al., 2011). Hence, even with ADAS technologies, from a single vehicle run off road perspective the speed limit could be set to at least 100 km/h on routes with continuous flexible roadside barriers installed.

Second, in the case with no roadside barriers installed, the travel speed must be adjusted according to the characteristics of the roadside area and the vehicles' ability to read or predict the roadside area. One approach in deriving the boundary conditions would be to design them around the worst-case scenario, which is represented in the Euro NCAP test protocols by a pole side impact at 30 km/h. Side collisions with fixed narrow objects naturally come with specific challenges due to the concentration of energy and the high level of intrusion to the occupant compartment. A strict boundary condition could therefore be based on the acceptable impact speed for side impacts against fixed narrow objects, typically trees and poles. The same rationale could be applied to rollovers resulting in collisions with fixed narrow objects.

A more common scenario though, would be for mid to high volume rural roads to comply with road design guidelines suggesting a roadside area to have a few meters of clear zone, accompanied by a slope of 1/3 or 1/4 depending on the desired degree of mobility. If the stricter boundary condition including rollovers into narrow fixed objects close to the road edge would require an impact speed not higher than 30 km/h, a rural road complying with most road design guidelines could probably allow for the vehicle to leave the road at around 60 km/h. The rationale behind this would be the vehicles' ability to protect the occupants in a rollover at this speed, or the vehicles' ability to use the clear zone to reduce the travel speed at least 30 km/h before potentially hitting a fixed object.

An intermediate scenario could be represented by an undivided road with a roadside area free from hazardous objects, with a slope designed to prevent rollover crashes, and with predictable friction and a non-obstructed view in the sensor horizon. In this case the speed limit could be set with the boundary conditions for the head-on crash load case in mind, i.e. a maximum travel speed of 80 km/h.

Collisions with moose/large animals

Passenger cars are generally not designed to withstand an impact with a moose or other larger animals at high speeds. Moose collisions involve high loads on the vehicle structure and are not included in standardized crash tests. Furthermore, these collisions do not engage the main structure of the car front-end: the moose often directly hits the windscreen area, which is a weak part of the car structure (Björnstig et al., 1984; Lövsund et al., 1989; Williams and Wells 2005). The crash severity in terms of delta V is generally low in these collisions, typically 8-15 km/h even at high speeds (Jakobson et al., 2015). In this delta V range, the probability of an airbag deployment is low (Hussain et al., 2006). Moose crash tests with cars show that interior intrusion can be extensive (Krafft et al., 2011; Jakobson et al., 2015).

An effective countermeasure to reduce collisions with moose and other large animals is a fence aimed at preventing their access to the road. Studies have shown a crash reduction of up to 80% on roads with such fences (Lavsund and Sandegren 1991). The use of road fencing has so far been prioritized on high volume and high-speed roads.

It is anticipated that further development of crashworthiness in this load case is not likely to be significantly pushed by legislation or NCAPs in the near future. Previous crash tests have suggested that the impact speed

should not exceed 70 km/h to be survivable (Ydenius et al., 2017). Based on this conclusion, the maximum acceptable impact speed against a moose might be set at 60 km/h to also help prevent severe injuries.

Previous studies report that 90% of fatal crashes with a moose occur in darkness or twilight (Ydenius et al., 2017). By 2030, it is expected that AEB detection of moose and other large animals will be improved in difficult lighting conditions and that the maximum pre-crash speed reduction could be 20 km/h. The 20 km/h is based on the same rationale as the pre-crash speed reduction in head-on crashes also with low TTC. This would also require sufficient sight lines in the roadside area to ensure a timely AEB triggering.

In summary, the maximum traveling speed should be 60 km/h on roads without wildlife fencing or without sufficient sight lines on the roadside. If the roadside area is sufficiently cleared from obstructing objects, thus increasing the chance of AEB triggering, the traveling speed could be increased to 80 km/h. This would also be beneficial for the maximum traveling speed for run off road crashes.

Summary of results

Figure 4 summarizes the maximum traveling and impact speeds for each specific load case.







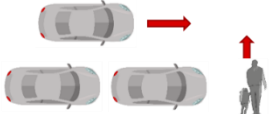
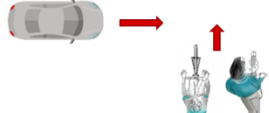
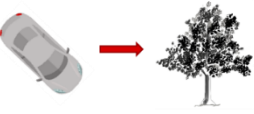

	Maximum acceptable impact speed (km/h)	Maximum safe travelling speed with optimal sight and road friction (km/h)
	dV 15	110
	60	80
	30	50
	40	40
	60	60
	40	40
	0	5-7
	20	40
	30	60
	60	80

Figure 4. Summary of maximum impact and traveling speeds for the included load cases.

The load cases in this work, summarized in Figure 4, can be grouped in three main areas of road user interactions similar to Truong et al. (2022):

- Vehicle priority areas where movement of people and goods is main priority, typically rural and semi-rural midblock sections and intersections,
- mixed traffic urban areas where motor vehicle through-traffic interact with intersecting vulnerable road users and active transport,
- pedestrian priority areas.

Starting with pedestrian priority areas, this work supports the idea that motor vehicles in this space will travel unconditionally with pedestrian movements as the limiting parameter. As a result, the travel speed in pedestrian priority areas is still assumed to be very low, 5-7 km/h, even with vehicles of MY 2030 equipped with AEB for vulnerable road users.

As for mixed traffic areas, motor vehicles are expected to be able to travel somewhat faster due to a more controlled interaction with vulnerable road users, primarily through dedicated and separated bike lanes and pedestrian crossings. The suggested maximum travel speed of 40 km/h, however, assumes no obstructed sensor sightlines, e.g. due to parked vehicles along the sidewalk.

Vehicle priority areas include the other five load cases (rear-end, head-on, side impacts, single-vehicle and large animals) and thereby require a more comprehensive system analysis for the road manager to set safe and appropriate speed limits on a route basis. On high functioning routes, speeds can be set to 100 km/h and above to accommodate high movement needs, if vehicles are separated from other oncoming vehicles, the roadside area is fitted with barriers and access points and intersections are grade separated. However, without physical separation, safe traffic needs to be accommodated by adapting travel speeds to the vehicle's ability to protect the occupants.

On a typical mid-block section, applicable for the load cases of head-on crashes, single vehicle crashes, rear-end crashes and collisions with large animals, the maximum common travel speed would be 80 km/h. However, there might be exceptions due to oncoming HVs or a hazardous and unpredictable roadside area that would require temporarily lower travel speeds at 50 or 60 km/h. Naturally, the maximum travel speed would also decrease if the available road friction was not optimal. Vehicle conflicts in uncontrolled intersections, especially between vehicles with large mass differences are expected to be one of the more challenging load cases. Due to the unpredictable nature of crossing vehicles, and the AEB systems' inability to fully detect oncoming vehicles at high speed from the side, a maximum travel speed of 60 km/h was deemed as safe, or 40 km/h if HVs or PTWs are involved.

The expert group concluded that the recommended travel speeds in the road transport system containing only motor vehicles of MY 2030 and beyond would be:

- 5-7 km/h in pedestrian priority areas,
- 40 km/h in mixed traffic urban areas,
- 50 to 80 km/h on roads without mid- and road side barriers,
- 100+ km/h on roads with continuous mid- and roadside barriers,
- 40 to 60 km/h in at grade uncontrolled intersections depending on mass differences to be accommodated.

While these recommended travel speeds are still based on the expected injury risk in the event of a crash, in line with Vision Zero, it is also stressed in this work that the frequency of crashes is expected to decrease due to the further development and implementation of ADAS. However, the reduction of crashes is not expected to be constant across the included load cases. This aspect is conceptually illustrated in Figure 5, with two examples where the "funnel" representing the number of cases between the safe driving phase and the crash has different sizes. Crashes with pedestrians are expected to essentially be eliminated (Figure 5 lower) while head-on collisions will still occur, although at a lower rate than today (Figure 5 upper). Although human crash tolerance will always be the ultimate boundary condition to guarantee a safe outcome in the event of a crash, it is expected that over time increased performance of vehicle safety systems will prevent a larger and larger proportion of crashes in all load cases.

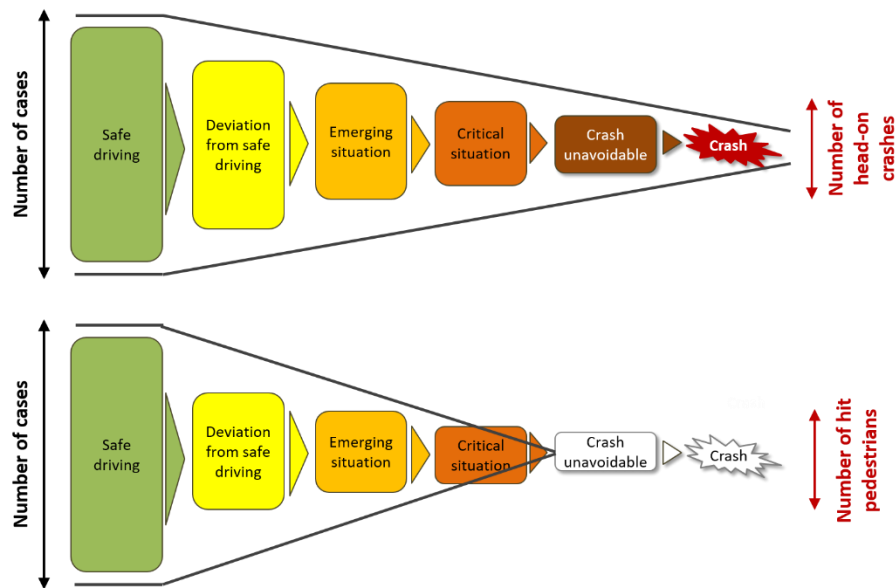


Figure 5. Conceptual illustration of chain of events leading to head-on collisions (upper) or car-pedestrian collisions (lower) with a MY 2030 passenger car.

DISCUSSION

General discussion

Transport policies across the world describe mobility as a function of accessibility and time spent in transport. Time spent in transport is, of course, a function of speed, thus speed limits and speed management form a natural issue to be managed in road infrastructure design and transport planning. The principles in setting speed limits vary across the world and time. The early days saw the “Red Flag Acts” while later, speed choice was solely the decision of the driver. Since many years ago, speed limits have existed more or less everywhere and have been set in accordance with the 85-percentile principle, i.e. the travel speed found appropriate by 85% of drivers. The only significant deviation from this principle has been some sections of the German “Autobahn”, where speed limits have not yet been set.

Today, speed and speed limits would be expected to reflect the safety standard of the road infrastructure (AEG 2020), in relation to the vehicle fleet, and the absence or existence of pedestrians and bicyclists. There is, however, no internationally harmonized framework for speed limits. In September 2020, the UN General Assembly endorsed the Stockholm Declaration where a recommendation was accepted for a maximum of 30 km/h in areas where vulnerable road users and vehicles mix, but the UN framework for road rules still does not deal with speed limits. The speed choice is, as a principle, still left to the driver of the vehicle and expressed as “...able to stop his vehicle within his range of forward vision and short of any foreseeable obstruction...” (UN 1968).

In more general terms, there is a recommendation from the UN to adopt the Safe System Principles meaning that the safety of the road transport system should be based on the human biomechanics tolerance for serious injuries. The idea to describe human injuries as a result of kinetic energy is not new, in fact it can be found as the central theme in the work of Haddon (Haddon 1970, 1980). At that time, few preventative methods were available. Still, the principles are used today as the foundation of safety, and they can be seen to include everything from primary to secondary prevention.

The basic principle behind Vision Zero, sometimes called the Safe System Approach, is to keep the amount of kinetic energy below the threshold for the biomechanical tolerance of the human body (Johansson 2009). This is a step further from general prevention principles as it explicitly attempts to control and limit the amount of kinetic energy. While this principle is quite wide and generic, it guides us to speed management and the protection of the human. By adding layers of protection to the human, road users can be exposed to a higher level of mechanical force, i.e. increase the speed (Corben et al., 2004). These layers can be categorized, where the most inner layer is physical protection of the body in the event of mechanical force directed towards a human. Several layers can be added, and we can also add a layer of reduced mechanical force prior to impact, as well as an overall reduction of kinetic energy by reducing speed (Strandroth 2015; Rizzi 2016).

The first attempt to propose speed limits based solely on the risk of fatality and serious injury which in turn is based on human tolerance to mechanical force, was published in 1996 (Tingvall et al., 1996). In this proposal, the speed limits were based on just a few boundary conditions, in essence the crashworthiness safety standard of a modern passenger car. In 1996, there were no standard cars available with any pre-crash technology that would reduce speed before impact. The road infrastructure safety was limited to separation of oncoming traffic. The next attempt to propose future speed limits was presented in 2011 (Eugensson et al., 2011). With representatives from both infrastructure providers as well as vehicle manufacturers, it aimed at proposing speed limits for future estimated 5-stars cars of MY 2020 or later. In this proposal, the crashworthiness of the passenger car was complemented with pre-crash technologies that would reduce speed before impact. Still, the proposal was based on assumptions of future technology rather than any empirical data, or even availability of the technology that the speed limits were based on. The future safety level of the infrastructure included a widespread use of crash barriers, both medians as well as roadside.

The current proposal of future speed limits goes beyond the two earlier attempts in that 1) it is partly founded in empirical data and 2) incorporates a further layer of safety, impacting the safe driving of the vehicles (see Figures 2 and 3). The assumption that vehicles of MY 2030 would not allow the driver to violate basic road rules could of course be challenged. It is, however, a fair assumption that the safety standard has reached a point that when the vehicle carries information about speed limits, can detect how the driver chooses the traveling speed and would as a consequence support the driver to not violate posted speed limits or even limit the speed, if necessary. The same would apply to drivers not performing in relation to distraction, under influence or fatigue. If, and how, the principle of a vehicle not allowing the driver to exceed fundamental road rules will be introduced is not known. It could be either vehicle regulations or consumer ratings, or both, but it does not seem unlikely that this principle will be well established within the time period up until 2030. While an important step has been taken with mandatory ISA through EU legislation (EU 2021), the development of partly automated driving is ongoing, where basic traffic rules like speed and headway distance would be followed. Thus, the car population would gradually support the driver to at least not exceed posted speed limits and adopt minimum time gaps to other road users.

Another factor related to technical limitation of maximum speed, is geofencing. Such technologies are likely to become more common, both as an initiative from municipalities that wish to control speed within certain areas, but also in organized traffic like freight transport services and public transport. These initiatives would likely stimulate the automotive industry to make non-overridable systems that can react to digital speed data available on the market.

In the boundary conditions for a car of MY 2030, it is considered possible that the car can leave its intended lane into oncoming traffic, or off the road. This might seem unlikely with the technology already existing on today's cars. While it is anticipated that such an event will be rare, it is still included as a load case, as overtaking would still be allowed, and it seems logical that the driver can still override the steering of a car of MY 2030. There are, though, important factors and conditions that reduce the risk of a crash and thus contribute to safety without changing the boundary conditions for speed. One such condition is the availability of machine-readable road signs and road markings. In particular road markings are essential for current and future cars with the ability to stay within the intended lane. Markings with low readability or covered by ice and snow reduce the benefits of lane support technologies.

A more complex condition is road grip, i.e. the result of the interaction of road tires and road friction. This is indeed a critical parameter, as the pre-impact braking is a very significant part of the control of kinetic energy at impact. A reduced road grip as a result of roads covered by snow and ice, and tires with non-optimal characteristics, would have detrimental effects on the ability to brake. This in turn would imply that the road infrastructure provider would have to set a minimum level for road maintenance and the vehicle manufacturer would have to control for the available road friction by autonomously reducing speed if the road grip falls below a specified level.

It is important to stress that the result of this study is to propose safe speeds that seem feasible for a car of MY 2030 or later. It is not a prediction based on empirical data, although such data forms the basis for the assumptions. Empirical data might be based on speed estimates that contain measurement errors and thus impact the quality of the statistical modeling. Still, they offer a useful guide to the current level of understanding of the relationship between speed and injury. They can also be used for finding the effects of reducing speed before impact through technology. For one specific load case, i.e. pedestrians, the biomechanical tolerance has been reduced to zero in the current study. Pedestrians were classified as "objects" that should not be hit at all, meaning

that pre-impact braking should be able to eliminate an impact. This boundary condition is based on the fact that there may not be any harmless collision between a car and a pedestrian. Even at very low impact speeds, the risk of a serious injury is still substantial. The pedestrian can fall to the ground, including being run over by the car. The desire to find a speed that is low enough to avoid hitting a pedestrian does not imply that the pedestrian crashworthiness of the car can be reduced or even removed - there will still be a few crashes where pedestrians will be hit by cars.

Implications

The results of this work show the indicative speeds where safety could be improved significantly through vehicle design and development. This is a guide to the automotive industry, regulative bodies and safety rating bodies, and last but not least, organizations procuring/using cars of different kinds. At the same time, it is also a guide to infrastructure providers and authorities setting speed limits. Roads and streets can be designed and maintained to accommodate vehicles with advanced technologies, and speed limits could be set accordingly. Geofenced limits could set appropriate limits through these indicative safe speeds. The standards of maintenance in terms of friction and readable markings/signs would be highlighted.

It must be stressed, that while the speed limit proposal is built on indicative maximum speed at impact, taking pre-impact braking into the calculation of maximum travel speed, the introduction of a number of other safety technologies would limit the number of crashes that would be relevant for maximum occupant protection. Even technologies like ESC, LKA or ELK greatly reduce the risk of a crash and thus limit the number of cases that lead to the utilization of injury mitigation technologies in a crash. This logic can be clearly seen in the chain of events approach to categorize and analyze the effects of multiple interventions (see Figure 2, 3 and 5). The exposure to potentially serious crashes will clearly be reduced, and this is an important step and development from the first attempt to set logical speed limits based on the safe system principles.

The results should be used to form new guidelines to transport planning, replacing the current practice of setting speed limits based on benefit/cost ratios between travel time and negative impact from safety. These old principles do not seem to be in line with Safe System Principles now adopted across the world (UN 2020). It would even be expected that the regulatory bodies of the UN system (ECE WP1 and alike) set the standards and rules for setting speed limits based on the safety standards conferred by infrastructure and vehicle fleets, alongside regulations for vehicle safety. In the end, speed management is a fundamental metric for the interaction between the vehicle manufacturers and road infrastructure providers.

Limitations and future work

While the present work has a number of important implications for future road safety work, there are a few limitations that are important to note. First, it should be stressed that not all possible load cases involving a passenger car were included (for instance, frontal impacts between passenger cars and PTWs). While several load cases were added, compared with Eugensson et al. (2011), it is still clear that future work should aim at addressing these gaps.

A further limitation is that it is clearly very difficult to know exactly how the road transport system will look like by 2050. A main assumption in this work was that the passenger car, as a means of transportation, will still be part of the road transport system in 2050, one way or another. While this might be debatable, it is also important to stress that this work did not attempt to quantify exposure with passenger cars in 2050 and that the presented results would not be affected by reduced exposure. Therefore, it can still be argued that this work is of relevance as long as passenger cars are used as means of transportation. We do not know to what extent, although we do not need to know that in this particular work.

Finally, it is also important to point out that injury risks are known to increase substantially with age. Crashes at 48 km/h delta V involving male car occupants above 55 years of age, for example, incur a 150% greater risk of producing serious injuries compared to crashes involving younger males (Kononen et al., 2011). High age is associated in particular with increased risk of rib fracture for car occupants and injury risks are known to also increase for cyclists and pedestrians (Wisch et al., 2017). The presented speed limits aimed to ensure a very low risk of fatality or serious injury. This will likely be achievable and achieved for the population of road users with very old individuals still incurring a higher risk of serious to fatal injuries if involved in crashes as a vehicle user.

However, safety for elderly car users must be improved, for example by lowering shoulder belt forces, verified in a regulatory or consumer testing low speed assessment (Digges and Dalmotas, 2007). However, even more drastic measures may be needed to make sure seniors are subject to very low injury and fatality risk similar to mid-aged and younger car occupants. Potentially, the same rearward facing restraint solutions used for children

could be used. Clearly, safety for elderly road users remains a challenge that requires further research into reducing crash and injury risks.

CONCLUSIONS

Human crash tolerance will always be the ultimate boundary condition to guarantee a safe outcome in a crash, in line with Vision Zero and over time, increased performance of vehicle safety systems will be able to prevent a larger and larger proportion of crashes in all load cases. The expert group concluded that the recommended travel speeds in the road transport system containing only motor vehicles of MY 2030 and beyond would be:

- 5-7 km/h in pedestrian priority areas,
- 40 km/h in mixed traffic urban areas, if there are no obstructed sensor sightlines, e.g. due to parked vehicles along the sidewalk,
- 50 to 80 km/h on roads without mid- and roadside barriers,
- 100+ km/h on roads fitted with continuous mid- and roadside barriers,
- 40 to 60 km/h in intersections, depending on vehicle mass differences.

This is a guide to the automotive industry, regulative bodies and safety rating bodies, and last but not least, organizations procuring/using cars of different kinds. At the same time, it is also a guide to infrastructure providers and authorities setting speed limits. Roads and streets can be designed and maintained to accommodate vehicles with advanced technologies, and speed limits could be set accordingly.

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