Background information related to road side safety

Background

In the past various projects related to the improvement of road design in general and the design of roadsides in particular have been funded by the EU (e.g. Dakota; Ripcord-Iserest, RISER etc.) or by organisations such as CEDR (e.g. Eraser, RISMET, SAVERS; IRDES etc.) (CEDR, 2014; G. Schermers et al., 2011; G Schermers & Charman, 2013; Thomson; et al., 2006).

In addition to these cross-country research efforts, individual EU-countries have committed resources to conducting research and developing national standards and guidelines for the design and operation of roads, including specific requirements for safe roadsides and dealing with aspects such as obstacle free zones and run off areas, slope characteristics, type of obstacles, screening and protection of obstacles; structural elements (frangible posts, masts, abutments etc.); load bearing capacity; etc. In the majority of cases these standards and guidelines are unique to the countries themselves although certain aspects related to markings, signing, guardrails and other furniture is subject to the European Committee for Standardization (CEN) standards (such as EN 12767: 2013; EN 1317) and maybe other standards such the international ASTM A741-11:2016). In most cases these aspects deal with new designs and limited attention is given to maintenance. Furthermore, these specifications may be a design requirement, compliance is often difficult to control during construction (e.g. transitions between different safety barrier types/systems). In practice these issues may have negative consequences on the safety performance of these roadside elements.

Even though most European countries have their unique roadside safety standards and guidelines, in their core almost all of them share very similar approaches in the way they define roadside risk and the procedures they recommend to mitigate it. This was clearly shown in SAVeRS Work Package One (*SAVERS (Selection of Appropriate Vehicle Restraint Systems) - WP1: Defining the Different Parameters which can Influence the Need and Selection of VRS*, 2014), under which the national roadside design guides and standards of 35 different countries were analysed and compared in detail. The result of this study has shown that roadside risk can generally be defined as the product of likelihood (including likelihood of a vehicle leaving carriageway and likelihood of an errant vehicle reaching a hazard) and consequences (for occupants of the errant vehicle and for third parties) of a roadside accident, as is illustrated in Figure 1.

In the standards and guidelines, the likelihood part of risk formula is assessed through clear zone models. A minimum recommended clear zone width is calculated for a roadside under evaluation and if there are any objects or terrain features located within that distance it is assumed that they are likely to be reached by an errant vehicle. Similarly, in the majority of standards and guidelines, the consequences part of the risk formula is assessed through listing of roadside objects and terrain features which are considered a hazard for each country; in other words, they are considered to have high enough consequences if reached by an errant vehicle, to warrant risk mitigation measures. While some countries such as the UK calculate the risk in terms of scale measures (such as equivalent fatalities per 100 million vehicle km) and check if it is under the acceptable limit, others adopt a binary approach of simply checking if objects which are considered as hazards are located within the minimum recommended clear zone or not. In either case, if the risk is perceived to be unacceptable, mitigation measures are justified.

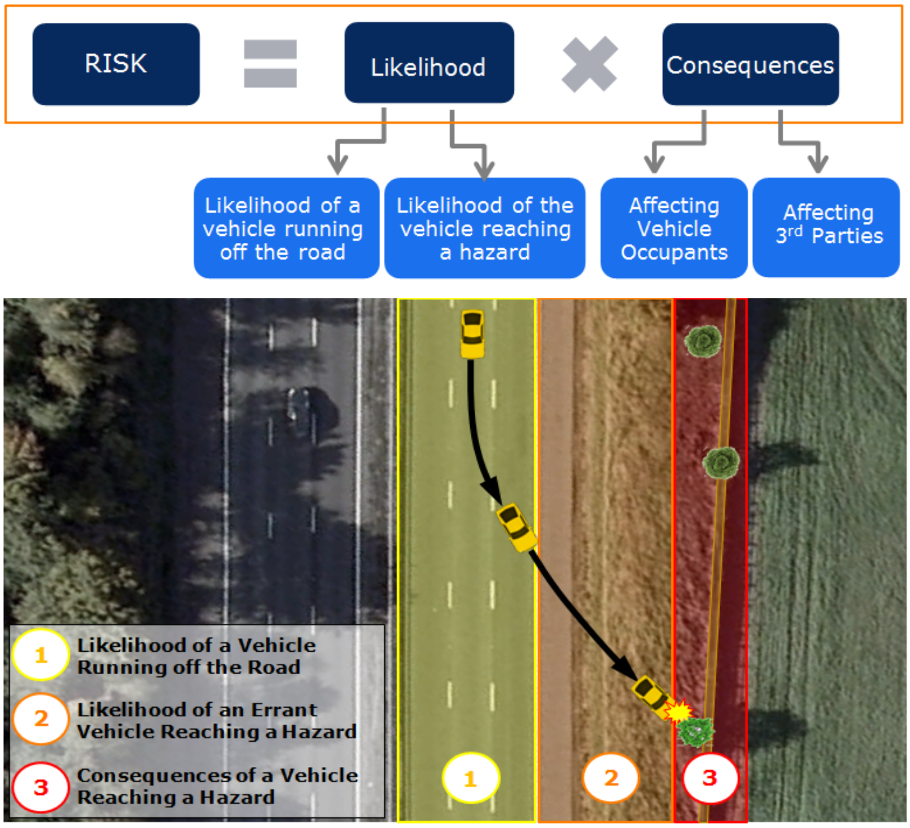


Figure 1: Risk from a roadside safety perspective

A fundamental issue that is directly related to roadside safety is the choice mitigation method, once the risk is identified as high enough. The risk can be mitigated through a number of measures, which would reduce either the likelihood or consequences of a vehicle leaving the travelled way. These often include the removal of the hazard (decreases both likelihood and consequences), relocation of the hazard further away from the road (decreases likelihood and consequences), replacing the hazard with a passively safe alternative or modifying it to be safely traversable (decreases consequences), shielding the hazard with vehicle restraint systems (decreases consequences but increases likelihood) or even just delineation (decreases likelihood). These measures can be grouped into two primary strategies, according to their fundamental effect. The first is to provide adequate clear zones (to remove or relocate any hazards or to replace them with passively safe alternatives) with a surface capable of accommodating and supporting an errant vehicle, which allows the average driver to regain control. The second is to shield the hazards with vehicle restraint systems, which decrease the consequences of leaving the carriageway as it replaces a potential uncontrolled high risk impact with a controlled and predictable one. Generally, countries seem to have adopted a mixture of these two strategies with the rule being providing (obstacle free) clear zones and the exception providing devices (such as guardrails, barriers) to screen off objects/obstacles that may constitute a safety hazard for road users. This is because, vehicle restraint systems are known to be hazards themselves (even if they pose lower consequences than the objects they are shielding) and therefore when cost is not taken into consideration, eliminating the likelihood of an impact through clear zones is seen as a lower risk option. The problem however, is that the majority of the roadside design standards and guidelines do not provide the necessary guidance to assess the decision between clear zone and shielding from an economic perspective.

Furthermore, in both cases an important factor remains unexplored; i.e. the definition of obstacles and the levels of maintenance over time. For example, trees become obstacles/hazards once they reach a certain diameter, greenery grows and restricts visibility and these aspects require monitoring. The same applies to frangible posts and masts as time affects their (safety) performance and they may require replacement. It is equally important that such "crash friendly" posts are not inadvertently replaced with rigid and potentially unsafe elements. A corroded or improperly installed vehicle restraint system can pose a higher risk to errant vehicles than the hazards it is installed to shield. On another level, a roadside barrier which was impact tested with an old vehicle (for example a pre-NCAP era vehicle with considerably low structural stiffness), may not be able to safely contain a modern one, such as an SUV. Effective management of roadside elements is essential to ensure that not only roadsides alongside new roads are safely designed and laid out but that these are also maintained and kept safe during the operational life of the road. During the operational life of the road the safety of road workers undertaking road side maintenance should be taken into consideration. It should also be noted that inherent to safe roadsides is effective management and quality control.

Over the past 50 years extensive research has been conducted into the relationship between clear zones and road safety (AASHTO, 2010; Elvik, Hoye, Vaa, & Sorensen, 2009), much of this in the USA and focussed on establishing the relationship between clear zone width, speeds, vehicle penetration rates and crashes. The results of this research has been conflicting and by no means conclusive with regards to what constitutes an optimum as far as a safe clear zone width is concerned. Additionally, there has been significant research into the effects of obstacles and objects near or adjacent to roads on crashes and crash outcomes[1]. Since the mid-1960's road safety engineers have made significant progress improving the design of barriers, guardrails and other devices (such as frangible posts, crash attenuators etc.) which aim at reducing the risk of serious injury to road users in the event of a collision. This research has to a large extent been the foundation for the development of numerous (international) standards and guidelines regulating and prescribing best practice when it comes to roadside design and in some cases maintenance.

In Europe, numerous guidelines and standards have been produced aimed at making roads in particular, and roadsides specifically, more forgiving. However, many of these are aimed at harmonisation of measures based on primarily theoretical (scientific) considerations. Consequently, the measures have not been widely implemented nor have pilot applications been researched and published. Furthermore, there are many different measures aimed at essentially the same problem without it being clear what the merits of each measure are when compared to the others. The CEDR funded project IRDES aimed to fill the identified gap by providing practical guidance for the implementation of forgiving roads. IRDES provides the means with which users could select the optimal treatment but with the clear ambition to also monitor the efficacy of this once implemented. The IRDES design guide brought together best practice design guidance on roadside safety. However, IRDES has not been implemented widely and the reasons for this need to be established to prevent re-occurrence.

In addition to IRDES, the EU funded RISER and CEDR funded SAVERS have also researched roadside safety and similarly the results have only been implemented on a limited scale. Although comprehensive, the research efforts have been predominantly focussed on establishing which roadside elements and criteria are essential for providing optimal (state of the art) roadside design. These efforts are generally classic in their approach and concentrate on specifying best practice and giving guidance for remedial treatments. The decision support algorithm developed in RISER (See Figure below) is an example of such a traditional approach (Thomson; et al., 2006). This promotes evaluation, followed by removal, modification and ultimately protection. However, a more fundamental approach may be to assess the merits of adopting a roadside safety strategy based on a clear roadside area versus for example, the extensive application of barriers. Cost-effectiveness is an aspect that may need to be included in such warrants or decision support algorithms, a feature that was included in the roadside assessment procedure developed under the Portuguese funded SAFESIDE research project (C. Roque & Cardoso, 2015; C. A. Roque & Cardoso, 2013).

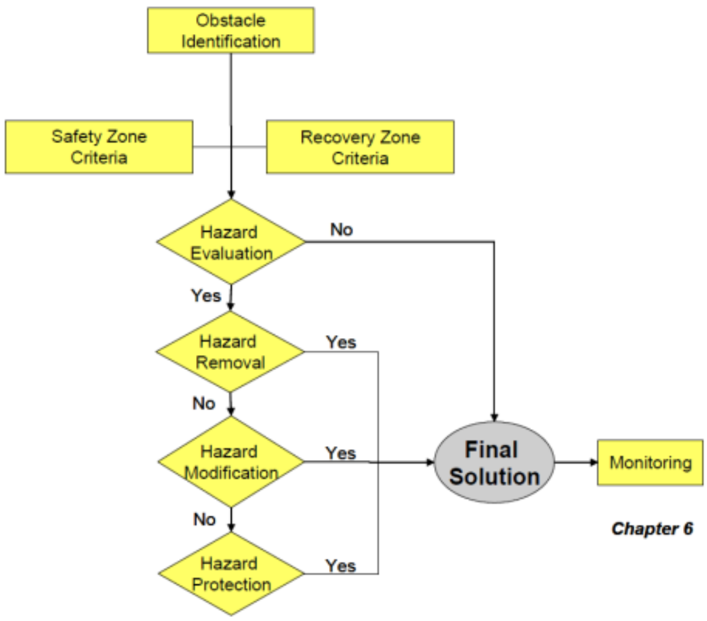


Figure 2 : Riser decision support algorithm

Furthermore, research on safe roadside design paid limited attention to aspects such as maintenance and safety during maintenance. Consequently, the procedures in guidelines and standards focus very much on the design of new elements (and roadsides) and seemingly make inadequate provision for ongoing safety compliance through the road life cycle. Maintenance and inspections of roadsides and roadside elements are seen as supplemental and are not part of the current standards and guidelines leading to potential discord between the setting of standards for new roads and maintaining them for the duration of the roads' life.

Overview of the problem and defined objectives

Safe systems approach

The Safe Systems approach (Bliss & Breen, 2009; ISO, 2012; Koornstra, Mathijssen, Mulder, Roszbach, & Wegman, 1992; F Wegman & Aarts, 2006; F. Wegman et al., 2008) calls for the prevention of crashes and where this is not possible, for conditions that will mitigate the effect of the crash in order to reduce the severity of injury to vehicle occupants. It aims to minimise situations in which there are high differences in the speed, direction or mass of road users (**Figure 3**) as well as to minimise the consequences of collisions with obstacles located close to the road. For road authorities this means designing, operating and maintaining roads that prevent certain conflicts from happening (functional and homogenous use). These roads should essentially be self-explaining (road users know what to expect and what to do) and forgiving (to allow road users the opportunity to correct residual mistakes without incurring serious damage). Although this concept is widely accepted throughout the world, it will take a significant amount of time before all existing road infrastructure complies with these requirements. However, various road authorities in Europe have incorporated this way of thinking into new road design and are taking steps to introduce procedures to address problems on the existing networks. These may include the redesign of existing roads and maintenance work (e.g. replacing damaged and even non-damaged non-standard safety barriers with standard compliant ones).

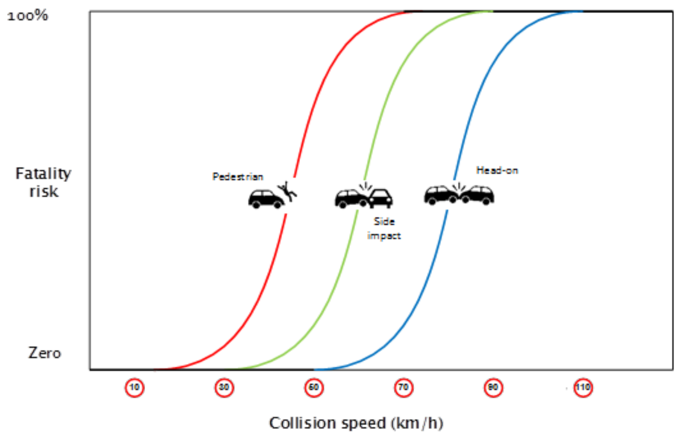


Figure 3: Safe systems philosophy

Crashes on EU roads

The motorway network in most European countries carry high traffic volumes (for e.g., in the Netherlands around 60% of all vehicle-kilometres are travelled on the motorways), even though they represent only a fraction of the total road network length (for e.g. in the

Netherlands less than 3%), but due to the high level of road infrastructure safety these roads are relatively safer than others (Figure 4). However, rural roads (which include mainly the primary rural road network, the 70, 80, 90 and sometimes 100km/h roads) remain by far the largest contributor with between 47 and 67% of all traffic fatalities occurring on these roads.

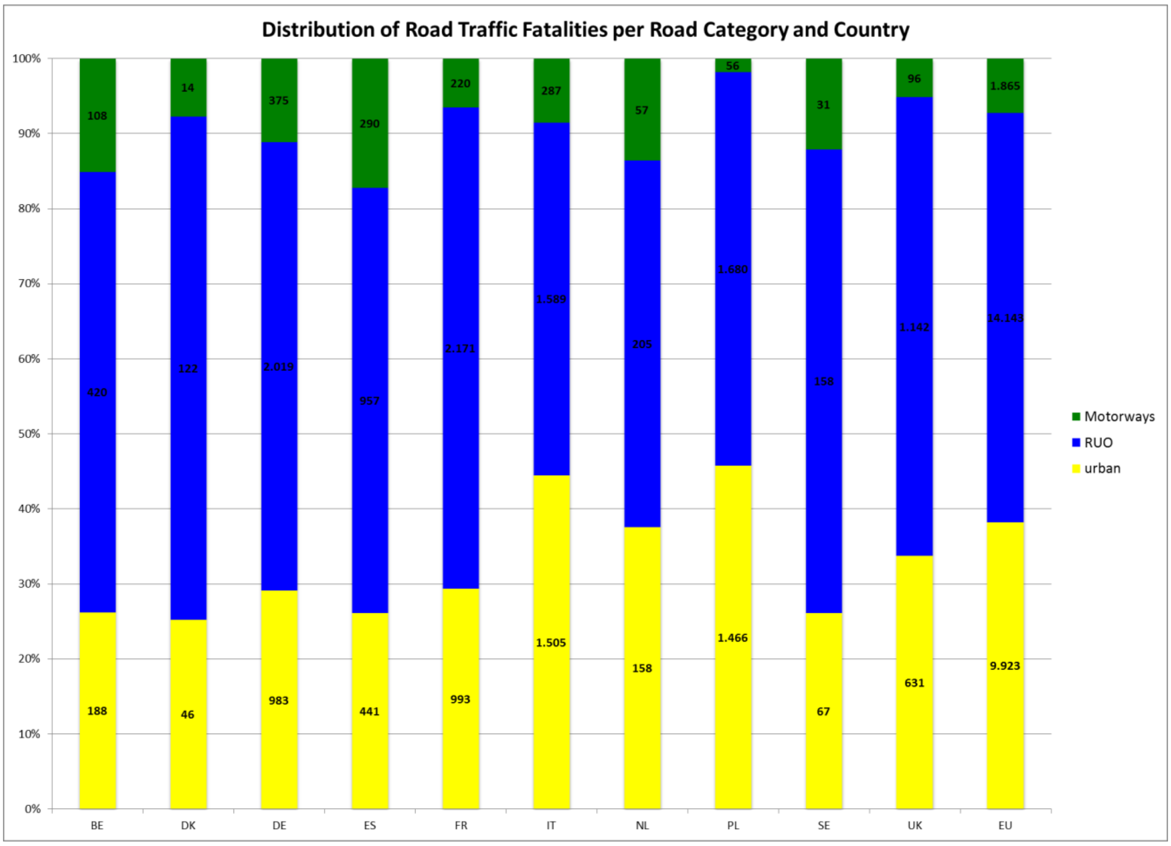
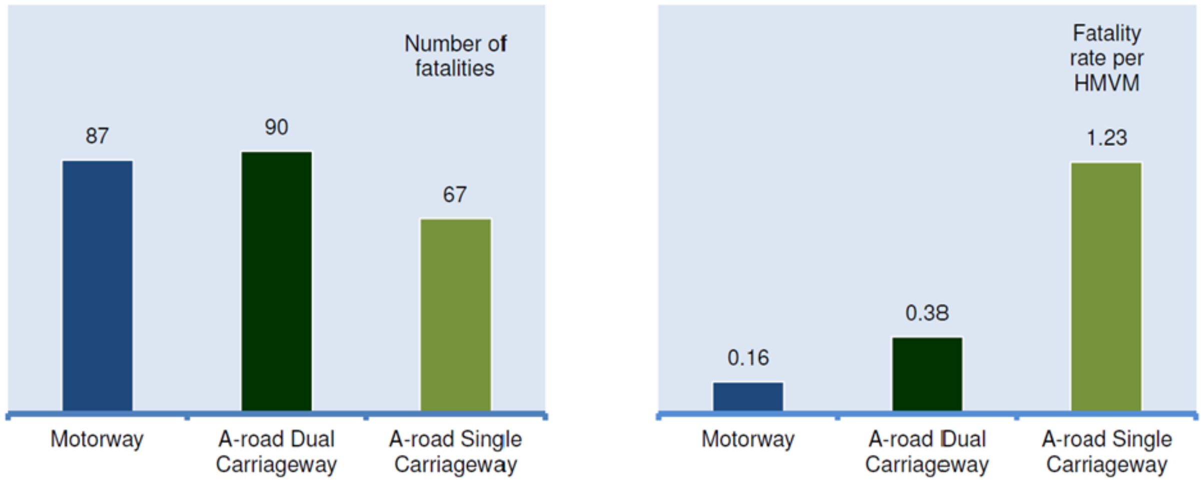


Figure 4: Road fatalities by road type in selected European countries (2005-2015, Source CADaS, 2017 (De Meester, 2011))

This is further demonstrated in Figure 5, for the Highways England Strategic Road Network (SRN). It can be seen that in 2013 the total number of fatalities recorded on the SRN motorways, dual carriageway A-roads and single carriageway A-roads were on comparable levels. However, when adjusted by the amount of travel in terms of Hundred Million Vehicle Miles (HMVM), it can be seen that A-road single carriageways had a fatality rate of approximately 8 times that of the motorways.

This is also supported by recent iRAP results for England, which identified on average four to five star rating for the majority of motorways located on the Strategic Road Network (SRN), whereas the high speed (60mph) single carriageway A-roads located on the SRN had an average of one to two star rating; a considerable difference in the level of safety provided through infrastructure (iRAP, 2009).



(a) Number of fatalities (b) Fatality rate per HMVM

Figure 5: Number and rate of Fatalities on Highways England SRN by road classification, 2013 (Highway Agency, 2014)

In Europe an ongoing problem remains the high proportion of crashes associated with (unsafe) roadsides and verges, namely single vehicle crashes (crashes with objects in the verge or roll-overs) and loss-of-control crashes resulting in head-on and other crash types. The DoRN (CEDR, 2016) illustrates the extent of the problem in four EU countries and this reveals that single-vehicle crashes constitute upward of 38% of all fatalities resulting from traffic crashes in the period 2005-2009. An update of this data using CARE/CADaS data confirms this trend (De Meester, 2011). Many of these are likely to be run-off road crashes (roll-overs) or single vehicle crashes with roadside objects/obstacles and can be directly associated with the design and maintenance of roadside areas. In addition to these directly attributable crashes there is also a proportion of crashes where the state of the roadside may influence other crashes, for example, poorly maintained verges restricting intersection or stopping sight distances etc.

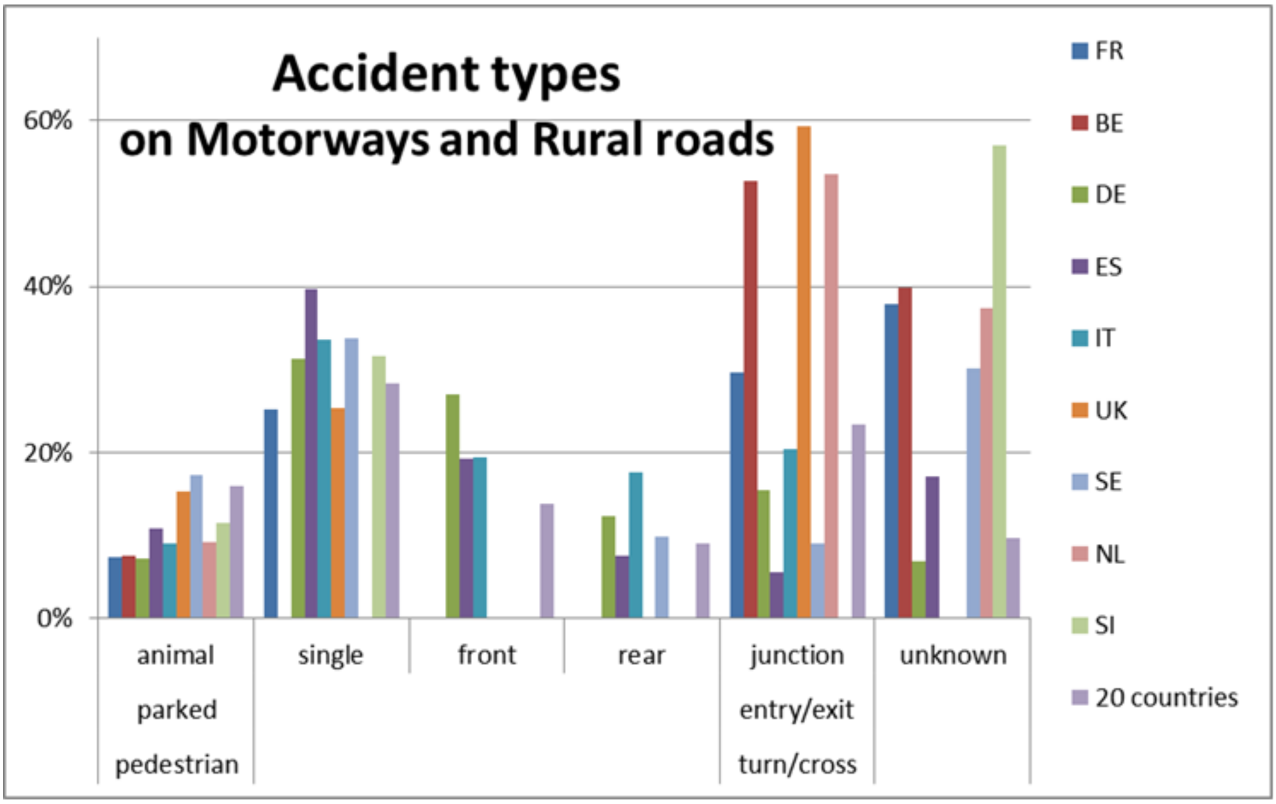


Figure 6: Fatalities by selected crash types in nine European countries (Source CARE/CADaS, 2017) 2016)

ROR Crashes and fatalities

A run-off-road crash (ROR) is defined by Edwards, Morris, and Manser (2013) as: *"a crash that occurs when a single vehicle departs the roadway to the left or right and then collides with another vehicle, with an obstacle on or off roadway, or rolls over after exiting a roadway"*.

ROR crashes are a severe problem, representing 51% of the fatalities in the US in 2011 (Khan, Abdel-Rahim, & Williams, 2014). In Europe, one third of the total fatalities are ROR crashes caused by drivers' errors (Tomasch, Hoschopf, Sinz, & Strnad, 2016).

In the Netherlands, ROR crashes represent one third of the total fatalities and one sixth of the serious injuries and the majority of them occur on roads with a speed limit of 80 km/h (SWOV, 2013). Moreover, during the period from 2005 to 2009, 62% of the vehicles involved in ROR crashes in the country were passenger cars. Table 1 and Table 2 show the ROR crashes in the Netherlands between 2005 and 2009 by type of road, speed limit and road characteristic.

Urban or rural	Speed limit	Fatal run-off-road crashes		Run-off-road crashes with serious road injuries	
		Number	Share compared to all crashes	Number	Share compared to all crashes
Urban	50 km/h	33	17%	202	9%
	70 km/h	3	36%	7	14%
Rural	60 km/h	27	47%	75	27%
	80 km/h	81	36%	242	26%
	100 km/h	10	32%	33	30%
	120 km/h	20	40%	71	37%
Total urban and rural		**198**	**30%**	**758**	**16%**

Table 1: Fatalities and seriously injured ROR crashes in the Netherlands between 2005 and 2009 per road type (Source: SWOV, 2013)

Road situation	Fatal run-off-road crashes		Run-off-road crashes with seriously injured	
	Number (share)	Share compared to all crashes	Number (share)	Share compared to all crashes
Bend	67 (34%)	64%	251 (33%)	50%
Straight road	109 (55%)	33%	392 (40%)	19%
Intersection and other	21 (11%)	10%	115 (15%)	5%
Total run-off-road crashes	**198 (100%)**	**30%**	**758 (100%)**	**16%**

Table 2: Fatalities and seriously injured ROR crashes in the Netherlands between 2005 and 2009 per road environment (Source: SWOV, 2013)

ROR crashes can be ‘controllable’ or ‘uncontrollable’. Controllable ROR crashes are those in which drivers can react and return to the lane after driving on the road shoulder. In the case of uncontrollable crashes, drivers cannot correct their trajectory before leaving the road.

Liu and Subramanian (2009) distinguished the following three different groups of factors contributing to ROR crashes:

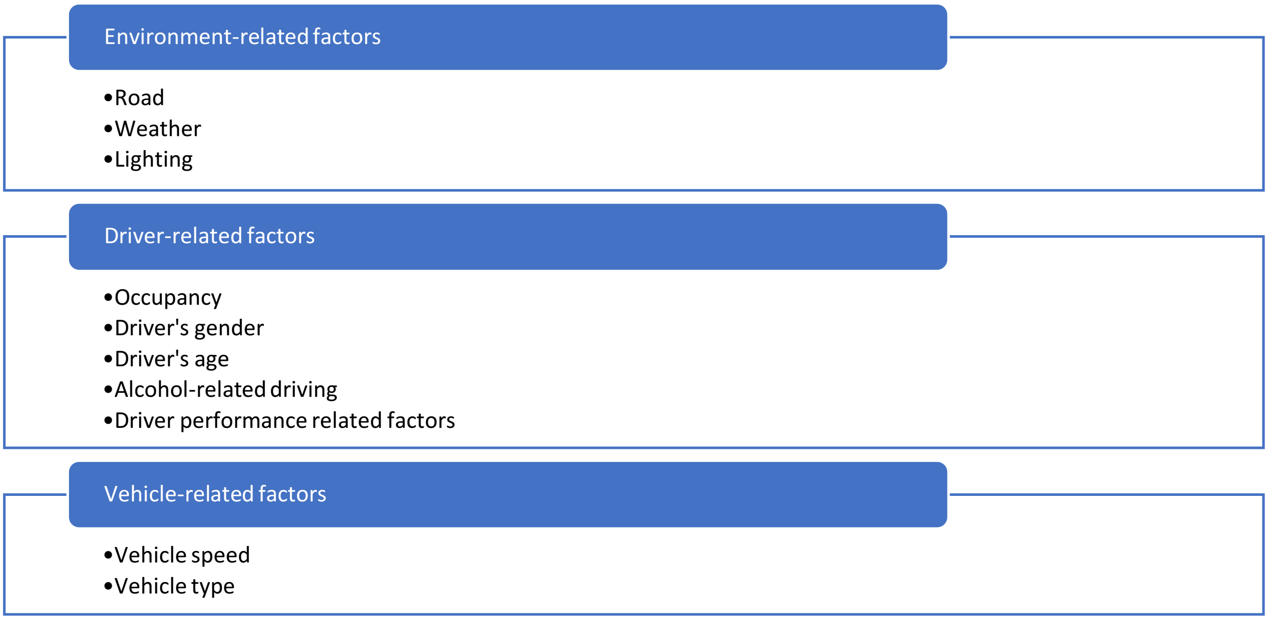


Figure 7: Summary of main factors contributing to ROR crashes

The main causes of ROR crashes are related to human errors. Different authors reported fatigue and distraction as main factors. For instance, McLaughlin, Hankey, Klauer, and Dingus (2009) concluded that 40% of the ROR crashes are caused by distraction or inattention of drivers and 11% by fatigue. In the Netherlands, these percentages are similar, with distraction or inattention being the cause of 28% of the ROR crashes, driving over the speed limit 23%, fatigue 14% and alcohol consumption 13% (Davidse, 2011) (Davidse, Doumen, van Duijvenvoorde, & Louwerse, 2011)

Focusing on the road characteristics that contributed to ROR crashes in the Netherlands, too narrow obstacle-free zones were the cause of 42% of ROR crashes, semi-hard shoulders 12% and too narrow or no hard strips 10% (Davidse, 2011) (Davidse et al., 2011).

1.1 Countermeasures for RoR crashes

Different measures can be used to avoid ROR crashes or reduce their outcomes. These countermeasures focus on the main factors causing ROR crashes, therefore countermeasures can be infrastructure and environmental-related or driver and vehicle-related (Edwards et al., 2013). A summary of these countermeasures is shown in **Figure 8** and explained in more detail in the following sections.

Infrastructure-related countermeasures

- Rumble strips and profiled edge markings
- Wide and paved road shoulders
- Avoid large drops at the edge of the pavement
- Ensure an appropriate obstacle-free distance
- Improve delineation of curvatures
- Improve road marking
- Guardrails

Driver and vehicle-related countermeasures

- Driving assistance systems
- Rumble strips

Figure 8: Summary of main countermeasures to reduce ROR crashes and its outcomes

1.1.1 Rumble strips and profiled edge markings

Rumble strips are a type of road longitudinal marking defined by Smadi and Hawkins (2016) as *'strips that create audible and tactile warnings that alert a vehicle's driver as it crosses the center or edge line of a roadway. When a pavement marking is applied over the rumble pattern, it is called rumble stripe'*.

The term rumble strips is mostly used in the US (Hatfield, Murphy, Soames Job, & Du, 2008). Depending on the country, they can also be called audio-tactile lane marking (ATLM) and raised Profile Lane Marking (PLM) when they are installed under the lane marking.

According to Torbic et al. (2009), four different types of rumble strips can be distinguished:

- Milled rumble strips: grooves are cut on the road pavement using a milling machine. These types of rumble strips are the most used and the installation is easy.
- Rolled rumble strips: in this case the grooves are pressed on the road surface when the asphalt is still hot.
- Formed or corrugated rumble strips: these type of rumble strips are used when the road surface is concrete.
- Raised rumble strips: installed by applying pieces of pavement on top of the road surface.

Rumble strips can be installed on the road shoulders, making drivers aware of the edge of the road or on the center line to alert drivers that they are about to drive on a different lane. Moreover, rumble strips can also be placed transversally on roads to alert drivers that they are approaching an intersection or an area where they should reduce speed.

There is currently no standard design or guidelines to use rumble strips. Therefore, the design and use depends on the different authorities or transport agencies that want to install rumble strips.

According to Tomasch et al. (2016), the rumble strips should generate an increase of noise inside the vehicle between 10 dBA and 15 dBA to be effective. Torbic et al. (2009) recommends the following design values regarding the noise that rumble strips should generate inside the vehicle: minimum design noise = 3 dBA, desirable design noise = 6 dBA and maximum design noise = 15 dBA. Different types of rumble strips generate different levels of noise pollution.

The main advantage of rumble strips is their effectiveness in reducing run-off the road crashes, since they alert drivers when they are about to drive out of the road, so they have time to react and drive back to the driving lane. Therefore, they are a good method to reduce run-off road crashes with low implementation and maintenance costs (Smadi & Hawkins, 2016).

The use of rumble strips leads to a reduction of crashes related to fatigue, inattentiveness, drivers under the influence of alcohol and drivers driving over the speed limit (Persaud, Retting, & Lyon, 2004).

The crash reduction derived from the installation of rumble strips differs depending on the type of road assessed in each study. Smadi and Hawkins (2016) concluded that the implementation of rumble strips leads to a reduction of 36% and 17% of crashes on rural two-lane roads and rural freeways, respectively. Turner, Steinmetz, Lim, and Walsh (2012) provide an overview of studies assessing the crash reduction after installing rumble strips in different countries. In total, there was an average reduction of 20% of crashes after installing rumble strips and 40% reduction in the case of run-off the road crashes. The same study concluded that the average reduction of crashes derived from the use of centre line rumble strips was 15%, with a reduction of 30% in the number of head-on crashes.

Although the durability of raised profile lane marking (PLM) is lower than for milled-in rumble strips due to wear problems, it is beneficial in cases of poor road visibility, because the edge lines are more visible in case of conditions affecting the road surface such as rain (Hatfield, Murphy, & Soames Job, 2008).

However, these types of road markings also have some disadvantages such as the noise created due to contact between the vehicle tyres and the rumble strips which is not only audible inside the vehicle but also to the environment outside of it.

According to Caltrans (2012) the use of rumble strips increases the level of noise outside the vehicle by 5 to 19 dB and inside the vehicle by 5 to 15 dB.

Lennie and Bunker (2004) concluded that vehicles drive at an average distance of 0.5 m from the edge line of the lane. Moreover, 20% of the vehicles drove at a distance lower than 0.3 m from the edge line. These short distances lead to drivers hitting the rumble strips accidentally when driving, creating exterior noise that can cause noise pollution and discomfort to people living in the vicinity of roads where rumble strips are installed. According to Torbic et al. (2009), this noise can be heard from a distance up to 2 km from the roads where the rumble strips are installed.

However, the exterior noise can also be beneficial in case there are people on the emergency lane and there is a vehicle traversing from the driving lane to the emergency lane (Goubert et al., 2014).

- When hitting a rumble strip, drivers can overreact and steer in an unsafe manner, leading to crashes (Hatfield, Murphy, Soames Job, et al., 2008).
- When rumble strips are only installed on the edge of the road, drivers may keep more distance from the rumble strip to avoid hitting it accidentally, driving closer to the adjacent lane. Therefore, the probability of crashes with vehicles driving on the adjacent lane can increase (Meyer, 2000).
- Moreover, some authors concluded that the use of audio-tactile line marking can cause a loss of control for cyclists and motorcyclists that drive over them (Noyce & Elango, 2004).

1.1.2 Wide and paved road shoulders

Road shoulders are meant to provide a space in which vehicles can stop in case of emergency. However, they can also be used by vehicles driving out of the lane to recover their trajectory and drive back on the lane. Nevertheless, if the shoulders are unpaved or too narrow their effectiveness is reduced. According to S Matena et al. (2007), ROR crashes had 50% more chances of occurrence on roads without shoulders compared to roads with shoulders of 1.8 m width.

Neuman et al. (2003) summarized the reduction of crashes on two-lane rural roads depending on shoulder width (Table 3).

Total Amount of Lane or Shoulder Widening		Percent Accident Reductions		
Total (ft)	Per Side (ft)	Lane Widening	Paved Shoulder Widening	Unpaved Shoulder Widening
2	1	5	4	3
4	2	12	8	7
6	3	17	12	10
8	4	21	15	13
10	5		19	16
12	6		21	18
14	7		25	21
16	8		28	24
18	9		31	26
20	10		33	29

Table 3: **Reduction of crashes on two-lane roads depending on shoulder width (Neuman et al., 2003)**

1.1.3 Pavement drop off management

When shoulders are not paved or hardened or when they are not appropriately maintained, drops can appear at the edge of the pavement (**Figure 9**). This can lead to a loss of control and a higher probability of suffering a ROR crash. Moreover, if there are drops on the road edge, it can be difficult for drivers to drive back on the lane after having traversed the road edge. Drops at the edge of the pavement can appear due to the erosion of unpaved shoulders or following a maintenance operation when extra material is added to the driving lane but not to the shoulder.

Figure 9: Example of a pavement edge drop (Hallmark et al, 2006)

1.1.4 Ensure an appropriate obstacle-free distance (Clear zone)

The objective of this countermeasure is to provide drivers with an appropriate area free of obstacles to reduce the probability of a crash against an object. As a result, drivers may potentially have more time to recover after leaving the road and the outcomes of ROR accidents are reduced. **Table 4** shows the reduction of ROR, head-on and sideswipe crashes on two-lane rural roads depending on the obstacle-free distance (or clear zone).

Amount of Increased Roadside Recovery Distance, meters (feet)	Percent Reduction in Related Accident Types (i.e., ROR+head-on+sideswipe)
1.5 (5)	13%
2.4 (8)	21
3.1 (10)	25
3.7 (12)	29
4.6 (15)	35
6.2 (20)	44

Table 4: Reduction of ROR, head-on and sideswipe crashes by obstacle-free distance (Neuman et al., 2003)

1.1.5 Improve delineation of curves

The objective of this measure is to avoid vehicles driving off the road on road sections with sharp curvature. This can be achieved by making the drivers aware that they are approaching a sharp curve or creating a situation in which drivers have to reduce their speed before entering the curve. In order to warn drivers, warning signs or special pavement markings can be installed. Other measures such as placing transverse markings or transverse rumble strips can be used to reduce driving speed. An example of pavement markings informing the road user about sharp curvatures ahead is shown in **Figure 10**.

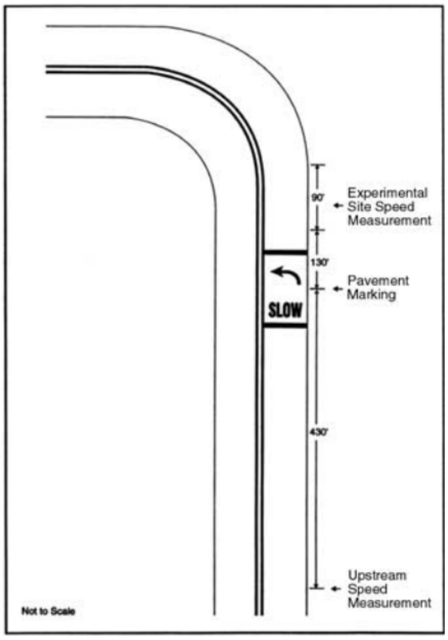


Figure 10: Example of an improved delineation of a sharp curve (Neuman et al, 2003)

1.1.6 Improve road marking

Road marking should be improved in dangerous locations (e.g. curves) to allow drivers to have a better idea of the lane edge. By improving the road marking, especially at hazardous locations, information is given to the drivers regarding the driving lane to in an attempt to prevent them running off the road because they cannot distinguish the lane edges. There are different possibilities to improve the road marking and its visibility. For instance, use markings with higher contrast, wider or raised pavement as explained before (Siddiqui, 2015).

This countermeasure is not focused on reducing the vehicles' speed but on making the edge lanes more clear to keep drivers on the lane. The costs of applying this measure are not high and it is estimated that ROR crashes may decrease by 15% (Neuman et al., 2003).

1.1.7 Guardrails

Guardrails are meant to reduce the outcomes of a ROR crash. When guardrails are installed, the speed of vehicles in the event of a crash may be lower but their primary function is reduce the outcome severity of a crash. However, they are an object on the roadside and therefore the incidence of crashes (especially damage only) is likely to increase.

1.1.8 *Driver and vehicle-related countermeasures*

These countermeasures consist of driver assistance systems installed in the vehicle to alert the driver that a ROR crash is about to occur. An example of such a system is a lane departure warning assistant (LDWA) or a lane keeping system (LKS) (G. Schermers, Malone, & van Arem, 2004). Moreover, some infrastructural measures, such as the use of rumble strips, can also contribute to reduce ROR crashes caused by driver-related errors. Rumble strips alert drivers that they are leaving the driving lane by means of noise and vibration.