Determining Safe Speeds

April 2025 v5

About the Road Safety Foundation

The Road Safety Foundation is a UK charity founded in 1986 which advocates for safe and healthy mobility through the adoption of a Safe System. Our recent work focuses on:

- Identifying investment packages likely to give high returns and analysing the safety performance of roads over time.
- Providing the approach, tools and training necessary to support road authorities in taking a proactive approach to road risk reduction.
- Undertaking research to progress knowledge and policy.

Over the last 20 years, the charity has maintained a particular focus on safer road infrastructure through the establishment of the European Road Assessment Programme and the development of the International Road Assessment Programme (iRAP) and its protocols for measuring infrastructure safety. The RSF is responsible for leading the Road Assessment Programme in the United Kingdom, and its work serves as a model of what can be achieved, with key research and innovation being replicated in RAP programmes across the world.

Recently, the charity has:

- Supported the business case for DfT's Safer Roads Fund and then carrying out surveys, support and modelling underpinning the investment of almost £200 million on nearly 100 local A roads in England.
- Provided support and technical insight to Highways England in their SRN-wide iRAP initiative.
- Led the Older Drivers Task Force report with government support to develop the national Older Driver Strategy Supporting Safe Driving into Old Age.

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Revision History

Version number	Date	Description
1.0	8th January 2025	Version sent to experts
2.0	28th February 2025	Revised version sent to experts
3.0	12th March 2025	Draft for consultation
4.0	28th March 2025	Final version
5.0	11th April 2025	Further amendments

Executive Summary

This report highlights the critical role of speed management in creating a Safe System in which road deaths and serious injuries have been eliminated. Grounded in the principles of Vision Zero, which asserts that no loss of life (or life-changing injury) is an acceptable consequence of mobility, this study provides evidence-based definitions of 'safe' speeds for various road types.

Safe System Key Principles

Two of the key principles underpinning a Safe System are:

1. Human Fallibility: Crashes are inevitable due to human limitations.
2. Human Fragility: The human body has limited tolerance of collision forces.

Vehicle speeds are a critical factor in road safety: higher speeds reduce the time that road users have to react to an emerging hazard and increase the energy that needs to be dissipated in the event of a collision. **For a Safe System to be realised, it is essential that speeds in the system are managed so that any collisions that still happen are survivable and do not result in life-changing injuries.** The system has many facets which need to work together: speeds that are 'safe' will depend on a number of factors such as road infrastructure and vehicle design along with the mix of road users.

A reimagined system, designed around human needs, can ensure collisions remain survivable and increase user confidence and comfort.

Challenges with Defining a Safe Speed

Variations in scientific literature regarding safe speeds arise from differences in study assumptions, jurisdictions, timeframes and methodologies. This makes it very difficult for practitioners to assess the applicability of research and inform decision-making. This report therefore synthesises available survivability research and expert input from a workshop to define 'safe' operating speeds for collision types where there is strong evidence.

What is Safe?

Under Vision Zero, there is zero tolerance of death or life-changing injury; however, there is no common definition of a life-changing injury, and identifying 'zero' accurately is not possible. Instead, most studies focus on a 10% risk of a fatal or serious injury corresponding to a score of three or more on the Maximum Abbreviated Injury Scale (MAIS).

It is recognised that, if risks are maintained at these levels, some road deaths and life-changing injuries will still occur; therefore, other parts of the system also need to be improved in parallel with improvements in speed management for a Safe System to be realised.

Key Findings

Based on the latest publicly available research, the evidence-based maximum operating speeds on British roads if most deaths and life-changing injuries are to be avoided are as follows:

- 10mph where there is a particular prevalence of pedestrians and/or bicyclists and/or motorcyclists, or where there is a heightened vulnerability of pedestrians to impact and injury (e.g. around schools, around hospitals, and in the vicinity of major sports or social/cultural events)
- 20mph in other locations where pedestrians and/or bicyclists and/or motorcyclists mix with cars
- 20mph where cars and HGVs mix and where:
    - head-on collisions are possible (i.e. single carriageways) or
    - side impacts are possible (e.g. at T-junctions and crossroads)
- 30mph where head-on collisions and side impacts are possible only between cars

Higher operating speeds may be consistent with a Safe System on roads which have fully segregated facilities for any pedestrians or bicyclists *and* a physical median between opposing directions of flow (including, for example, no T-junctions or crossroads). On these roads (i.e. some dual carriageways including motorways), the priority is to provide adequate roadside infrastructure measures to ensure that road users are suitably protected if they run-off the road at current operating speeds.

Conclusions

The expert panel agreed that those working toward a Safe System should aim for operating speeds where no more than 10% of collisions result in a death or serious injury. Where there is no option to segregate road users of different mass from one another, the speeds required to remain within the 10% threshold are much lower than current operating speeds and often lower than even many road safety professionals might expect. Where these speeds are not implemented, a higher risk of serious or fatal injury is effectively being tolerated.

Translating these findings into policy and practice is complex. Where operating speeds are higher than the speeds identified, the potential strategies are to bring operating speeds down, improve infrastructure provision, or both. Further work is needed to develop comprehensive speed management guidelines.

Delivering a fully Safe System is a long-term endeavour, and full implementation will take time. However, emerging vehicle technologies, including passive safety improvements and active collision-avoidance systems, are expected to help a Safe System to be realised at the operating speeds identified in this paper. Future developments in vehicle technologies may eventually allow for increases in these speeds whilst still remaining within the 10% threshold. As more research becomes available, and as the road system as a whole evolves further, these speeds will warrant further review.

In the meantime, prioritising speed management will substantially reduce fatalities and serious injuries, bringing road systems closer to achieving Vision Zero goals. Any reduction in operating speeds toward the identified ‘safe’ speeds will have a meaningful impact on road safety.

Contents

1. Introduction

A person is killed or seriously injured on Britain's roads every 18 minutes, on average. Many would agree that this is far too frequent. Vision Zero is a long-term aspiration for zero road deaths and serious injuries based on the moral position that no death or serious injury should be considered an acceptable by-product of mobility. The aim of a Safe System is to systematically eliminate the potential for road collisions to result in death or serious injury, and thus to reach zero.

Two of the key principles of a Safe System are that:

1. Human beings are fallible – crashes are inevitable due to the normal attentional, processing and functionality of human beings
2. Human beings are fragile – the human body has limited tolerance of collision forces

These two key principles are normally accompanied by the notion of shared responsibility and the idea that the system should be strengthened so that if one part fails, other parts of the system protect the user.

Managing speed is a key element of any credible road safety approach including the delivery of a Safe System: higher speeds mean that there is less time for road users to react to an emerging hazard, making a collision more likely, and, should a collision occur, more energy needs to be dissipated, resulting in higher severity injuries. Managing speeds so that people can walk away from crashes without serious harm is necessary because of the fallibility and fragility of road users. Rather than road users being expected to navigate a legacy system that has not been designed to fully accommodate the needs of the road user, the system should be re-shaped around the needs of the user. Achieving this would mean the user is able to successfully and safely use the system and feel comfortable in doing so.

The system has many facets; these need to work together to ensure that collisions that do happen are survivable: speeds that are 'safe' will depend on a number of factors such as road infrastructure and vehicle design along with the mix of road users. For example, higher speeds can be permitted under the Safe System where all vehicles are moving in the same direction and non-motorised users are absent, such as on motorways. On single carriageways where head-on crashes are more likely (because there is no physical separation of opposing vehicles) and where side impact crashes are more likely (due to junctions being T-junctions or crossroads, for example), lower speeds are necessary. Speeds need to be lower still where people without the protection offered by a car are present.

1.1 What do we mean by safe?

Injury severity is often measured using the Maximum Abbreviated Injury Scale (MAIS), which corresponds to the most severe injury to the body, and ranges from 1 (a minor injury in the AIS definition) to 6 (maximal or currently untreatable). This is referred to in this paper using, for example, MAIS 3+, to refer to all injuries which are serious (3), severe (4), critical (5) or currently untreatable (6). There is little doubt that a Safe System should systematically eliminate the potential for road death and the most serious life-changing injuries, though there is limited insight available in the literature that reflects only higher levels of severity (e.g. MAIS 4+). Some argue that the elimination of all MAIS 3+ or even MAIS 2+ injuries should be included in the Safe System (noting that some life-changing lower limb injuries can be MAIS 2, i.e. classified as a moderate injury on this particular scale, and even a MAIS 1 minor neck injury can have a long-term impact). The literature indicates that achieving this by managing vehicle speeds alone would be incredibly challenging as the gap between the legacy road network and a system that would prevent all such injuries is considerable. For example, a pedestrian who simply loses their balance and falls over may land awkwardly such that they break a bone and sustain long-term nerve or muscle damage, even without coming into contact with a vehicle.

Therefore, there can be no vehicle speed that results in absolutely zero risk of a serious injury occurring. In all of the literature on speeds which are 'safe', there is subsequently some necessary acceptance of some level of risk of a serious injury. The consensus in the literature is that a 'safe' speed is one at which there is no more than a 10% risk of a fatal or serious injury (MAIS 3+) occurring in the event of a collision. Ten percent is used for practical reasons given limitations implicit in the data used to inform the risk functions: smaller sample sizes at lower thresholds, in terms of the number of MAIS 3+ casualties, make results less reliable.

In 2023, around a quarter of reported injury collisions resulted in someone being killed or seriously injured. Appendix A provides some initial analysis indicating how this proportion has varied over time and how it can vary by road type; further work is required to gain greater insight into how this varies depending on operating speed on different road types.

1.2 Purpose of this work

There are various pieces of scientific literature over the last 20 years based on in-depth collision investigation data analysis that provide insights into the notion of a 'safe' speed. While the literature is extremely informative, some findings initially appear to conflict with one another, and there are differences in approach that mean they will necessarily provide slightly differing results. These include:

- Different inclusion criteria and sampling methods, e.g. most studies exclude cases where occupants were not wearing a seat belt, many exclude roll-overs etc.
- Different jurisdictions with different vehicle standards making some studies more applicable to the UK than others
- Different timeframes of studies, i.e. the age of vehicles typically included in the studies and how current the findings are given changes in the vehicle fleet
- Different severity thresholds for inclusion in analyses (e.g. 10% of all crashes are fatal, or 10% of injury crashes are fatal or serious or …)

- The speed measure against which the results are presented (e.g. delta-v, impact speed, closing speed etc.)

This makes it challenging for road authorities to reliably identify 'safe' speeds for any given set of circumstances.

The aim of this work is to provide road safety practitioners with clear information on operating speeds that are compatible with the Safe System, based on a synopsis of the evidence and expert consensus. This work does not explore the issue of speed *limits* in detail but focusses on operating speeds: operating speeds are affected by numerous factors – the speed limit itself is only one of these.

In this paper, various key pieces of scientific literature on the topic are reviewed with the aim of identifying safe speeds in a variety of circumstances. The literature typically considers collisions in three broad categories:

- Head-on collisions between motorised vehicles
- Near-side impact collisions between motorised vehicles
- Collisions between motorised vehicles and vulnerable road users (i.e. pedestrians and bicyclists)

Most studies consider cars and motorcycles; only a few consider goods vehicles as well.

Note that there is currently insufficient evidence for a 'safe' speed for run-off road collisions. This is likely because run-off road collisions have a greater number of potential variables such as type of object struck, distance from the running lane and angle of collision. This makes it difficult to draw simple conclusions using in-depth collision investigation data; instead, detailed analysis of a given road (e.g. using an iRAP Star Rating survey) would be required. The priority here should therefore be to provide adequate roadside protection to ensure that road users are suitably protected if they leave the road at current operating speeds.

The collision types considered also do not include rear-end shunt collisions since the evidence is relatively poor and what evidence is available would suggest higher permissible 'safe' speeds than for the other collision types in any case. That is, the focus of this work is on roads which have an inherently higher risk given their structure and use (i.e. single carriageways and other roads used by vulnerable road users).

Following on from the literature review, the consensus from an expert workshop is presented.

1.3 Terminology

The **operating speed** is the speed at which traffic travels in free-flowing conditions.

The **impact speed** is the speed of a vehicle *in the impact direction* when the impact occurs.

The **closing speed** is the relative speed between two collision partners (e.g. the sum of the two vehicles' impact speeds in the event of a head-on collision).

Delta-v refers to the change in velocity experienced by a participant in the event of a collision; this is governed by the conservation of momentum, and therefore differences in mass between collision participants are critical.

What does conservation of momentum mean?

When a car hits a pedestrian, the car's speed is unlikely to be very much affected by the impact itself, so its delta-v is likely to be close to zero, while the delta-v of the pedestrian can be assumed to be the speed of the impacting vehicle.

When a car hits the side of a stationary heavy goods vehicle, the heavy goods vehicle is unlikely to move very much while the car probably comes very close to a complete halt. The goods vehicle will have a delta-v of close to zero and the car's delta-v will be very similar to its impact speed.

When one car travelling at 40mph, say, hits the side of another car which is stationary, the car which was moving before the collision is likely to be slowed but not to come to an immediate halt, while the car which was stationary is likely to be moved to some extent. If the two cars are identical, the delta-vs of both vehicles are likely to be about 20mph: one car slowing from 40mph to 20mph, the other increasing from 0mph to 20mph.

In all three scenarios, the car which was moving before the collision has the same weight etc. but its delta-v will differ depending on the relative weight of the other participant in the crash (i.e. the pedestrian, the heavy goods vehicle or the other car).

1.4 Relationship between impact speed, closing speed and delta-v

The closing speed in a two-vehicle collision is the sum of the two vehicles' impact speeds. In a 90^{o} side impact collision between two vehicles, the impact speed of the vehicle with its side being impacted is zero; this means that the closing speed is simply the impact speed of the other vehicle.

Delta-v is the best predictor of injury severity in collisions. In a side impact between two vehicles of equal mass, the delta-vs of both vehicles are typically half of the impact speed of the impacting vehicle (though there may be differences given other factors such as the relative stiffness of the two vehicles). In a head-on collision between two vehicles of equal mass with the same impact speed, the delta-vs are typically the same as the impact speeds. More generally in collisions between vehicles of the same mass, the delta-vs of both vehicles are typically the average of the two vehicles' impact speeds.

When there is a collision between two vehicles of different masses, the lighter vehicle will usually have a higher delta-v than that of the heavier vehicle. That is, the occupants of the lighter vehicle are likely to sustain more severe injuries than would be the case were the other vehicle of the same mass. A 'safe' system takes account of the occupants of the lighter car in a two-car collision, not just the occupants of a car of the same mass (which implicitly also takes account of the occupants of the heavier car). The delta-v of the lighter car in a collision between two cars which differ in mass can typically be up to 20% more than would be the case if the cars had the same mass. See Appendix B for more details.

2. Literature Review

2.1 Wramborg 2005

Per Wramborg's work in this area in Sweden has often been a first point of reference. The earliest citation of this appears to be in his 2005 paper 'A New Approach to a Safe and Sustainable Road Structure and Street Design for Urban Areas'. This included the three graphs shown in Figure 1, Figure 2 and Figure 3.

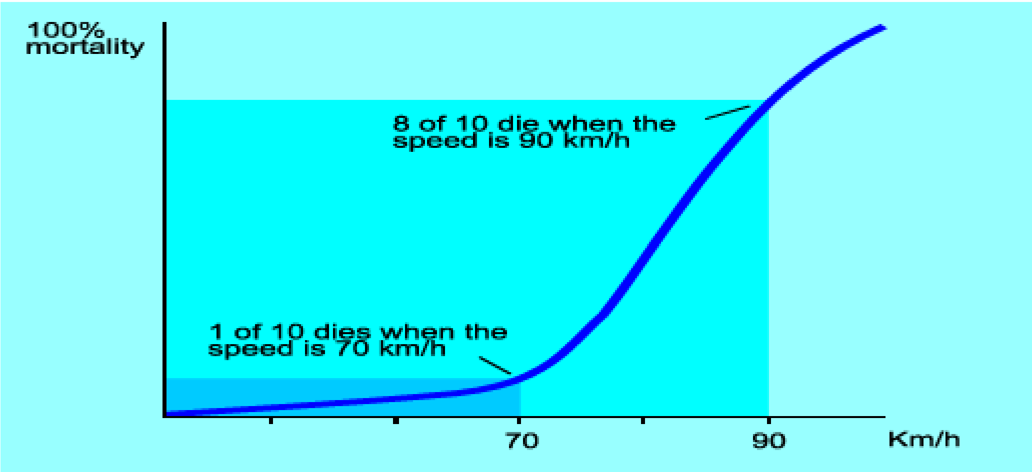


Figure 1 Probability of Car Driver / Passenger Fatality by Head-On Collision (Wramborg 2005)

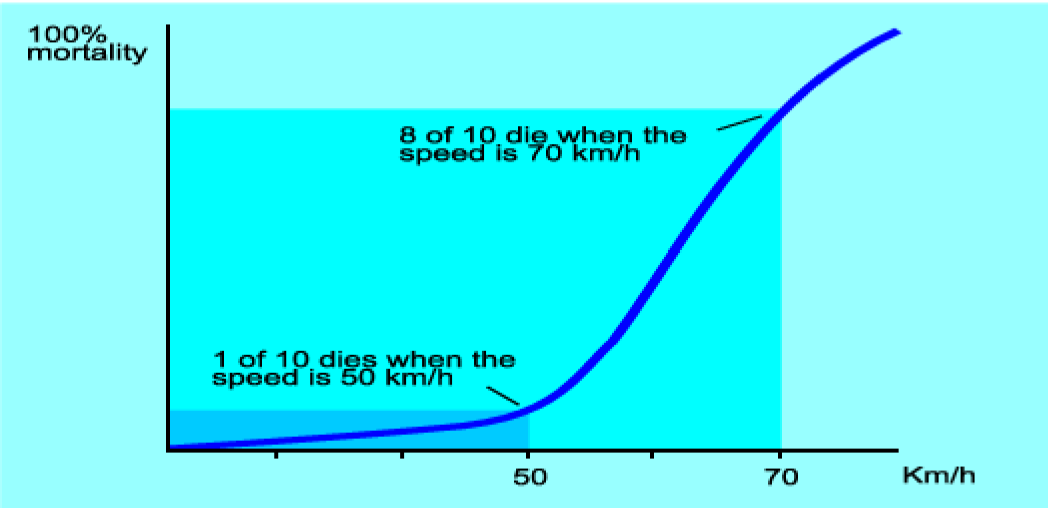


Figure 2 Probability of Car Driver / Passenger Fatality by Side Impact Collision (Wramborg 2005)

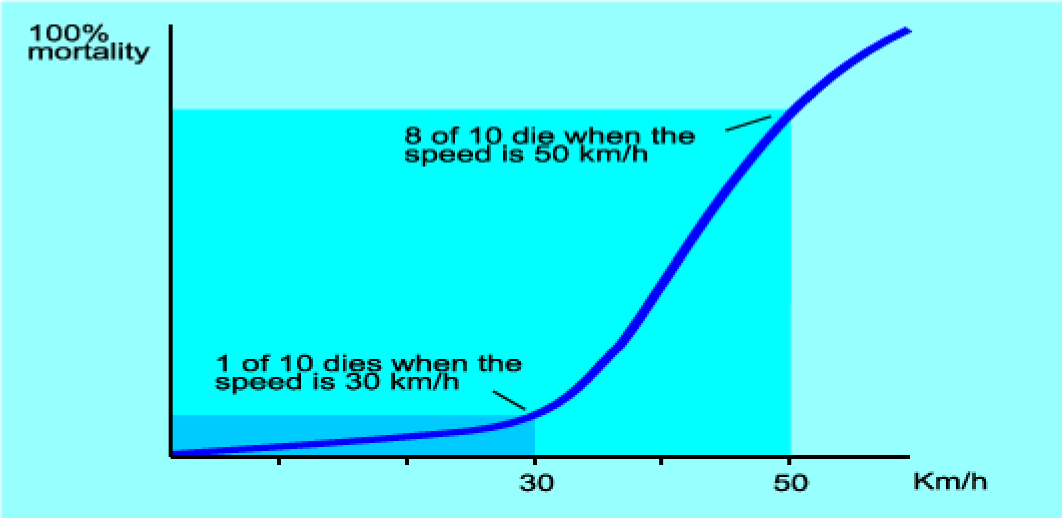


Figure 3 Probability of Pedestrian / Cyclist Fatality by Car Collision (Wramborg 2005)

These graphs have subsequently been presented in various formats over the years and have been interpreted as suggesting the following speed limits should apply:

- 70km/h (approx. 44mph) where head-on collisions are possible, i.e. on single carriageway roads
- 50km/h (approx. 31mph) where side impacts are possible, e.g. at T-junctions and crossroads
- 30km/h (approx. 19mph) where there are pedestrians and/or bicyclists

There are a number of issues with these graphs that make the use of these values in this way questionable. For example,

- The motor vehicles referred to are only cars – motorcycles and larger goods vehicles were not considered
- The underlying data used to produce them is unclear: it is not known, for example, whether these were based only on car occupants who were wearing seat belts, and whether the speeds refer to those at which collisions actually occurred, or the change in speed experienced at the point of impact
- The graphs refer to the probability of death, whereas the Safe System considers both death and serious injury
- In addition, these graphs were first published some 20 years ago, so it is likely that they are based on cars without the same level of safety provision as the vehicle fleet today.

As vehicle technology evolves, and depending how quickly new vehicle safety features penetrate the vehicle fleet, this is likely to be an on-going issue to some extent – the collisions analysed inevitably relate to vehicles in the historic vehicle fleet rather than those in the future vehicle fleet.

2.2 Richards and Cuerden 2009-2010

At TRL, David Richards and Richard Cuerden subsequently carried out similar analyses based on collisions in Great Britain between 2000 and 2009. Their work was published in various places including:

- 'The Relationship between Speed and Car Driver Injury Severity'. Richards and Cuerden (2009)
- 'Relationship between Speed and Risk of Fatal Injury: Pedestrians and Car Occupants'. Richards (2010)

This work used data from the Co-operative Crash Injury Study (CCIS), the On The Spot (OTS) project, and police fatal files; drivers who were not wearing a seat belt were excluded from the analysis, as were vehicle rollovers. (The curves in the two papers are slightly different from one another as more collision data were available by the time of the latter paper.) Collisions resulting in fatalities were analysed, as in Wramborg's work; in addition, those collisions resulting in casualties who were killed or seriously injured (KSI) were analysed in the earlier paper.

The results in the earlier of the two papers were based on 603 injured belted drivers in frontal impacts (64 fatal, 463 serious and 76 slight) and 117 injured belted drivers in side impacts (21 fatal, 75 serious and 21 slight). The results in the latter of the two papers were based on 197 pedestrian casualties (66 fatal, 74 serious and 57 slight), 620 injured belted drivers in frontal impacts (66 fatal, 478 serious and 76 slight), and 118 injured belted drivers in side impacts (21 fatal, 76 serious and 21 slight). In both cases, the results were weighted to be nationally representative given the numbers of collisions in 2005-2007.

For vehicle-vehicle collisions, the speed value used as the independent variable was delta-v. For collisions involving a pedestrian, the impact speed was used and the analysis was restricted to those collisions where the pedestrian's first point of impact was the front of the car; sideswipes, for example, were excluded.

The analysis implicitly assumed that there is a reported injury collision. Collisions at lower speeds are less likely to result in an injury or to be reported to the police so this will, in effect, over-estimate risk at speeds of less than around 15mph.

The results for 'car drivers in frontal impacts with other cars', i.e. head-on collisions between two cars, were as shown in Figure 4.

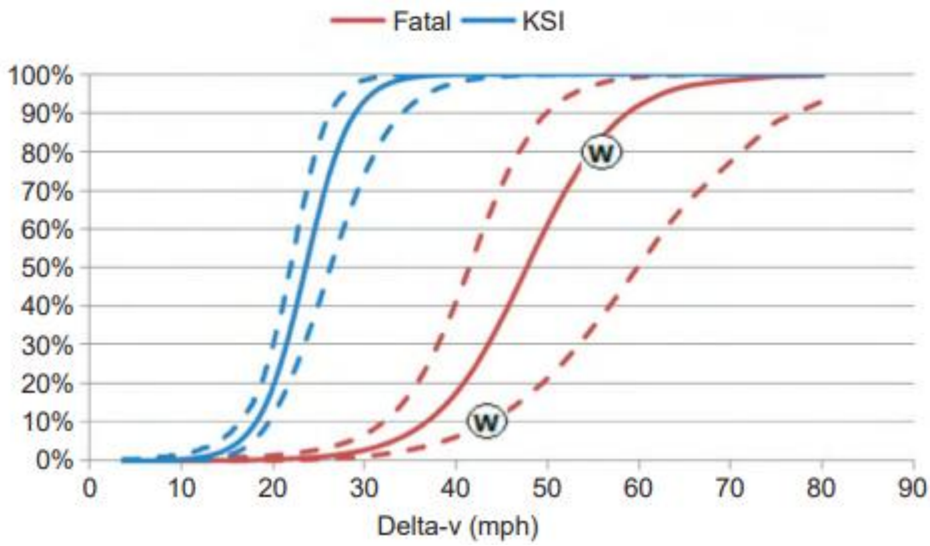


Figure 4 Speed injury risk curve for car drivers in frontal impacts with other cars (Richards and Cuerden 2009)

The solid lines represent the central estimate whereas the dotted lines indicate the confidence intervals around them; the 'W' in circles indicates the values highlighted in Wramborg's equivalent graph. The confidence intervals around the fatal curve are inevitably much wider than those around the KSI curve given that there are many more KSI collisions than fatal collisions alone.

This implies that, for example, if a car is involved in a reported injury head-on collision with another car, has a delta-v of 24mph, and the driver is wearing a seat belt, they have an approximately 50% chance of being killed or seriously injured as a result of the collision. The central values for fatalities at various speeds are as shown in Table 1.

Table 1 Risk of car driver fatality in frontal impact by the delta-v of the impact (Richards 2010)

Delta-v	**30mph**	**40mph**	**50mph**	**60mph**
Killed in frontal impacts	3%	17%	60%	92%

The results for 'drivers in side impacts', i.e. for drivers who were on the side of a car which was struck by another car, were as shown in Figure 5 and Figure 6 – Figure 5 from the earlier paper, Figure 6 from the latter:

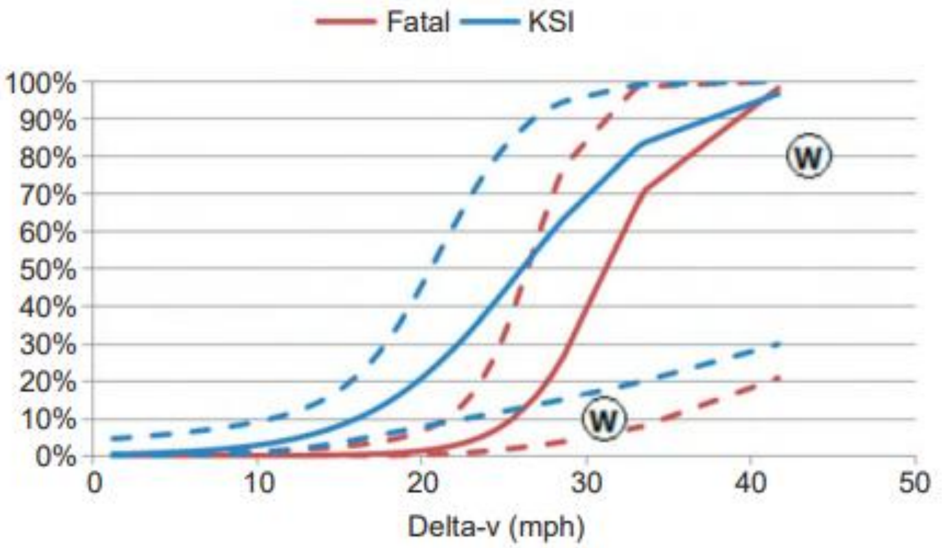


Figure 5 Speed injury risk curve for car drivers in side impacts with other cars (Richards and Cuerden 2009)

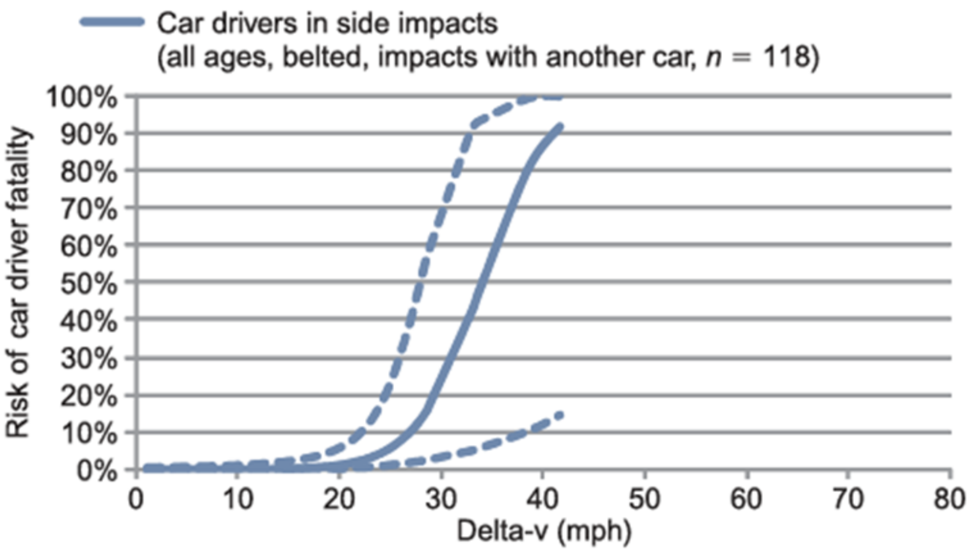


Figure 6 Risk of car driver fatality calculated using logistic regression from the OTS and CCIS dataset (Richards 2010)

The first graph here implies that, for example, if a car is involved in a reported injury side impact collision with another car, has a delta-v of 26mph, and the driver is wearing a seat belt, they have an approximately 50% chance of being killed or seriously injured as a result of the collision. The central values for fatalities at various speeds as shown in the second graph are as shown in Table 2.

Table 2 Risk of car driver fatality in side impact by the delta-v of the impact (Richards 2010)

Delta-v	**30mph**	**40mph**
Killed in side impacts	25%	85%

The results for pedestrian fatalities were as shown in Figure 7.

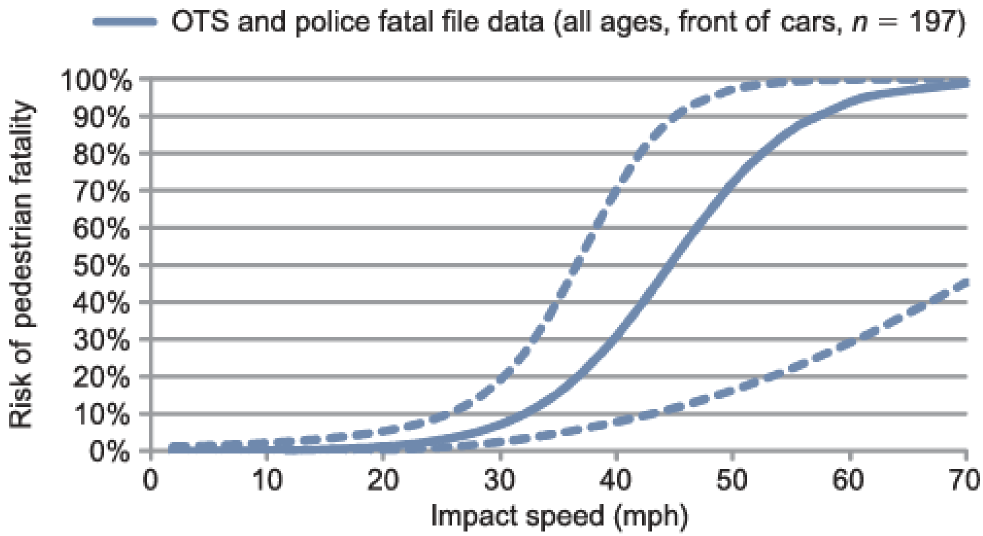


Figure 7 Risk of pedestrian fatality calculated using logistic regression from the OTS and police fatal file dataset (Richards 2010)

The central values for fatalities at various speeds are as shown in Table 3.

Table 3 Risk of pedestrian fatality by the impact speed (Richards 2010)

Delta-v	**30mph**	**40mph**
Pedestrian fatality	7%	31%

This curve is broadly consistent with those which can be derived from other studies, though comparison between different datasets highlights the uncertainty in the curve given all of the different variables that cannot be accounted for by the analysis. Nonetheless, when differentiating between age groups, child pedestrians appear to be at lower fatality risk than those aged 15 or more, while elderly pedestrians have a higher fatality risk than those of other adults.

2.3 Jurewicz et al 2016

Chris Jurewicz and colleagues in Australia have explored the same subject. In 2016, they published a peer-reviewed paper entitled ‘Exploration of Vehicle Impact Speed – Injury Severity Relationships for Application in Safer Road Design’. They looked at the probability of fatal and serious injury, defined as MAIS 3+, given a collision which resulted in damage, or what they call a ‘tow-away event’, based on the results from a series of previous studies from the USA, most notably Bahouth et al (2014).

They considered rear-end collisions and passenger-side collisions as well as the ‘usual’ three collision types. The analysis was restricted to post-2002 vehicle models, to front seat occupants wearing a seat belt aged 16-55, to inelastic collisions between vehicles of equal mass (the pedestrian collision type aside), and excluded secondary collisions and rollovers. The results for collisions between vehicles were as shown in Figure 8.

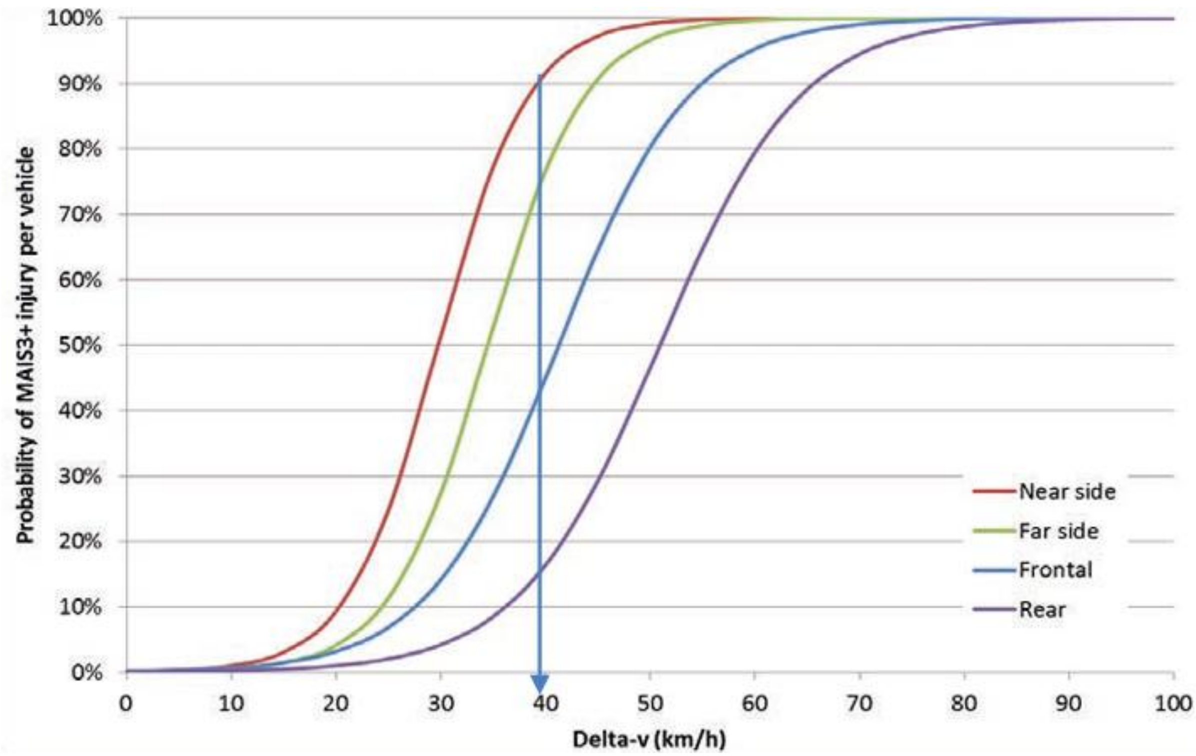


Figure 8 Probability of severe injury of front seat occupants vs. delta-v of a vehicle in a crash (Jurewicz et al 2016)

The approximate impact speed which results in a 10% risk of a fatal or serious injury in a pedestrian-vehicle collision was found to be 20km/h (approx. 12mph). The critical delta-vs in vehicle-vehicle collisions were found to be:

- Head-on: 30km/h (approx. 19mph)
- Near side: 20km/h (approx. 12mph)

- Far side: 24km/h (approx. 15mph) (but lower than 20km/h if a passenger is present)

The authors note that the value for head-on collisions, 30km/h (approx. 19mph), is substantially lower than the equivalent value in Wramborg's work of 70km/h (approx. 44mph). The slightly lower speed in passenger-side collisions when a passenger is present is particularly notable given that most studies focus on only drivers: extra protection is often given to drivers compared to that given to front seat passengers, presumably given that there are fewer front seat passengers than drivers using the road. However, this suggests that speeds may need to be lower than that suggested in some of the literature in relation to side collisions when passengers are prevalent.

2.4 Fitzharris et al 2022

Michael Fitzharris and colleagues at Monash University considered a similar theme. In 2022, they published the 'Enhanced Crash investigation Study (ECIS) – Speed, crash risk and injury severity, ECIS report 2'. This was a peer-reviewed study of Victorian roads in Australia, and the data appear to have been from between mid-2014 and the end of 2016. They also looked at the probability of a MAIS 3+ injury but given that a collision resulted in hospitalisation.

The probability of the driver sustaining a serious injury at different impact speeds in frontal impacts and in side impacts, given the driver was hospitalised, was found to be as shown in Table 4.

Table 4 Probability of a hospitalised driver sustaining a MAIS 3+ injury in a frontal or side impact crash by impact speed (Fitzharris et al 2022)

Impact speed	Frontal	Side
30km/h (approx. 19mph)	34%	43%
50km/h (approx. 31mph)	46%	54%
80km/h (approx. 50mph)	63%	69%
100km/h (approx. 62mph)	74%	77%

In both cases, the relationship was found to be broadly linear within this range of impact speeds. The lowest speeds for which results are presented was 20km/h (approx. 12mph), where the probabilities were both still well above 10%, but given the driver was hospitalised, it is difficult to compare the results with those in other papers.

2.5 Lubbe et al 2022

Nils Lubbe and colleagues at Autoliv also published a peer-reviewed paper in 2022, 'Safe speeds: fatality and injury risks of pedestrians, cyclists, motorcyclists, and car drivers impacting the front of another passenger car as a function of closing speed and age'. Closing speed refers to the relative speed between two collision partners (e.g. the sum of the two vehicles' impact speeds in the event of a head-on collision). They first did a literature review for each of the four types of collision, with the following headlines:

- Hussain et al (2019) carried out a systematic review and meta-analysis relating to pedestrian safety and found that there is a 10% fatality risk for a pedestrian in a collision with a car with an impact speed of 37km/h (23mph)
- Jeppsson and Lubbe (2020) found that there is a 10% fatality risk for a cyclist in a collision with a car with an impact speed of 60km/h (approx. 37mph)
- Ding et al (2019) found that there is a 10% fatality risk for a motorcyclist in a collision with a car at a closing speed of 114km/h (approx. 71mph)
- Doecke et al (2020) found that there is a 10% serious injury risk for a car occupant at a closing speed of 71-108km/h (approx. 44-67mph)

Lubbe et al then analysed data from the German In-Depth Accident Study (GIDAS) relating to collisions involving the relevant vehicle types, from 1999-2020 – GIDAS records a sample of injury collisions though results were weighted to reflect national data.

Collisions involving rollovers were excluded and people who were 14 years old or younger, or whose age was not known, were also excluded. Age was included as a variable in the model, as well as speed. The results were based on 2,477 cyclists, 7,383 drivers, 424 motorcyclists, and 1,242 pedestrians.

They also found that cyclists are typically less likely than pedestrians to sustain lower severity injuries at a given speed. They speculated that this is because of crash helmets, diet, exercise and fitness, and that the bicyclist's injuries were more likely to be from their falling to the ground rather than from direct contact with the car.

Lubbe et al suggested that the recommendations of the Academic Expert Group for the 3rd Global Ministerial Conference on Road Safety indicated that a 10% risk of a MAIS 3+ may be considered a safe speed. They found that a 10% risk of sustaining at-least-serious injuries in a collision involving a passenger car corresponds to the closing speeds shown in Table 5 for a road user of the median age in their data.

Table 5 Closing speed of passenger car corresponding to a 10% MAIS 3+ injury risk for road users of median age (Lubbe et al, 2022)

Road user type (age)	Closing speed
Pedestrians (46)	29km/h (approx. 18mph)
Cyclists (39)	44km/h (approx. 27mph)
Motorcyclists (37)	48km/h (approx. 30mph)
Car drivers (39)	112km/h (approx. 70mph)

That is, they concluded that there was a 10% MAIS 3+ injury risk for a car driver aged 39 in a head-on collision at a closing speed of 112km/h (approx. 70mph) (e.g. both cars having impact speeds of 56km/h (approx. 35mph)).

Although the values here are a little different to those from other studies, the authors explained that they are not inconsistent, as differences in collision type definitions, in cars, and in the people involved in collisions can account for the differences in results. However, this does highlight that there is inevitably a great deal of uncertainty about the values.

They subsequently suggested that safe speed limits would be 25km/h (approx. 16mph) where cars and pedestrians mix, 20-25km/h (approx. 12-16mph) where bicycles or motorcycles mix with cars, and 55km/h (approx. 34mph) where head-on impacts between cars are possible, or 75km/h (approx. 47mph) if all cars are equipped with Automated Emergency Braking (AEB). However, they also noted that injury risk consistently and substantially increased with age; for example, a motorcyclist aged 65 injured in a collision with a car would have a 10% probability of sustaining a MAIS 3+ injury at a closing speed of around 30km/h (approx. 19mph). This implies that lower speed limits may be required where older road users are prevalent.

2.6 Truong et al 2022

Jessica Truong and colleagues at Monash University carried out a thorough literature review for their 2022 peer-reviewed paper entitled 'Utilising Human Crash Tolerance to Design an Interim and Ultimate Safe System for Road Safety'. Truong et al noted that early injury risk curves suffered from under-reporting bias, so over-estimate fatality risk, though the speeds remain relevant to fatal and serious injuries. They also argued that 10% is an appropriate boundary to use as risk curves are challenging to interpret in the lower risk band due to their mathematical construction, making a choice of 0% infeasible. Unlike many of the other papers referenced in this document, Truong et al defined serious injury as MAIS 2+ and/or any whiplash injury resulting in symptoms lasting longer than one month, and severe injury as MAIS 3+ and/or any whiplash injury resulting in symptoms lasting longer than six months.

Truong et al then used the results from various pieces of the reviewed literature including Rosen and Sander (2009), Ding et al (2019), GIDAS (2021), Doecke et al (2021), Autoliv (2021), Krafft et al (2005), and Australasian NCAP (2021), to suggest the values shown in Figure 9.

Crash Type	10% Risk for Serious Injury		10% Risk for Severe Injury	
	Delta-v km/h	Impact Speed km/h	Delta-v km/h	Impact Speed km/h
Car to Pedestrian crash	No impact allowable	No impact allowable	20	20
Car to powered two-wheeler (PTW)	No impact allowable	No impact allowable	30	30
PTW to wide object	N/A	25	N/A	50
PTW to narrow object	No impact allowable	No impact allowable	No impact allowable	No impact allowable
PTW to ground	N/A	N/A	N/A	75
Car to bicyclists	No impact allowable	No impact allowable	20	20
Side Impact–Car to Car (of equal mass)	20	40	30	60
Side Impact–Heavy Vehicle into Car	20	20	30	30
Head On Impact–Car to Car (of equal mass)	25	25	50	50
Head on Impact–Car to Heavy Vehicle	25	10	50	25
Rear End–car to car	10	20	20	40
Rear End–heavy vehicle into car	10	10	20	20

Table based on risk curves on relatively modern vehicles and belted occupants, rounded to the nearest 5 km/h.

Figure 9 Delta-v and Impact Speed with a 10% risk for serious and severe injury for different crash types (Truong et al, 2022)

2.7 Baker et al 2022

Claire Baker and colleagues at Imperial College, London looked specifically at head injuries in their 2022 peer-reviewed paper ‘The relationship between road traffic collisions dynamics and traumatic brain injury pathology’. They used RAIDS data from 2013-2020 for their analysis, focussing on delta-v, the change in velocity, as the speed variable. Rather than using the MAIS scale, however, they used the Mayo classification system for Traumatic Brain Injury (TBI), which has three different classifications:

- Moderate-severe (Definite)
- Mild (Probable)
- Symptomatic (Possible)

Although they did not separate them out in their graphs, Baker et al emphasised that lateral delta-v is more severe than longitudinal delta-v.

They found that, in a collision between a pedestrian and a car with a delta-v of 32km/h (approx. 20mph), on a pedestrian crossing for example, there is a 26% chance of a moderate-severe TBI to the pedestrian; with a delta-v of 48km/h (approx. 30mph), there is a 39% chance of a moderate-severe TBI to the pedestrian.

2.8 Tingvall et al 2022

Claes Tingvall and colleagues at Chalmers University of Technology in Sweden published 'Saving lives beyond 2020: The next steps in 2022'. Having reviewed a wealth of literature, they recommended a speed limit of 30km/h (approx. 19mph) in urban areas in order to protect vulnerable road users. For example, they highlighted that Jurewicz et al (2016) found that serious injury risk begins to increase sharply at 20km/h (approx. 12mph), and that Ohlin et al (2016) found that 30km/h (approx. 19mph) may still result in serious injuries for bicyclists.

2.9 Lubbe et al 2024

Building on their 2022 paper, Nils Lubbe and colleagues at Autoliv explored risk curves in their peer-reviewed paper last year entitled ‘Injury risk curves to guide safe speed limits on Swedish roads using German crash data supplemented with estimated non-injury crashes’. They also argued that 10% should be used as the threshold, in terms of the probability of death or serious injury, to stay away from the less reliable tail of the injury distribution curve, though recognised that a target closer to zero will ultimately be required to reach zero serious injuries.

The 80km/h (approx. 50mph) speed limit on single carriageways in Sweden is based on a survivable head-on collision between two modern cars. However, Lubbe et al noted that Rizzi et al (2023) questioned if this should actually be 50km/h (approx. 30mph) where cars mix with heavy goods vehicles. Lubbe et al also noted the findings of two studies by Doecke et al, based on US data:

- The 2020 study found that there was a 10% MAIS 3+ risk at 108km/h (approx. 67mph) for front, 71km/h (approx. 44mph) for side, and 53km/h (approx. 33mph) for head-on collisions
- The 2021 study found that there is a 1% MAIS 3+ injury risk to car occupants at impact speeds of 17km/h (approx. 11mph) in head-on collisions

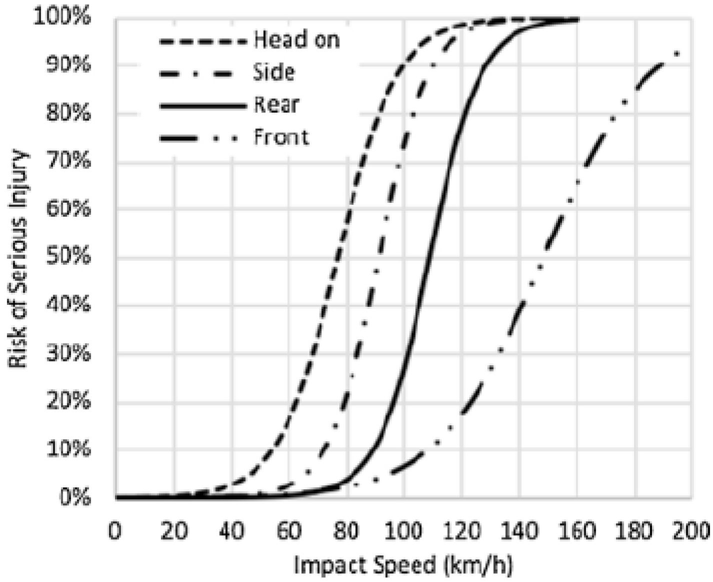
Lubbe et al then used GIDAS data from 1999-2022 to study injury outcomes for front seat occupants, who were wearing a seat belt and who were 13 or older, in cars with a frontal airbag and with a EuroNCAP Adult Occupant Protection score of 25 points or more (or, for non-assessed cars, post-2013 models only), in collisions that did not include a rollover. They supplemented the data with estimated property damage only collisions, in order to generate both conditional (i.e. given an injury collision) and unconditional (i.e. given any collision) injury risk curves. The differences between the two sets of values are notable at low speeds, but only marginal at higher speeds.

Lubbe et al found that differences between German and Swedish injury severities were smaller than between US and Swedish injury severities, and that the German GIDAS data are applicable to Sweden. Given any collision, they found that there was a 10% risk of a MAIS 3+ injury at impact speeds of 70-75km/h (approx. 44-47mph), regardless of the collision type, though the values are subject to uncertainty, the lower bounds being at approximately 60km/h (approx. 37mph) for all collision types.

Using this conservative value, and assuming that vehicles travel at the speed limit and do not slow down before a collision would suggest that a speed limit of 60km/h (approx. 37mph) would be required at junctions. On single carriageways away from junctions, Automated Emergency Braking (AEB) would normally be expected to reduce pre-collision speeds, enabling a higher speed limit. Lubbe et al used an estimate from Rizzi et al (2023), suggesting that AEB would reduce impact speed by 20km/h (approx. 12mph) in frontal collisions, thus enabling an 80km/h (approx. 50mph) speed limit.

2.10 The World Bank 2024

The World Bank, with external contributions, published ‘Speed Management Research: A Summary Comparison of Literature Between High-Income and Low and Middle-Income Countries’ last year. They quote various relevant studies, albeit non-European ones, including the values from Jurewicz (2016) above, and the earlier of the Doecke studies referred to above, including the relevant injury distribution curves, as shown in Figure 10.



Source: Doecke et al., (2020).

Figure 10 Impact speed risk curves for vehicle occupants for head-on, front, side and rear impacts (The World Bank 2024)

Combining the Doecke (2020) study with Hussain et al (2019), cited above, the World Bank suggested the values shown in Figure 11 based on a 1% risk of a fatal or very serious injury outcome.

Crash scenario	Approximate impact speed for a 1% fatal or very serious injury risk threshold
Head-on, hitting at	30 km/h
Front, hitting at	65 km/h
Side, being hit at	50 km/h
Rear, being hit at	65 km/h
Pedestrian, being hit at	20 km/h

Sources: Doecke et al. (2020); Hussain et al., (2019).

Figure 11 Threshold impact speeds for 1% risk of a fatal or very serious injury outcome, per vehicle (The World Bank 2024)

2.11 Considerations

Given the other factors present in the road environment and the fragility of the human body, there are no definitive speeds such that fatal and serious injuries are guaranteed to be avoided in the event of any collision. Therefore, determining what constitutes a 'safe' speed currently necessitates tolerating a level of risk of death or serious injury, however small. Though there is some debate about this, the consensus in the literature is that a 10% level of risk of death or serious injury (MAIS 3+) in the event of a collision is an appropriate aspiration. This may equate to a lower level of risk of death or life-changing injury, for example, given how wide the definition of 'serious' is.

Improvements in vehicle safety have meant that collisions at a given travel speed are now less likely to result in death or serious injury than was previously the case, because of greater pre-collision braking and, in the case of vehicle occupants, in-vehicle protection. This trend is expected to continue as the vehicle fleet further modernises. All other things being equal, this would increase the speeds that relate to a given level of risk. On the other hand, if the masses of collision-involved vehicles increase, the speeds related to a given level of risk will decrease. Similarly, an aging population and the subsequent increase in the fragility of the average road user would, all other things being equal, reduce the speeds that relate to a given level of risk.

This means that any study of fatal and serious injury risk using historical collision data cannot directly predict future risk: the exact speed at which there is a given level of risk will constantly be changing depending on, amongst other factors, the age of the people and of the vehicle fleet that are using the road.

When reviewing literature on this subject, this is further complicated by differences in the vehicle fleets and populations considered in each study. For example, studies in the US are less relevant to the UK than many European studies given the differences in vehicle standards.

Different studies also have different starting points; while most consider the level of risk given that a collision of any sort has occurred, some only consider the level of risk given that at least one person in a collision was injured or hospitalised. The differences in results are notable at lower speeds, though less relevant at higher speeds (because any collision at higher speeds is likely to result in some form of injury, however slight).

Most studies exclude casualties who were not wearing a seat belt at the time of the collision, and many exclude collisions involving rollovers, given differences in the collision and injury dynamics. Other exclusions sometimes apply depending on the study.

In addition, there are differences in what is viewed as constituting a serious injury: in Europe, MAIS 3+ is normally used but some studies suggest that MAIS 2+ may be more appropriate, and there is an argument for using the TBI scale for head injuries.

Finally, some studies use delta-v as the speed measure, while others use impact speed or closing speed. Some studies then link back to travel speed and/or speed limit.

For this study, it has been necessary to assume that the level of risk is not likely to change substantially from that studied in research published in the last 10-20 years, as cited in this document and that, where relevant, car occupants are wearing a seat belt. (Clearly this means that the risk of a MAIS 3+ injury to a car occupant who is not wearing a seat belt could be substantially higher than 10%.)

3. Expert workshop

Following the collation of all of the evidence described above, an expert workshop was convened. The participants in this workshop were:

- Jolyon Carroll (Senior Research Specialist in Biomechanics at Autoliv)
- Suzy Charman (Executive Director of the Road Safety Foundation)
- Richard Cuerden (TRL Head of Road Safety)
- Richard Frampton (Loughborough University)
- Brian Lawton (Road Safety Research and Policy Officer at the Road Safety Foundation)
- Andrew Morris (Professor of Human Factors in Transport Safety, Loughborough University)
- Steven Reed (Loughborough University)
- Johan Strandroth (Director of Lösningar)
- Jessica Truong (Director of Lösningar)

Experts at the workshop systematically worked through each of the main crash types, assessing the evidence in relation to each of these in a consistent fashion, to identify operating speeds which would be consistent with a Safe System, assuming that the operating speed and the impact speed would be the same – the reasons for this assumption are explored in Section 4. Consensus was achieved on the appropriate maximum operating speeds for each crash type scenario.

3.1 Collision between a car and a pedestrian

For a 10% risk of a MAIS 3+ injury to a pedestrian in the event of a collision with a car, both Jurewicz et al (2016) and Truong et al (2022) suggest an impact speed of 20km/h (approx. 12mph), while Lubbe et al (2022) suggest an impact speed of 29km/h (approx. 18mph).

Given studies suggest that the impact speed needs to be a little less than 20mph, and the experts did not want to imply undue accuracy by specifying a speed between 10mph and 20mph, they suggested a pragmatic approach of a lower operating speed where conflicts between cars and pedestrians are more likely.

Expert consensus for maximum operating speeds where cars mix with pedestrians: 20mph (or 10mph where there is a particular prevalence of pedestrians or where there is a heightened vulnerability of those people to impact and injury (e.g. around schools, around hospitals, and in the vicinity of major sports or social/cultural events).

3.2 Collision between a car and a bicycle

For a 10% risk of a MAIS 3+ injury to a bicyclist in the event of a collision with a car, Truong et al (2022) again suggest that impact speeds cannot be higher than 20km/h (approx. 12mph), while Lubbe et al (2022) suggest that closing speeds could be up to 44km/h (approx. 27mph).

In the latter case, it is suggested that this equates to a speed limit of 20-25km/h (approx. 12-16mph), effectively allowing for a head-on collision with both impact speeds being the same as the speed limit.

Given studies suggest that the impact speed needs to be a little less than 20mph, and the experts did not want to imply undue accuracy by specifying a speed between 10mph and 20mph, they suggested a pragmatic approach of a lower operating speed where conflicts between cars and bicyclists are more likely.

Expert consensus for maximum operating speeds where cars mix with bicyclists: 20mph (or 10mph where there is a particular prevalence of bicyclists).

3.3 Collision between a car and a motorcycle

For a 10% risk of a MAIS 3+ injury to a motorcyclist in the event of a collision with a car, Truong et al (2022) suggest an impact speed or delta-v of 30km/h (approx. 19mph), while Lubbe et al (2022) suggest a closing speed of 48km/h (approx. 30mph), so again suggest a speed limit of 20-25km/h (approx. 12-16mph).

Given studies suggest that the impact speed needs to be a little less than 20mph, and the experts did not want to imply undue accuracy by specifying a speed between 10mph and 20mph, they suggested a pragmatic approach of a lower operating speed where conflicts between cars and motorcyclists are more likely.

Expert consensus for maximum operating speeds where cars mix with motorcyclists (excluding dual carriageways away from junctions other than slip roads): 20mph (or 10mph where there is a particular prevalence of motorcyclists).

3.4 Side impact collision between cars

For a 10% risk of a MAIS 3+ injury to a car occupant in the event of a side impact collision with another car of the same mass, Jurewicz et al (2016) suggest a delta-v of 20km/h (approx. 12mph) while Richards and Cuerden (2009) suggest a delta-v of around 16mph.

Truong et al (2022) suggest an impact speed of 60km/h (approx. 37mph) or delta-v of 30km/h (approx. 19mph). Lubbe et al (2024) suggest impact speeds of 70-75km/h (approx. 44-47mph) and therefore, to be conservative, speed limits of 60km/h (approx. 37mph).

Adjusting these figures downwards given that the delta-v of the lighter car in a two-car crash can typically be up to 20% more than the average impact speed – see Section 1.4 – these figures mean that the impact speed of the impacting car should be no more than approximately:

- 21mph (Jurewicz et al, 2016)
- 27mph (Richards and Cuerden, 2009)
- 31mph (Truong et al, 2022)
- 36-39mph (Lubbe et al, 2024)

Expert consensus for maximum operating speeds at junctions where side impacts are possible (e.g. T-junctions and crossroads) with only cars: 30mph

3.5 Head-on collision between two cars

For a 10% risk of a MAIS 3+ injury to a car occupant in the event of a head-on collision with another car of the same mass, Jurewicz et al (2016) suggest an impact speed or delta-v of 30km/h (approx. 19mph). Richards and Cuerden (2009) suggest a similar speed – a delta-v of around 18mph – albeit that this work assumed an injury collision rather than any collision.

Lubbe et al (2022) suggest a closing speed of some 112km/h (approx. 70mph), e.g. both cars having impact speeds or delta-vs of 56km/h (approx. 35mph). They therefore suggest a speed limit of 55km/h (approx. 34mph), or higher if all cars are equipped with Automated Emergency Braking.

Truong et al (2022) suggest an impact speed or delta-v of 50km/h (approx. 31mph). Lubbe et al (2024) suggest impact speeds of 70-75km/h (approx. 44-47mph), and therefore an 80km/h (approx. 50mph) speed limit.

Adjusting these figures downwards given that the delta-v of the lighter car in a two-car crash can typically be up to 20% more than the average impact speed – see Section 1.4 – these figures mean that the impact speed of the cars should average no more than approximately:

- 16mph (Jurewicz et al, 2016)
- 15mph (Richards and Cuerden, 2009)
- 29mph (Lubbe et al, 2022)
- 26mph (Truong et al, 2022)
- 36-39mph (Lubbe et al, 2024)

Expert consensus for maximum operating speeds where head-on crashes are possible (i.e. single carriageways) with only cars: 30mph

3.6 Collisions involving heavy goods vehicles

While it is widely acknowledged that speeds need to be lower where the road user mix includes heavy goods vehicles – for example, Rizzi et al (2023) suggest a 50km/h (approx. 31mph) speed limit rather than an 80km/h (approx. 50mph) speed limit is required on single carriageways, and a 40km/h (approx. 25mph) speed limit at junctions – there are fewer studies on the subject. Truong et al (2022) suggest the same delta-v values as above but equate this to half the impact speed given the differences in mass, though varying geometries mean that this approach could under-estimate injury severity.

Expert consensus for maximum operating speeds at junctions where HGVs mix with cars: 20mph

4. Future developments

In the work above, it was assumed that operating speeds and impact speeds would be the same. While there may be some slowing of vehicles from their travel speeds prior to impact, and this may become more common as vehicle technology evolves, this cannot be assumed in any given collision.

Fitzharris et al (2022) found that just over half of drivers in their study braked immediately before a collision, reducing their speed by slightly over 30%, though the impact speed was just over 15% lower than the travel speed even amongst the vehicles that did not brake. On roads with speed limits of 50km/h, 60km/h, and 70 km/h (i.e. approx. 31mph, 37mph and 44mph), they found average reductions of 3-4mph amongst non-braking vehicles.

Lubbe et al (2022) also found that speeds reduced immediately before impact; the average pre-impact speed reductions by a car in a collision with another road user were as shown in Table 6.

Table 6 Average speed reduction by passenger cars in collisions with another road user of a given type (Lubbe et al 2022)

Car	Motorcycle	Pedestrian	Bicycle
10km/h (approx. 6mph)	4km/h (approx. 2.5mph)	6km/h (approx. 4mph)	3km/h (approx. 2mph)

On roads with speed limits of lower than 50mph, therefore, both studies suggest that the average speed reduction of a car prior to a collision can typically be only a few miles per hour; while even a small reduction in speed can be beneficial to safety outcomes, the speed reduction may be minimal for a sizeable proportion of vehicles involved in collisions today.

Looking forward, Strandroth et al (2019) suggested that it may be 2050 before cars built to today's 5-star standards have permeated throughout the on-road fleet in Victoria, Australia. They noted that such vehicles are "likely to be equipped with Autonomous Emergency Braking (AEB) for low and high speed, including braking for vulnerable road users, Intelligent Speed Assist (ISA), Lane Keep Assist (LKA) and Autonomous Emergency Steering (AES)."

When calculating safe speed limits, Lubbe et al (2024) applied a 20km/h (approx. 12mph) reduction in impact speeds in head-on collisions due to AEB. This was a crude estimate of the benefit of AEB from Rizzi et al (2023) if both cars were equipped with AEB; Rizzi et al suggested that this would be a reasonable performance for head-on AEB in 2030 model vehicles for reasonably large overlaps assuming a one second time-to-collision judgement.

Rizzi et al's figures were based on calculations by Hasegawa et al (2017). Hasegawa et al assumed that the time from judgment to braking was 0.2 seconds, and that deceleration then increased at a constant rate for 0.5 seconds to reach a maximum deceleration of 8.8m/s^2. They then calculated that a one second time-to-collision judgment would reduce the closing speed by approximately 43km/h (approx. 27mph) if both vehicles braked from speeds of 80km/h (approx. 50mph). That is, if two cars with AEB were both travelling directly towards each other at 50mph, the assumptions imply that the closing speed would be approximately 73mph, so both would have impact speeds of approximately 36mph.

However, Rizzi et al noted that such substantial speed reductions will be hard to achieve in some cases such as those with small overlaps; referencing Spitzhüttl and Liers (2019), they said that the time-to-collision "at which a collision becomes unavoidable and triggers AEB, if detected correctly, can be very small even for the simpler rear-end crashes". Investigating the potential of measures such as full deceleration once a rear-end collision becomes unavoidable, Spitzhüttl and Liers found that "passive safety measures could be possibly activated 0.3-1.1 seconds prior to the imminent collision for the majority of cases".

While a 20km/h (approx. 12mph) reduction in impact speed in head-on collisions may therefore be achievable by AEB in some circumstances, this suggests that such a substantial reduction cannot be assumed even when all cars are equipped with AEB.

While many road users will undoubtedly benefit from improved vehicle technology, it is inevitable that many of the vehicle models on the road today will continue to be on the road for the next twenty years or more, and the risk to some road users may actually increase as the masses of other vehicles on the road increase. It is therefore unlikely that operating speeds will be able to be increased substantially from the values above within a Safe System until beyond 2050. Rather, emerging vehicle technologies, including passive safety improvements and active collision-avoidance systems, may simply help a Safe System to be fully realised at the operating speeds indicated above in the future.

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Appendix A: Historic severity levels in injury collisions

A simple analysis of collision numbers indicates that the likelihood of an injury collision resulting in death or serious injury is substantially above 10%. (If damage only collisions were included in the analysis, this percentage would be lower, albeit that this is likely to affect only collisions at lower speeds.) Figure 12 shows the percentage of injury collisions which resulted in death or serious injury each year from 1979 – when serious collisions were first counted separately from other collisions – until 2023.

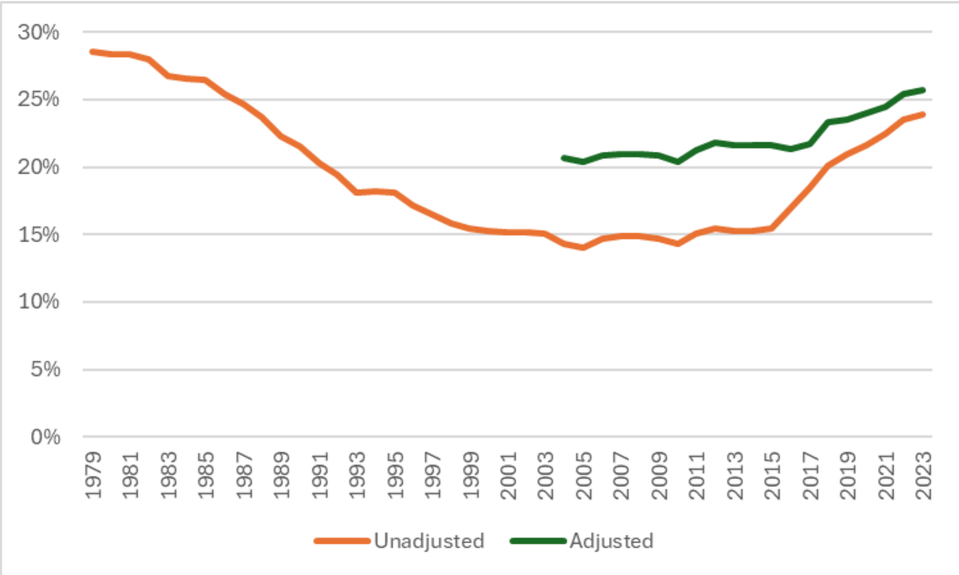

Figure 12 Percentage of injury collisions resulting in death or serious injury 1979-2023

For many years, the proportion of injury collisions which resulted in death or serious injury was falling, reaching a low of 14% in 2005 when there were approximately 28,000 reported fatal or serious collisions. However, in 2004, the 'adjusted' series began, this correcting for the misclassification of many serious crashes as slight crashes. This identified approximately 41,000 reported injury collisions which were fatal or serious, some 21% of them.

The percentages based on both series were broadly flat from 2004 to 2010, but have been increasing since then, and may soon exceed those values from the earliest years for which the data are available. In 2023, there were 27,000 reported fatal and adjusted serious collisions, representing 26% of reported injury collisions (with the unadjusted series percentage at 24%). But for the two years when Covid-related restrictions noticeably affected crash patterns, the number of reported fatal and serious injury collisions itself was lower than ever. However, the recent increases in the proportion of reported injury collisions resulting in death or serious injury may be a cause for concern.

One possibility which might contribute to this rise is any increase in the level of under-reporting of slight collisions: if there has been a reduction in the proportion of slight collisions which are reported, the percentage of reported injury collisions which are fatal or serious would have gone up, all other things being equal. Another possibility is that improvements in vehicle safety are preventing reported slight collisions disproportionately more than reported serious collisions: this would result in the percentage increasing even as the numbers of serious collisions are being reduced.

In Figure 12, the (adjusted) 2023 percentage is shown for each speed limit on non-motorway roads, and separately for motorways, to give an indication of how the likelihood varies depending on the possible speeds involved.

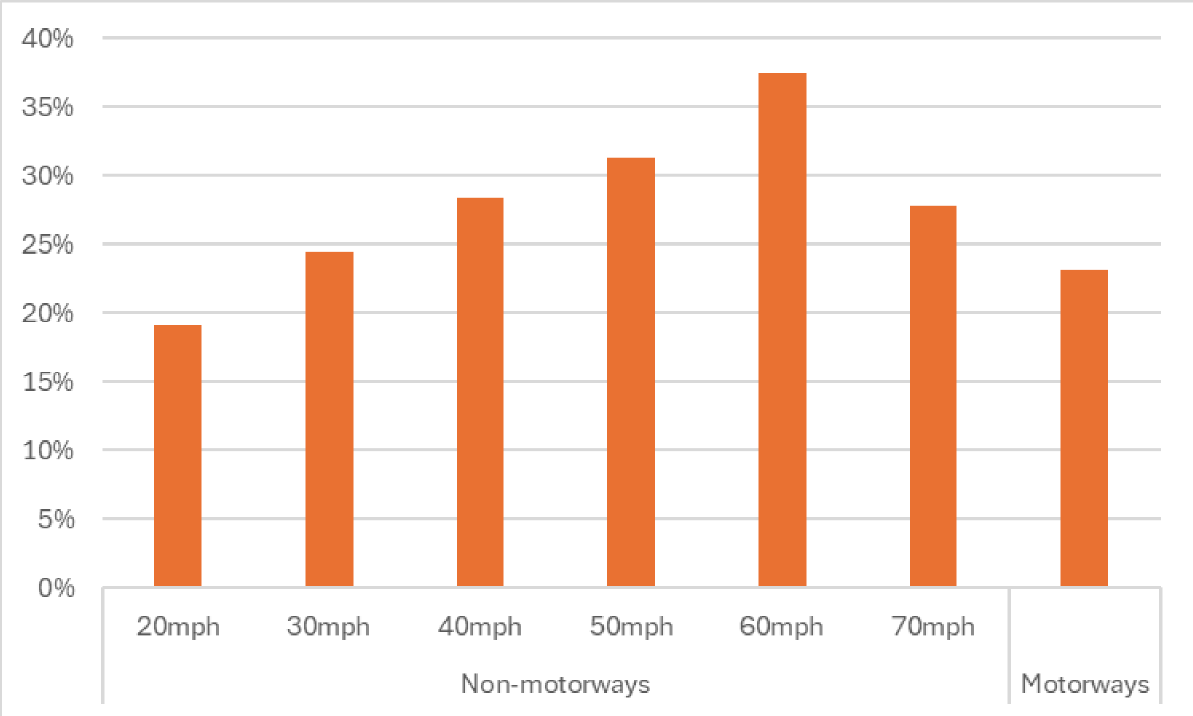

Figure 13 Percentage of reported injury collisions which were fatal or adjusted serious in 2023

This shows that, the higher the speed limit, the greater the likelihood of a reported injury collision resulting in a death or serious injury, apart from on roads with a 70mph speed limit and on motorways.

Were damage only collisions also included in the calculation, the percentages would be lower. This would be expected to reduce the figures for lower speed limits more than those for higher speed limits, thus exacerbating the differences in likelihood of a collision resulting in a death or serious injury depending on the speed limit.

The figures for non-motorway roads with speed limits of 50mph and 60mph are particularly concerning – on non-built-up roads as a whole, more than one in three reported injury collisions result in death or serious injury. (Note that this figure accounts for speed limits of 50mph, 60mph and 70mph; approximately two-thirds of injury collisions on non-built-up roads are on roads with a 60mph speed limit. This implies that, for a Safe System to be achieved, operating speeds are too high on single carriageways with the national speed limit of 60mph.)

The exceptions of roads with a 70mph speed limit and motorways are notable: these reflect the benefits of:

- Opposing flows being separated on dual carriageways (including motorways), substantially reducing the likelihood of head-on collisions, and
- Junctions being bypassed by through traffic (through the use of slip roads), and many junctions which are encountered being roundabouts, reducing the likelihood of side impacts.

This demonstrates that, with appropriately designed infrastructure, increased safety can be achieved at higher speeds.

Given that the speed variable in the graph above is the speed limit, it is likely that many collisions will be at speeds lower than the speed limit indicated. It should therefore be emphasised that the probability of an injury collision resulting in death or serious injury at the speed limit itself is likely to be higher than the figures above might initially suggest. Further work is required to gain greater insight into how the proportion of collisions which are fatal or serious varies depending on the operating speed on different road types.

Appendix B: Delta-v changes owing to mass differences in two-car impacts

For simplicity, many scientific studies model the delta-v in a two-car collision by assuming that the cars have the same mass. While this reflects an average two-car collision, there is often a difference in the masses of two such cars. The lighter car will usually experience a change in velocity which is greater than would be the case if the cars were of the same mass. The occupants of the lighter car are subsequently likely to sustain more severe injuries than would be the case were the collision with a car of the same mass. (Similarly, the heavier car will usually have a smaller delta-v and its occupants are subsequently likely to sustain less severe injuries.)

A 'safe' system takes account of the occupants of the lighter car in a two-car collision, not just the occupants of a car of the same mass (which implicitly also takes account of the occupants of the heavier car). The elevation in the delta-v of the lighter car when the masses of cars in a collision differ therefore needs to be considered.

As an example, compare a head-on collision between two Ford Pumas which have impact speeds of 30mph with the same collision but where one of the cars is instead a Kia Sportage. The Ford Puma was the highest selling car in 2024 and has a mass of 1,400kg; the Kia Sportage was the second highest selling car in 2024 and has a mass of 1,700kg.

In the former case, both cars would have a typical delta-v of 30mph; in the latter case, however, conservation of momentum determines that the Ford Puma will have a typical delta-v of approximately 33mph, and that the Kia Sportage will have a typical delta-v of approximately 27mph. That is, a 21% increase in the mass of the 'other' car results in an elevation in the typical delta-v of the lighter car of 10%.

The relationship between the relative mass, average impact speed, closing speed, and typical delta-vs of the vehicles, given the conservation of momentum, is shown more broadly in Figure 14.

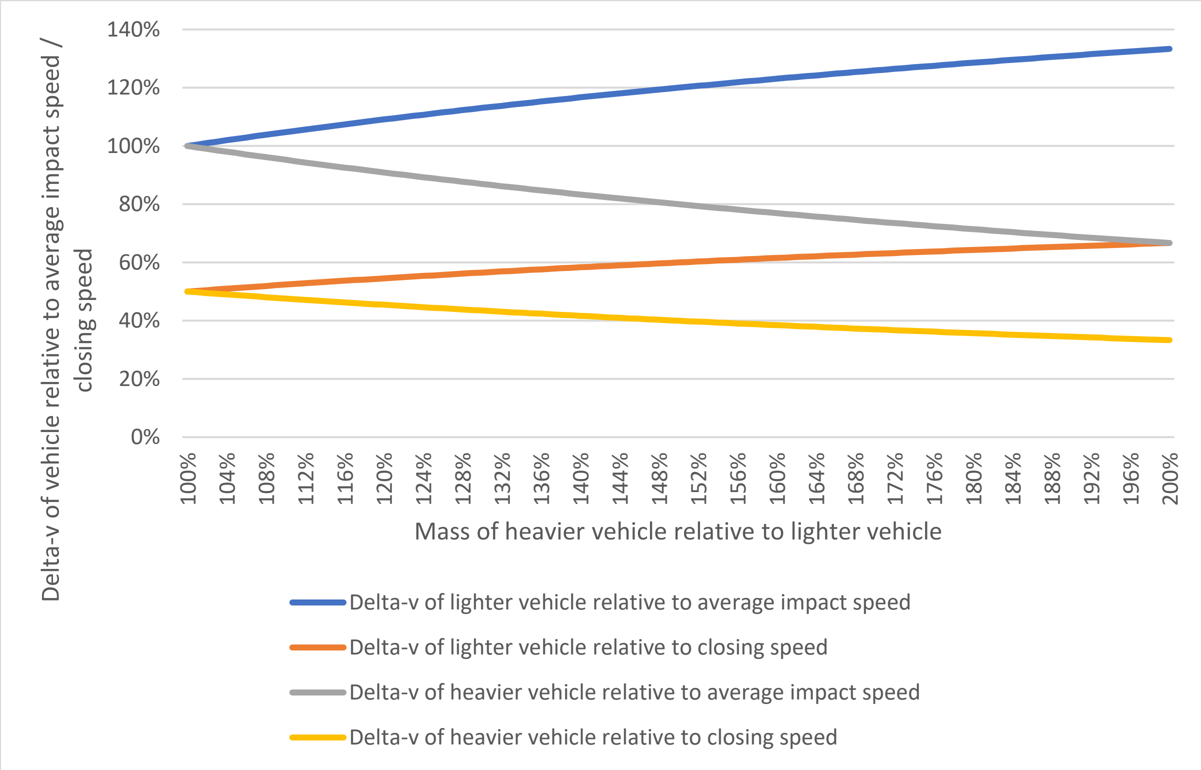

Figure 14 Typical delta-v of a vehicle relative to the average impact speed and closing speed given the relative mass of the vehicles involved

This graph shows how, for example, the typical delta-v of the lighter vehicle increases as the masses of the vehicles diverge, up to the point where one vehicle has twice the mass of the other. At this point, the typical delta-v of the lighter vehicle is 33% more than the average impact speed. However, collisions between two cars with such a large difference in mass are relatively rare.

The 25th percentile mass of the top ten selling cars in 2024 was 1,400kg and the 75th percentile mass of the top ten selling cars in 2024 was 1,915kg, a ratio of 1.37. Therefore, less than 10% of two-car collisions today would be expected to be between cars where one has a mass which is more than 37% more than the other. In a collision with this difference in mass, as the graph above shows, the typical delta-v of the lighter car is approximately 16% more than the average impact speed. That is, the delta-v of the lighter car would typically be:

- 46mph if the average impact speed in a head-on collision is 40mph
- 35mph if the average impact speed in a head-on collision is 30mph
- 23mph if the impacting car in a side collision has an impact speed of 40mph
- 17mph if the impacting car in a side collision has an impact speed of 30mph

The 25th percentile mass of the top ten selling cars in 2024 was 1,400kg and the 75th percentile mass of the top ten selling *electric* cars in 2024 was 2,000kg, a ratio of 1.43. Therefore, less than 10% of two-car collisions between 2030 and 2050 would be expected to be between cars where one has a mass which is more than 43% more than that of the other. In a collision with this difference in mass, as the graph above shows, the typical delta-v of the lighter car is approximately 18% more than the average impact speed. That is, the delta-v of the lighter car would typically be:

- 47mph if the average impact speed in a head-on collision is 40mph
- 35mph if the average impact speed in a head-on collision is 30mph
- 24mph if the impacting car in a side collision has an impact speed of 40mph
- 18mph if the impacting car in a side collision has an impact speed of 30mph

These figures all indicate that the delta-v of the lighter car in a two-car collision can frequently be at least 10% greater than the average impact speed; in extreme cases, it may even be over 30% more than the average impact speed. However, in the vast majority of two-car collisions in the foreseeable future, the heavier car is unlikely to have a mass which is more than 50% greater than that of the lighter car; with this mass differential, the typical delta-v of the lighter car would be 20% more than the average impact speed. Rather than the delta-v being the same as the average impact speed, therefore, it should be borne in mind that the delta-v of the lighter car may often be up to 20% higher than the average impact speed.

A more accurate measure of the difference between the masses of two cars in 90% of collisions may be possible to obtain from real-world collision data; this may enable the use of a delta-v which is lower than 20% more than the average impact speed in survivability calculations relating to collisions between cars.