CEDR Transnational Road Research Programme

Call: Safety

Funded by Belgium-Flanders, Ireland, Netherlands, Slovenia, Sweden, United Kingdom

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Provision of Guidelines for Roadside Safety (PROGReSS) – Roadside safety elements, state of the art report

WP5 Quality management and final report

Deliverable 5.1

December 2019

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CEDR Call: Safety

Provision of Guidelines for Roadside Safety (PROGReSS) – Roadside safety elements, state of the art report

WP5 Quality management and final report

Start date of project: 01/09/2017 End date of project: 30/12/2019

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Version: 1.0

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Glossary of Terms (WHO, 2015)

Barrier terminals: the ends of safety barriers which often need to be protected by crash cushions.

Breakaway columns: lighting or telegraph poles, designed to break or collapse on impact.

Bridge pier: the support columns of bridges.

Central refuges: areas in the middle of the carriageway, where pedestrians can stop and wait until the road is clear before crossing.

Clear zoning: the systematic removal of all hazardous features near the roadside, to minimize the chances of injury should a vehicle run off the road.

Crash cushions: energy-absorbing applications that can be attached to barrier terminals and other sharp-ended roadside objects to provide crash protection on impact.

Crash-protective roadsides: collapsible or breakaway roadside objects or energy-absorbing "cushions" on barriers and rails that reduce the severity of injury on contact.

Crash-protective vehicles: vehicles designed and equipped to afford interior and exterior protection to occupants inside the vehicle as well as to road users who may be hit in the event of a crash.

Forgiving roadside objects: objects and structures designed and sited in such a way that they reduce the possibility of a collision and severity of injury in case of a crash as well as accommodating errors made by road users. Examples are collapsible columns, guard fences and rails, and pedestrian refuges.

Guard fences and rails: rigid, semi-rigid or flexible barriers which are situated at the edge of a carriageway to deflect or contain vehicles, or in the central reserve to prevent a vehicle crossing over and crashing into oncoming traffic.

Low-cost and high-return remedial measures: low-cost, highly cost-effective engineering measures applied at high-risk sites following systematic crash analysis.

Median barrier: safety barrier positioned in the centre of the road that divides the carriageway, deflects traffic and often has energy-absorbing crash-protective qualities.

Motorised two-wheelers: a two-wheeled vehicle powered by a motor engine, such as a motorcycle or moped.

Offset deformable barrier test: a frontal crash test that aims to reproduce real-world conditions of car-to-car frontal crashes. In this test, the front of the striking vehicle partially overlaps a deformable barrier.

Reflectors: materials that reflect light as an aid to visibility. They may also be fitted to non-motorised transport and roadside objects.

Road infrastructure: road facilities and equipment, including the network, parking spaces, stopping places, draining system, bridges and footpaths.

Roadside furniture: functional objects by the side of the road, such as lamp posts, telegraph poles and road signs.

Road traffic crash: a collision or incident that may or may not lead to injury, occurring on a public road and involving at least one moving vehicle.

Road traffic fatality: a death occurring within 30 days of the road traffic crash

Road traffic injuries: fatal or non-fatal injuries incurred as a result of a road traffic crash.

Road user: a person using any part of the road system as a non-motorised or motorized transport user.

Rumble strips: a longitudinal design feature installed on a roadway shoulder near the travel lane. Rumble strips are made of a series of indented or raised elements that alert inattentive drivers through their vibration or sound. They may also be used for speed reduction.

Safety barriers: barriers that separate traffic. They can prevent vehicles from leaving the road or else contain vehicles striking them, thus reducing serious injury to occupants of vehicles.

Safety performance standards: definitions or specifications for equipment or vehicle performance that provide improved safety. They are produced nationally, regionally, or internationally by a variety of standard-producing organisations.

Self-explanatory road layouts: the use of engineering measures such as road markings and signs that make clear the course of action by different road users.

Skid-resistant surfacing: surface material on a road or pavement designed to prevent vehicles from skidding or pedestrians from slipping.

Transition zones: road marking or features forming a gateway which marks transition from higher speed to lower speed roads, for example, rumble strips, speed humps, visual warnings in the pavement and roundabouts.

Unforgiving roadside objects: objects and structures designed and sited in such a way that they increase the chances of collision and severity of injury in case of a crash. Examples are trees, poles and road signs.

Utility poles: poles at the roadside with a particular function, such as telegraph poles, road traffic sign poles and lighting poles.

1 Introduction

In 2016 CEDR published a call for research proposals under the theme “Safety” and comprising the following four separate topics:

A. Safety for both Road Worker and Road Users - reduce incursions in to work zones

B. Driver Distraction – (Digital) Billboards

C. Guidance for Safe roadsides

D. Self-explaining systems for VRU safety in non-urban areas

The overall aim of this research programme was to improve knowledge in road safety among road authorities in a manner that allows for the improvement of road design, operation and maintenance standards, guidelines and network strategies. A principal goal of the Safety research programme was effective dissemination and it clearly stated that the research should be directed at finding practical, implementable solutions to current problems in these project areas and to deploy strategies to ensure that these solutions find support among National Road Authorities.

Topic C-Guidance for safe roadsides strives to improve roadside safety on European roads. Although much work has been done on roadside safety by CEDR and other organisations in Europe, this is an issue that remains a major road safety problem especially on rural roads in EU member countries. To an extent this is attributed to a combination of issues including a lack of uniformity across country guidelines, insufficient empirical evidence of the effectiveness of treatments and the relationship with crashes, differences in approaches and a general lack of understanding of the consequences of deviations from recommendations in guidelines.

As in the 2009 (Safety at the Heart of Road Design) and 2013 (Safety) programmes, CEDR is pursuing the aim of producing and disseminating practical and user-friendly guidelines and tools for its member road authorities to address the problem of single vehicle crashes resulting from run-off-road events and during the maintenance of road verges. The emphasis of the 2016 programme is on dissemination, primarily through a synthesis and adaptation of past research, a user needs study and pilot studies and demonstrations of processes aimed at achieving safe and forgiving roadsides in support of the safe systems philosophy.

PROGReSS – Provision of Guidelines for Roadside Safety is the project funded within the CEDR 2016 Safety Call, topic C, in which the results of a status quo review of available EU roadside safety standards and guidelines are combined with the experiences from National Road Authorities in applying these in the design, operation and maintenance phases of EU high speed roads (speed limits higher than 70 km/h). A special emphasis is put on the six funding countries (Belgium-Flanders, Ireland, Netherlands, Slovenia, Sweden, and United

Kingdom), plus Germany and Portugal which are included to increase the geographic representation of the results.

The primary objectives for PROGReSS are:

- To review existing roadside safety design, maintenance and operational requirements for clear (obstacle free) zones and also for road restraint systems (as defined by for e.g. EN 1317).
- To determine to what extent National Road Authorities in Europe and their contractors are capable of implementing and maintaining compliance with the standards and guidelines throughout the life cycle of roads.
- To develop recommendations for safe roadside design and management ensuring broad acceptance among member National Road Authorities of CEDR.

1.1 Structure of the Project

The PROGReSS work plan comprised a total of seven work packages (WP), five of them dealing with the essential content of the project, one work package for dissemination and a project management work package to ensure smooth project progress and provide liaison between the CEDR management team and the project team. WP 1 consisted of a technical review of existing standards and guidelines in each of the contributing countries, and a consolidation of knowledge on the design and management of rural roadsides internationally. The primary aim of WP 2 was to establish current working practices with respect to the design and management of (safe) roadsides in Belgium-Flanders, Ireland, Netherlands, Slovenia, Sweden and the United Kingdom (the countries funding this research). WP 2 based this primarily on personal interviews with National Road Authorities (NRAs) in the six funding countries, plus representatives from National and Regional Road Authorities (RRAs) in Germany and Portugal. In order to gather information from a broad range of respondents, an internet-based questionnaire survey was issued to road authorities, contractors, consultants, those in academia and those involved in research from different countries.

Results from WP 1 and 2 have been used in WP 3, to identify the effective, promising and innovative practices used by different road authorities and to prepare a complete assessment of roadside safety management to develop the intended roadside safety evaluation tool.

WP 4 aimed to test and gain insight in the use of the tool developed in WP3, to further develop the first alpha version of the Roadside Safety Organisational Robustness Assessment Tool to a fully capable final version. For this purpose, a two-stage pilot testing phase was adopted for testing the practicality, ease of use, de-bugging and for the identification of other improvements.

- Pilot stage 1: a review and initial assessment of the tool without a real-life case. This aimed at getting input of the usability and comprehensibility before testing it in real life cases
- Pilot stage 2: full scale test of the tool in real life cases. This aimed at getting feedback from participating NRAs applying the tool in practice to current and ongoing projects and work procedures.

The outline of the structure of PROGReSS as well as the linkages between the different work packages is illustrated in **Figure 1**.

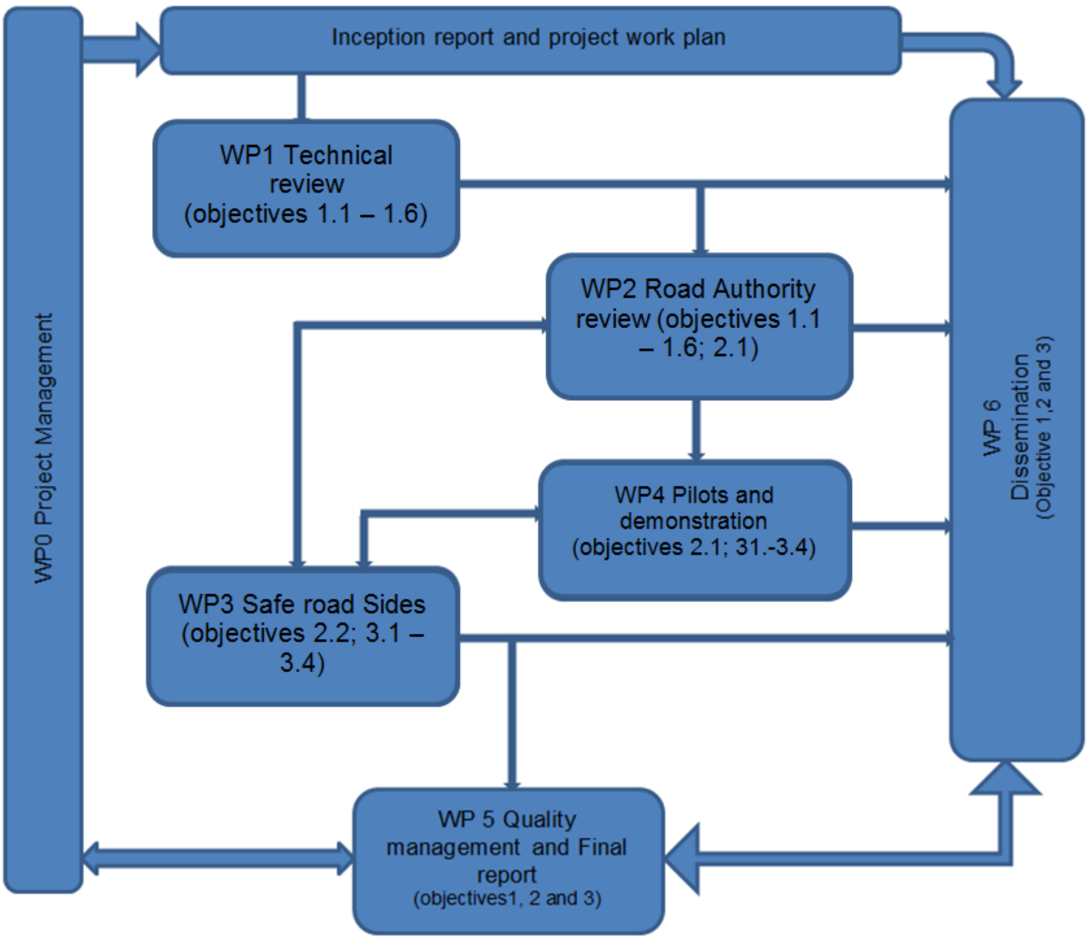


Figure 1: Project outline and linkages between work packages

1.2 Purpose of this Deliverable

The purpose of this report is to bring together the most relevant results of all the foregoing Work Packages and document this in a compressed summary report. Chapter 2 provides a brief overview of the development of road safety in Europe and the role Run-off-Road crashes play. In addition, guidance on how to provide safe roadsides is given by mentioning selected relevant projects. Furthermore, the structure of the risk model is explained and options are discussed. Chapter 3 points out the main results of the literature research which had led to a list of 150 quantified roadside safety measures. Another aspect mentioned in this chapter is the comparison of guidelines of the six countries funding this project plus Portugal and Germany. Within Chapter 4, the main aspects concerning the current practice in safe roadside design as well as typical problems associated with applying these guidelines and standards are mentioned. Furthermore, common problems concerning the provision of safe roadsides are stated. Based on input given by national and regional Road Authorities as well as by consultants and practitioners various issues, problems and shortcomings experienced are reported in Chapter 5 in a structured way leading to recommendations for further developments. Chapter 6 introduces the "Roadside Safety Organisational Robustness Fault Tree" aimed to offer guidance on how to detect the most relevant elements to be improved in order to increase traffic safety by means of design and management of safe roadsides along higher order rural roads. How this fault tree is transformed into an EXCEL-Tool and how this tool was tested are topics of Chapter 7. Chapter 8 outlines the main results of PROGReSS and provides the conclusions and recommendations. More detailed reports of the various work packages are available on the project website www.cedrprogress.eu and later on the CEDR website (www.cedr.eu).

A further goal of this report is to propose an implementation plan specifically for CEDR in which an outline will be provided with which to improve compliance with roadside design and management standards and guidelines.

One further intention of this project was to describe relevant cross-section design features and roadside elements, their positive and negative aspects and to provide guidance to their application and maintenance requirements, including aspects such as cross-section design features (e.g., curbs, berms, and edging), facilities for other modes (e.g., cycle and/or footpaths); utilities and signage and verge and related elements (clear zones, barriers, drainage ditches, utility poles, signage, snow, storage areas and maintenance areas). However, as the project developed it became quite apparent that the nature of the support tool was more directed at the management processes relating to roadside safety as opposed to the initially intended design support tool. Consequently and in consultation with the PEB, it was decided not to pursue or cover these aspects.

2 Safe Roadsides

2.1 Scale of the Roadside Safety Problem in Europe

Facing the burden of over 40,000 traffic fatalities per year in the European Union, in 2001 the European Commission set a target to halve the number of traffic fatalities by 2010 (European Commission 2001) and, based on very positive experiences, again to reduce that in half by 2020 (European Commission 2001). To support this target set by the European Commission, many member countries introduced programmes to deal with the road safety problem. These efforts have resulted in a significant decline in the number of fatalities on EU roads over the period 2007 to 2017 (**Figure 2**).

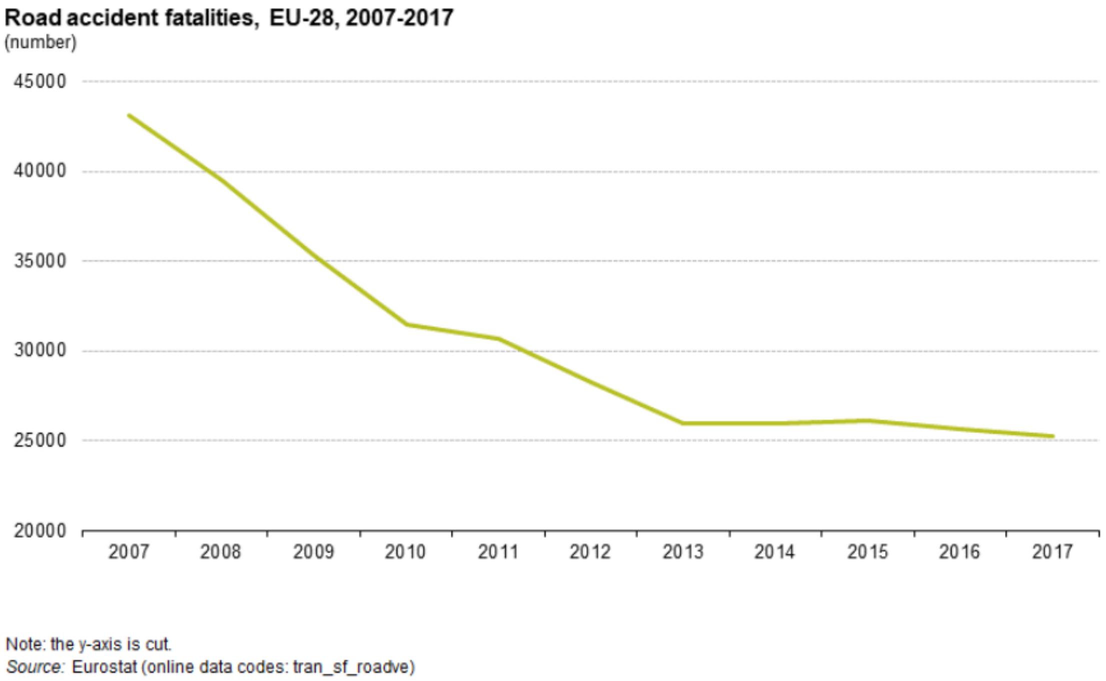
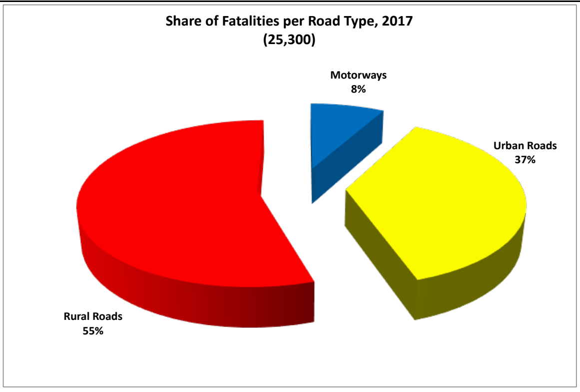


Figure 2: Traffic fatalities in the EU over 2007-2017 (Eurostat, 2019)

To achieve this goal, improvements in all relevant areas were necessary, hence road infrastructure had to be improved too. One sustainable approach in supporting this goal was to increase the safety level of road design and road construction, not only of those roads of the Trans-European Network for Transport (TEN-T). The distribution of fatalities across the various road types in Europe reveals that rural roads in particular have a significant contribution of 55%. Analysis of the crash data on these roads show that the vast majority of fatalities occur on road sections rather than on intersections. Due to the fact that 87% of all fatalities on rural roads occur between intersections it is evident that the design of roads may be a major concern (**Figure 3**).



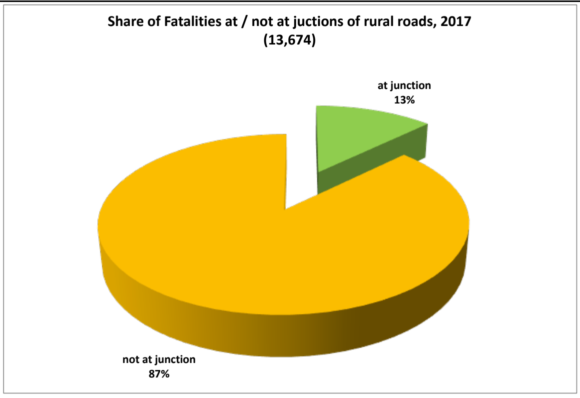


Figure 3: Fatalities by road type in the EU (European Commission 2017, European Commission 2018)

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. 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**).

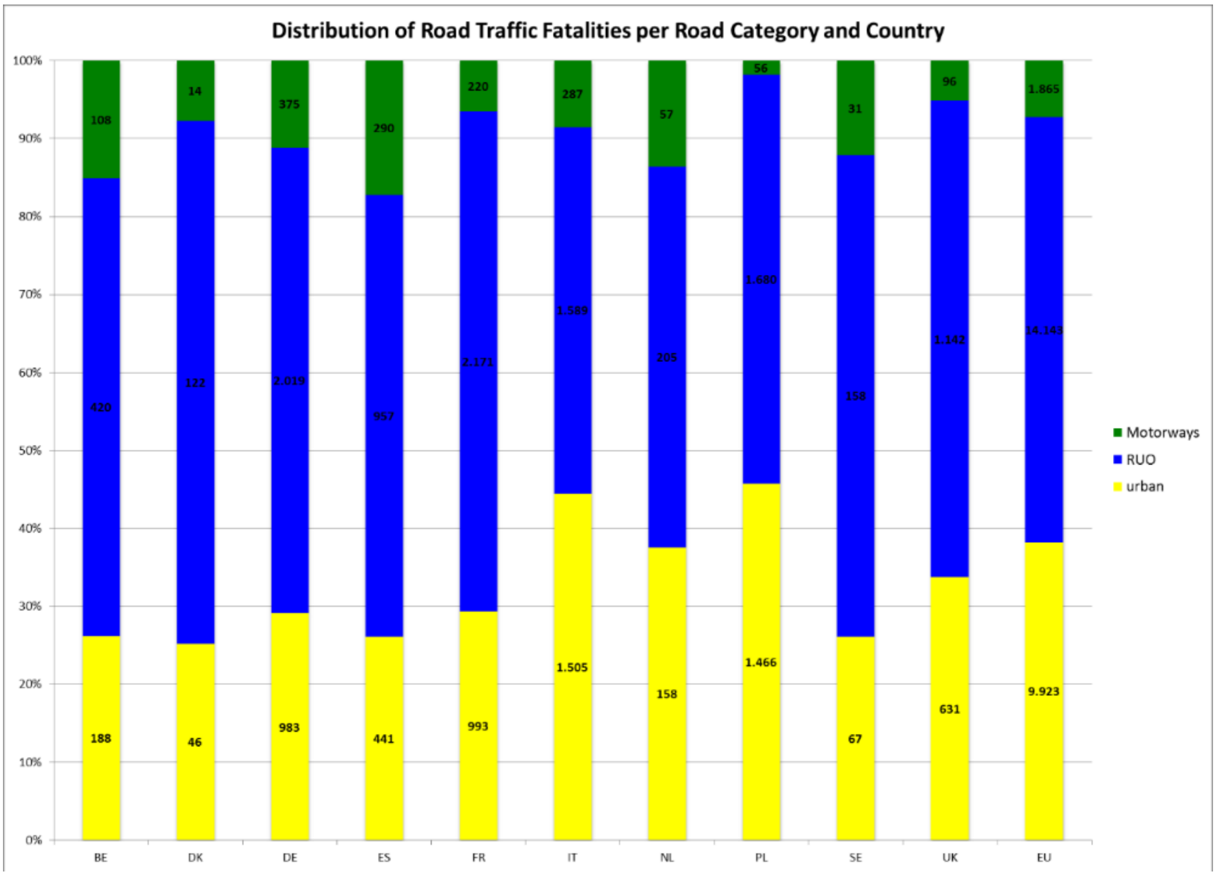


Figure 4: **Road fatalities by road type in selected European countries over 2005-2015, CARE database, May 2017** (European Commission 2018)(European Commission 2017)

This is further demonstrated in **Figure 5**, for the Highways England Strategic Road Network (SRN). In 2013 the total number of fatalities recorded on the SRN motorways, roads of the highest order with a dual carriageway and those with a single carriageway were on comparable levels. However, when adjusted by the amount of travel in terms of Hundred Million Vehicle Miles (HMVM), roads with a single carriageway had a fatality rate of approximately 8 times of the motorways.

This is also supported by recent iRAP results for England, which identified an average of four to five-star rating for the majority of motorways located on the SRN. In contrast the high speed (60mph) single carriageway A-roads located on the SRN had an average of one to two-star rating.

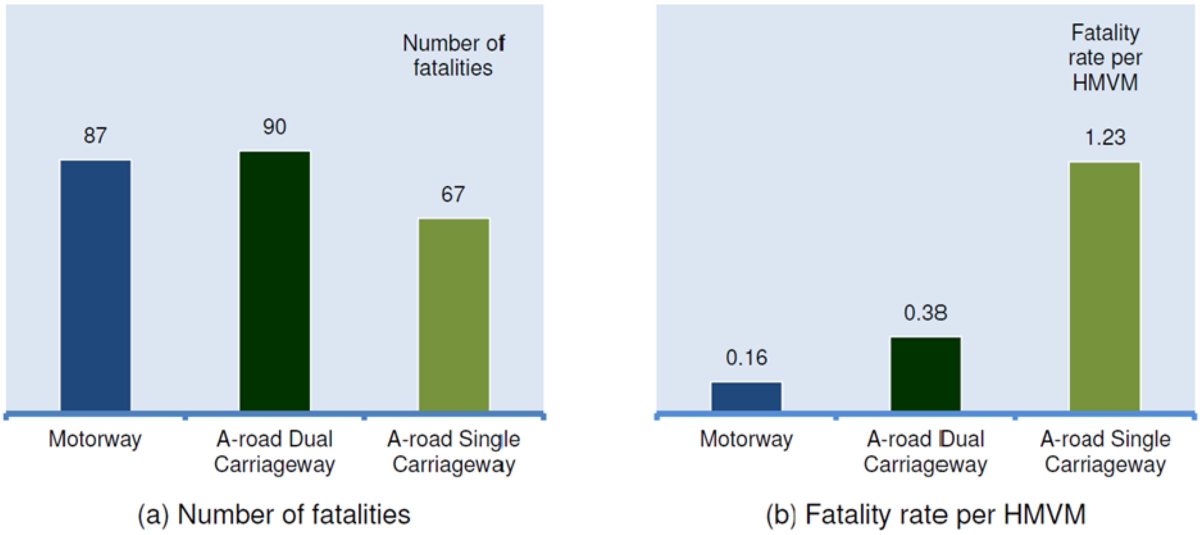


Figure 5: Number and rate of Fatalities on Highways England SRN by road classification, 2013 (The Highways Agency, 2014)

In Europe an ongoing problem remains the high proportion of crashes associated with (unsafe) roadsides and verges, namely single-vehicle crashes and loss-of-control crashes resulting in head-on and other crash types. Information of selected countries extracted from the CARE/CADaS database reveals that in the period 2017-2018 single-vehicle crashes constitute up to 35% of all fatalities resulting from traffic crashes on rural roads (**Figure 6**) and up to 27% on motorways **(Figure 7)**. Even though many of these accidents are likely to be associated with the design and maintenance of roads, the accident severity can be directly associated with the design and maintenance of roadside areas. In addition to these directly attributable crashes there are also a proportion of crashes where the condition of the roadside may influence other crashes, for example, poorly maintained verges restricting intersection or stopping sight distances.

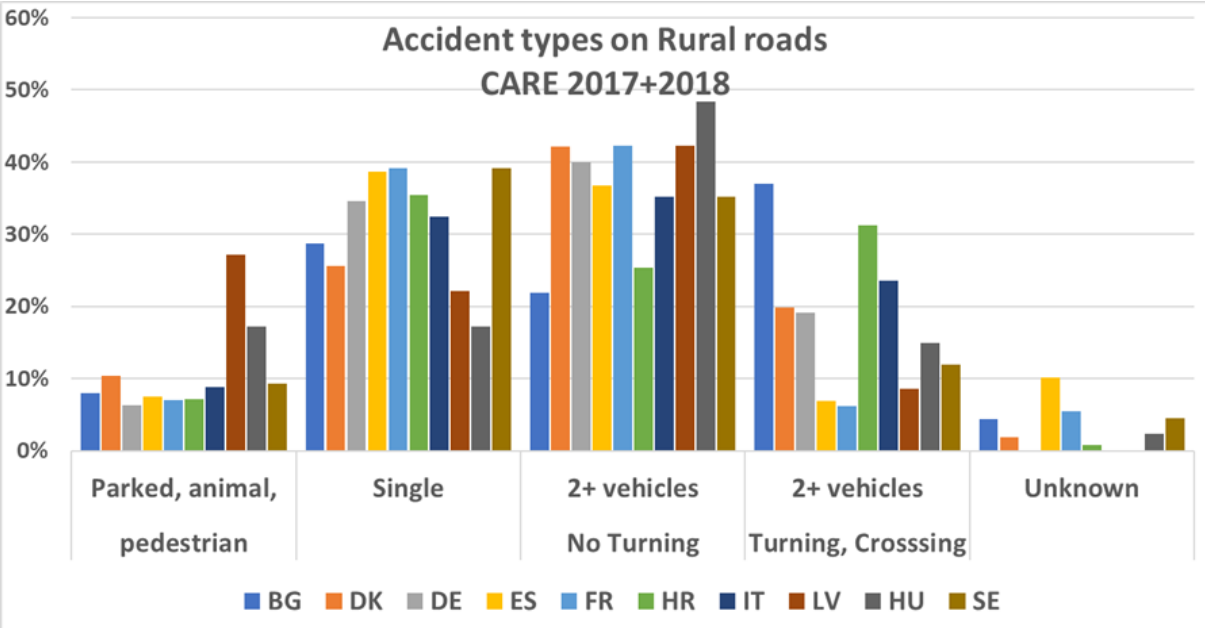


Figure 6: **Fatalities on rural roads grouped by crash types in ten European countries (n=15.553) (Care database, January 2020)**

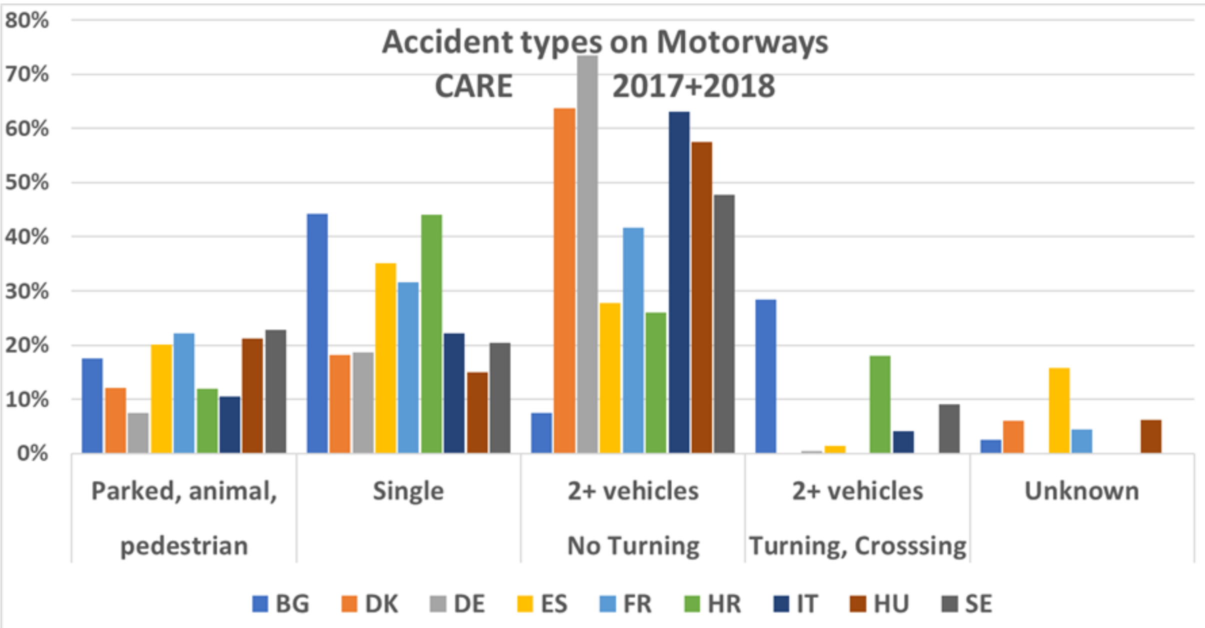


Figure 7: **Fatalities on motorways grouped by crash types in nine European countries (2.966) (Care database, January 2020)**

Based on these figures it becomes obvious that in previous Research Programmes on Safety (2009, 2013), CEDR pursued the aim of producing and disseminating practical and user-friendly guidelines and tools for its member road authorities to address the problem of single-vehicle crashes resulting from run-off-road events and during maintenance of road verges. In light of road safety developments of past years, the traffic safety target set by the European Commission, and the knowledge already available, the emphasis of the CEDR Programme 2016 is on dissemination and implementation of results. This will be achieved primarily through a synthesis and adaptation of past research, a user needs study, pilot studies and demonstrations of processes aimed at achieving safe and forgiving roadsides in support of the safe systems philosophy.

2.2 Importance of ROR Crashes for Traffic Safety

A run-off-road crash (ROR) is defined by Edwards, Morris et al. (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"*.

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

- Environment related factors
    - Road
    - Weather
    - Lighting
- Driver related factors
    - Occupancy
    - Gender of driver
    - Age of driver
    - Alcohol related driving
    - Driver performance related factors
- Vehicle related factors
    - Vehicle speed
    - Vehicle type

ROR crashes are a significant problem, representing 51% of road fatalities in the US in 2011 (Khan, Abdel-Rahim et al. 2014). In Europe, one third of road fatalities are ROR crashes and driver error has been attributed as a primary cause (Tomasch, Hoschopf et al. 2016).

In the Netherlands, ROR crashes represent one third of road fatalities and one sixth of the serious injuries. The majority of these accidents 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.

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/verge. In the case of uncontrollable crashes, drivers cannot correct their trajectory before leaving the road.

In the period from 2013 to 2016 uncontrollable ROR crashes accounted for 3151 (24%) fatal accidents in Germany. In three quarters of the crashes the vehicle collided with an obstacle next to the carriageway. 10% of these 'obstacles' were safety barriers (own calculations based on the database of the German Statistical Office).

The main causes of ROR crashes are related to human errors. Different authors reported fatigue and distraction as main factors. For instance, McLaughlin, Hankey et al. (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 et al. 2011).

Focusing on 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, Doumen et al. 2011).

These percentages make it clear that mitigating ROR crashes or at least their severity would lead to a significant improvement in road traffic safety.

2.3 Guidance on how to provide Safe Roadsides

Over the past 50 years extensive research has been conducted into the relationship between clear zones and road safety (Elvik, Hoye et al. 2009, AASHTO 2010), 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 have 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 (van Petegem 2012, Schermers and Van Petegem 2013, van Petegem and Louwerse 2015, Petegem, Louwerse et al. 2017, Louwerse and Petegem 2018) 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 if struck. This research has to a large extent been the foundation for the development of numerous (international) standards regulating and prescribing best practice when it comes to roadside design and in some cases maintenance.

In Europe, numerous standards have been produced aimed at making roads in particular, and roadsides specifically, more forgiving. However, many of these are aimed at the 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 various 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 (La Torre et.al., 2011). 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 (CEDR, 2014). 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 8**) is an example of such a traditional approach (Thomson; Fagerlind; 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 (Roque and Cardoso 2013, Roque and Cardoso 2015).

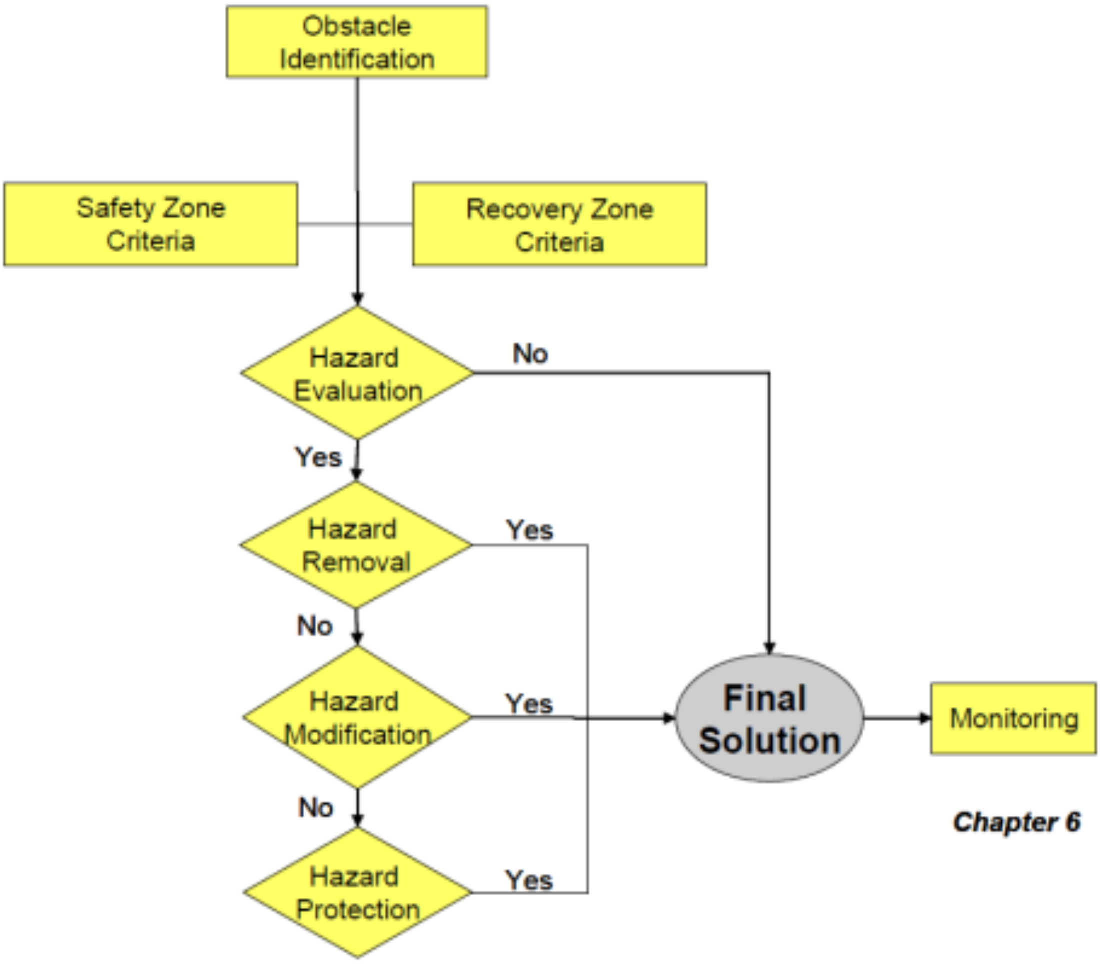


Figure 8: RISER decision support algorithm (Thomson, 2019)

Furthermore, research on safe roadside design paid limited attention to aspects such as maintenance and safety during maintenance. Consequently, the procedures in 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 leading to potential discord between the setting of standards for new roads and maintaining them for the duration of the roads' life.

2.4 Development of a systematic approach to Roadside Safety Management

Even though most European countries have unique roadside safety standards, most share similar approaches in the way they define roadside risk and the procedures they recommend for mitigating it. This was clearly shown in SAVeRS (Erginbas at al., 2014), under which the national roadside design guides and standards of 35 different countries were analysed and compared in detail. This study defined roadside risk as the product of likelihood (including the likelihood of a vehicle leaving the carriageway and the likelihood of an errant vehicle reaching a hazard) and consequences (for occupants of the errant vehicle and for third parties) of a roadside accident (**Figure 9**).

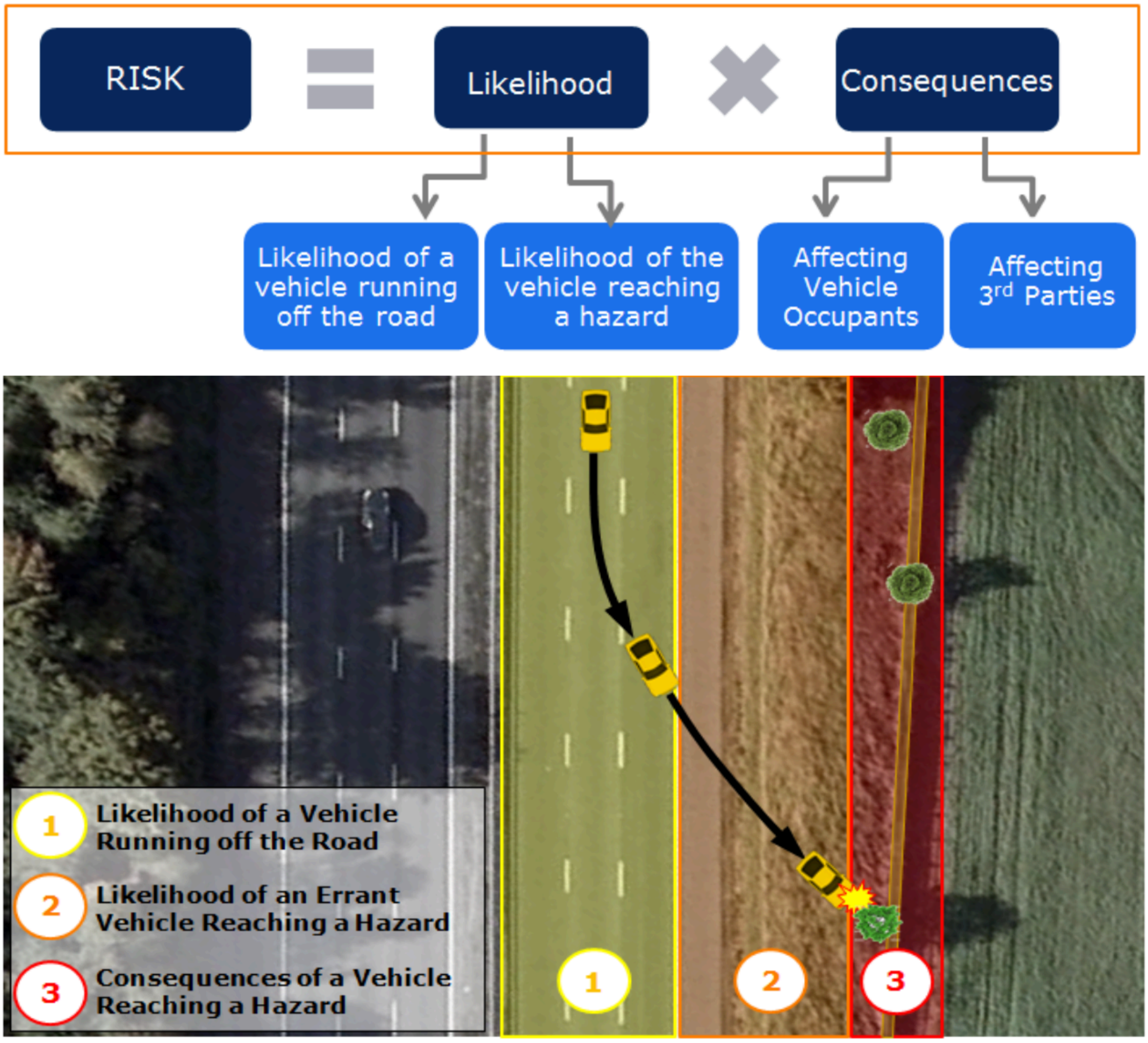


Figure 9: Risk from a roadside safety perspective (Erginbas et al., 2016)

In the standards, the likelihood part of the 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 area it is assumed that they are likely to be reached by an errant vehicle. Similarly, in the majority of standards, the consequences part of the risk formula is assessed through the identification of roadside objects and terrain features which are considered a hazard for each country; in other words, they are considered to have high consequences if reached by an errant vehicle and therefore 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 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.

A fundamental issue that is directly related to roadside safety is the choice of mitigation method, once the risk is identified as high. 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 (again decreases both 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 and the second is to shield the hazards with vehicle restraint systems. 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 vehicle restraint systems to screen off objects/obstacles that may constitute a safety hazard for road users. Vehicle restraint systems are considered 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 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, namely the definition of obstacles and the levels of maintenance over time. For example, trees become obstacles/hazards once their trunks reach a certain diameter, greenery grows and restricts visibility and these aspects require monitoring. The same applies to vehicle restraint systems, frangible posts and masts, time (ageing/deterioration) could affect their (safety) performance and they may require replacement (2019). It is equally important that such systems and "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 lower 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. Associated with the maintenance of roadsides is the safety of road workers. Inherent to safe roadsides is effective management and quality control.

3 Safe Roadside Design - Available Knowledge and Comparison of Guidelines

The analysis of available knowledge was based on an extensive literature review of several roadside safety projects as well as on a collection of the most relevant studies related to the application of guidelines and standards in the improvement of roadside safety. This review focused on studies that explored and highlighted the relationship between compliance to standards/guidelines and safety. The intention was to establish to what degree road authorities can determine the consequences of deviations from recommended standards and practice on safety when making design choices.

Based on analyses of 10 roadside safety projects and 137 studies one can say that not a single project had looked thoroughly into the application of guidelines and standards on roadside safety. Based on 13 selected studies none of these were related to the application of European guidelines and standards on roadside safety. Only three of these related to the application of other guidelines and standards. The remain 10 studies were focused on neighbouring roadside safety issues rather than directly on the application of guidelines and standards. Based on these results one could conclude that the effect of the application of guidelines and standards on roadside safety has not been sufficiently studied or reported in scientific journals in Europe or the rest of the world.

To lay the foundation for the establishment of best practices an in-depth literature review was focussed on quantified relationships between roadside design elements and parameters (which are featured in the roadside design guidelines of the six funding countries) and the frequency and severity of real world crashes. The aim was to evaluate the relevance of the roadside design guidelines and standards for traffic safety. To illustrate all identified relationships between the different roadside design elements with road safety in general, and crashes in particular, a matrix was developed. Within this matrix, roadside design elements and related parameters were grouped into three categories, with regards to their relation to the risk model from a roadside safety perspective. These categories are:

- likelihood of leaving the carriageway.
- likelihood of reaching a hazard and
- consequences of reaching a hazard.

In total 150 roadside safety features were identified to contribute to road safety by the frequency and/or severity of crashes in this literature review. The elements are related to

- clear/obstacle free zones,
- hazards reduction,
- side slopes,
- shoulders,
- drainage structures,
- passively safe poles and
- roadside and median barriers.

The selected Roadside design elements/parameters and their effects on crashes are listed in deliverable 1.1 of this project (Cardoso et al., 2018).

Furthermore, the standards and guidelines for roadside design and management of the six funding countries plus the relevant CEN standards were analysed in order to establish the relationship between the design and management of roadside elements and factors with traffic safety in general and crashes in particular. The positive result is that Belgium (Flanders), Ireland, Netherlands, Slovenia and Sweden include requirements in their RRS standards relating to the area at the side of the road which should be kept free of hazards. UK is the only funding country which does not specify clear/obstacle free zones in their standards. Concerning the Directive of the European Union on Road Infrastructure Safety Management (RISM) no impact on road equipment and component selection quality was determined. However, with the aim of improving safety for all road users on all rural roads within the EU by a high level of safe road infrastructure it is proposed to extend the reach of the RISM Directive to include Non-TEN-T roads. (During this research project an amended version of the Directive was published. This amended version extended the scope of the Directive beyond the trans-European transport network (TEN-T) to cover motorways and primary roads outside the network as well as all roads outside urban areas that are built using EU funds in whole or in part.)

In addition, the standards and guidelines that relate specifically to roadside maintenance and operations were assessed to establish whether maintenance of roadside furniture and equipment are related directly to road safety or whether these are inferred (i.e. preventive versus reactive). An overview as to what is current practice was obtained. Specific attention was given to road worker safety during maintenance of roadsides. As a result, it could be stated the UK has the most comprehensive maintenance standards and guidelines when compared to the other five funding countries. Concerning temporary safety measures applying to roadworks, health and safety for temporary construction sites, employer responsibility relating to employee safety and personal protective equipment have been implemented across the EU between 1989 & 2008 and have been adopted by all countries. It could be stated that roadside operations and maintenance procedures appear to be of a similar format with country specific differences in terms of the frequency of inspections.

To judge different approaches the roadside safety performance in the six funding countries plus Germany and Portugal, a benchmarked based on crash data analysis was carried out. The analysis points out the importance of this topic for traffic safety. Within the decade 2006-2015 almost 28,000 persons were killed in ROR crashes in the six funding countries plus Germany and Portugal. Regrettably using the data available it was not possible to calibrate ROR crash prediction models.

In order to go further into detail concerning the possible impact roadside design has on traffic safety, 54 road safety inspection (RSI) reports conducted in Ireland were analysed. These reports were carried out over a period of six years (2012 – 2017) covering 4,000km of National roads. Using Latent Dirichlet Allocation (LDA), the aim was to analyse how relevant the aspect of roadside safety is in the frame of RSI, by searching for keywords mentioned in the RSI reports, divided into two groups: problems found; and proposed solutions. The analysis point out that the important keywords ‘’forgiving roadside’’ and ‘’clear zone’’ as well as the relevant European technical standards (EN 1317 and EN 12767) are absent from the extracted latent topics. A further approach was to detect co-occurrence patterns of attributes related to ROR crashes identified from road safety inspection reports, as well as the intervention patterns associated with these crashes. As a result, it could be stated that the frequency of topics related to roadside safety is higher in the problems record set than in the solutions record set, meaning that problems are more easily identified and related to the roadside area than interventions may be (Cardoso et al., 2018, Roque et al., 2019).

4 Safe Roadside Design - Current Practice

To give important input to the (further) development of approaches towards safe roadsides, the current practice was analysed by personal interviews with representatives from the NRAs of the six funding countries as well as Portugal and Germany. In addition, representatives from RRAs, consultants and practitioners in Europe were invited to share their knowledge via an internet-based questionnaire.

One target of the survey questionnaire was to assess the application and use of design standards and guidelines regulating roadsides and verges alongside rural roads with speed limits higher than 70km/h (40mph) and generally including the higher order rural roads. In addition, questions concerning maintenance and quality control procedures were asked.

With the aim to increase the response rate from different European countries the survey was provided in English, French and German. Even though a much higher response rate was anticipated information from 15 of the 28 member states of the European Union were received. Responses were received from 13 NRAs, 7 RRAs plus two Road Operators and two Consultants. In addition, four Research Institutes responded to the questionnaire thus the project received input from 33 organisations (The WP2 (Connell and Hall 2019) report mentions 34, this however is a typing error in the report).

To estimate the relevance and usefulness of multinational approaches in the field of road infrastructure safety, one question was on the awareness of road safety research programmes, and their impact, if any, upon national rules and regulations. Based on the 33 responses from 15 different countries it could be stated that almost 60% (19/33) were aware of previous road safety research programmes financed by CEDR. One could judge this as a positive result, but it has to be mentioned that huge differences exist. Of 19 previous road safety programmes mentioned by respondents, awareness of said programmes ranged from 1 to 14. Concerning the relevance of these programmes, the vast majority of those respondents who are aware are of the opinion that the output of these programmes are useful, which counts for 95% (18/19). However, only three quarters (14/19) made use of the findings.

Following a review of narratives added by respondents, it appears that the results of previous CEDR project were useful on different levels which ranged from the exchange of experiences, to assistance in writing country guidelines. Furthermore, the value of collaboration and of common development of guidelines was mentioned. Those who did not find the outputs of previous CEDR programmes useful suggested that difficulties exist when attempting to update or revise national guidelines based on the results of an international project. Another aspect is that the findings of the project reports are not suitable for direct integration into guidelines. In addition, it was mentioned that there is not always value to be gained from the results when compared to existing knowledge at the national level.

Focussing on the current national approaches respondents were asked to provide information and links to their guidelines/design standards, if available. In addition the respondents were asked for their assessment of the suitability of said guidelines/design standards to provide a high level of roadside safety.

With regard to roadside design, 88% (29/33) indicated that a design standard is available within their country. 76% (22/29) consider their roadside design standards to be sufficient for a high level of roadside safety. With regard to roadside maintenance, 64% (21/33) indicated that a design standard is available within their country, however only 52% (11/21) consider their roadside maintenance standards to be sufficient for a high level of roadside safety. This response, which equates to 33% (11/33) of all respondents, is of concern and suggests that perceived issues exist in this area.

With regard to guidelines/design standards for road works, 85% (28/33) indicated that a design standard is available within their country. 71% (20/28) consider their road works design standard to be sufficient for a high level of roadside safety. Narrative included with some responses suggests that standards are not always used or followed however, several responses indicated that road works standards are currently being reviewed or updated.

In order to ascertain the role of RSA and RSI on roadside design and operations the questionnaire requested respondents to provide information relating to the role these tools play. In addition, the questionnaire asked for information concerning the implementation of the RISM Directive which required the establishment of procedures for Road Safety Impact Assessments (RSIA), training requirements for road safety auditors, safety ranking and management of the road network in operation (NSM) in addition to RSA and RSI.

15% (5/33) of respondents indicated that the RISM Directive has not been implemented in their jurisdiction, however upon further examination, these responses were received from those working in Regional or Local Road Authorities which have no responsibility for TEN-T roads.

The implementation of the RISM Directive across the countries represented appears to be high with RSAs being undertaken on TEN-T roads in all countries. RSIA shows an implementation rate of 89% (25/28), RSI shows an implementation rate of 93% (26/28) and NSM shows an implementation rate of 82% (23/28).

To gain an understanding of the use of crash statistics in each jurisdiction, respondents were asked to provide information relating to the role of roadside safety performance. 66% (22/33) indicated that their organization has established processes for monitoring roadside safety. While this figure may appear to be low, it is noted that some respondents are employed in areas other than national or regional road authorities and therefore would not be in a position to collect such data. Of those that indicated that their organization makes use of crash statistics there was a large variation in the frequency of data review, the amount of data collected/available and the quality of incident data available.

Furthermore information relating to typical problems associated with roadside safety in each jurisdiction and information relating to data collection for single vehicle and RoR crashes as well as crashes with objects/hazards in the roadside was collected. The analyses of the responses points out that similarities exist. Unprotected hazards, with specific mention to trees, at the roadside is an issue across all sectors surveyed. Insufficient space for obstacle free zone/clear zone has also been identified across most sectors. Incorrect use of VRS and substandard/non-compliant designs has also been highlighted as an issue. 61% (20/33) indicated that data on RoR crashes, single vehicle crashes and crashes with objects/hazards in the roadside is collected in their jurisdiction.

In an effort to understand whether ‘hazard’ or ‘obstacle’ was a defined term within the guidelines/standards in each jurisdiction, the project team requested definitions, if available, from the respondents as this would have a bearing on potential proposals for safe roadsides. 82% (27/33) indicated that 'hazard'/'obstacle' is a defined term. The respondents were also asked whether roadside features/road restraint systems (RRS) could become hazards after the design phase. Discounting five respondents that answered "Not Applicable" the remaining respondents answered 50% Yes and 50% No (14/28). Respondents from nine organizations provide their definitions. Comparing these definitions it becomes obvious that huge differences exist. To give only two examples of how this is defined in two different sets of requirements/standards:

- A hazard is a feature (e.g. embankment) or object (e.g. lighting column) that can cause harm or loss. Harm or loss can be physical, financial or economic, strategic, or be time-based, or any combination of these.
- An area or a section next to the roadway, in which hazards exist for uninvolved third parties, areas or occupants of vehicles requiring protection, if vehicles depart the roadway. Obstacle or hazard is defined depending on the distance to the road and slope of the embankment next to the verge
    - **Hazard level 1**: areas with a special risk to third parties requiring protection (such as chemical plants at risk for explosions, intensively used locations, adjacent rapid transit lines with approved speeds of > 160 km/h (100mph), structures at risk of collapse).
    - **Hazard level 2**: areas with a special risk to third parties requiring protection (such as adjacent heavily frequented walkways and bicycle paths, adjacent rail lines with more than 30 trains/24 h, adjacent roads with ADT > 500 vehicles/24 h).
    - **Hazard level 3**: obstructions with a special risk to vehicle occupants (such as non-deformable extensive obstacles vertical to the direction of travel, non-deformable select individual obstacles, noise barriers).
    - **Hazard level 4**: obstructions with a special risk to vehicle occupants (such as still deformable, circumnavigable / shearable selective individual obstacles, crossing ditches, rising slopes (1: 3 inclination), dropping slopes (Height > 3 m and inclination of > 1: 3), water with a depth of > 1 m, wild water).

With the aim of determining whether there are existing common processes relating to the evaluation of hazards/obstacles and the resultant selection of design options that could be applied across all Member States, the project team requested information from the respondents. 76% (25/33) indicated that there is a process for dealing with hazards either by way of a dedicated standard/guideline or alternative. Respondents from three countries indicated that no such process is in place in their jurisdictions.

A philosophy of forgiving roadsides, the basis of which is verges free of hazards or with crash friendly infrastructure, was developed by the IRDES ERA-NET project in collaboration with the CEDR Technical Group Road Safety and was published in 2013 (La Torre et al, 2013). The project team wanted to gather information relating to design approach with regard to the philosophy of forgiving roadsides versus the application of RRS. 88% (29/33) indicated that the philosophy is promoted within their jurisdiction. 70% (23/33) suggested that a policy to provide a clear or obstacle free zone before a guardrail/RRS is installed exists within their design standards. However, it is noted that the satisfaction rates for the area of land available either side of the road typically being sufficient to provide the required forgiving roadside was 42% (14/33) and those that encountered difficulties when attempting to install RRS due to poor ground conditions, existing utility ducting etc. amounted to 51% (17/33).

The project team wanted to gather information relating to typical problems associated with applying guidelines and/or standards in order to determine whether common problems exist amongst those surveyed. It was also intended to gather information relating to maintenance of roads following construction and problems identified during RSI, which are undertaken on existing roads. It can be seen that "Cost implications (i.e, poor rate of return, lack of initial funding, etc.)" creates the most difficulty amongst those surveyed followed by "Insufficient space available to install a RRS".

In determining whether funding constraints and costs can have an impact upon the provision of safe roadsides at design level, it was discovered that 55% (18/33) indicated that funding constraints and/or construction costs are a factor when assessing whether to provide forgiving roadsides via the introduction of clear zones/obstacle free zones. Concerning the alternative of providing a forgiving roadside versus the introduction of a VRS, 52% (17/33) indicated that funding constraints and/or construction costs are a factor.

A question was posed to those employed by road authorities requesting information relating to the role that contractors and consultants play, if any, in the development and revision of standards and/or guidelines. The specific question resulted in 23 responses (those employed by road authorities). 78% (18/23) indicated that consultants and contractors are engaged with during updates to design standards. Contractors were asked whether there is a mechanism for providing feedback to the roads authority or author of design standards and/or guidelines. Of the four contractors that responded to the questionnaire, 50% indicated "Yes" and 50% indicated "No".

In addition to the development of new and innovative approaches, the exchange of experiences is another aspect of multinational projects. To develop recommendations that could improve roadside safety, the project team requested information relating to successful and innovative risk mitigation measures, at an individual site level. The following is a selection of the responses received:

- A road authority decided years ago that passively safe lighting columns would be the standard choice for lighting supports.
- RRS with underrun protection installed across a regional road authority jurisdiction.

- Make the road more visible in darkness (reflectors, vertical beacons in curves, lighting at intersections and in dangerous places).
- There are shoulder rumble strips applied along almost the entire length of the network.

Similar to the question posed above, the project team requested information relating to successful and innovative risk mitigation measures, on a network wide level. The following is a selection of the responses received:

- Main process includes the promotion and implementation of Road Infrastructure Safety Management procedures such as Road Safety Audits and Road Safety Inspections.
- Plan-based approach to roads: improvement measures in accordance with sustainable safe guidelines.
- In the formation and further updating of the Framework Design process, the designing party must also submit the designs of the safe verge to the client first.
- We have an independent assessment scheme for non-harmonised products. Products have to go through independent third-party checks to ensure manufacturers or test houses didn't cheat on impact tests.

5 Roadside Safety - Structure of possible Shortcomings

One main output of this project is to draft a user specification for future roadside safety guidelines by making use of the findings of the survey. To achieve this aim, the survey responses were analysed in detail to identify and understand the various issues, problems and shortcomings experienced by road authorities.

Based on analysis of the survey responses received a mind map was created to visually organize the identified factors. The responses were structured in the following groups of topics:

1. network monitoring,
2. design,
3. implementation/installation,
4. operational life, including RSI.

5.1 Network Monitoring

The survey results have shown that 33% of the respondents do not have established processes for the monitoring of roadside safety through incident statistics, while a number of respondents included issues such as lack of detail in the collected data or lack of periodic reviews (see Section 4).

Based on these findings the first important aspect is network safety performance monitoring. Ideally, NRAs should monitor the roadside safety issues on their network, including regular reviews of incident statistics so that they can have an in-depth understanding of the problems they are facing, as well as the factors that lead to them. If the reasons and mechanisms of the RoR casualties are not understood, the NRA will have limited ability to consider these problems within their roadside design guidelines and regulations and therefore apply the necessary countermeasures and/or undertake research to further understand the phenomenon. Ultimately, preventable issues would persist and continue to contribute to RoR casualties.

These findings led to the following recommendation:

It is recommended that NRAs should put in place processes for efficient network safety performance monitoring, so that the local roadside safety issues can be better understood. Guidelines should include requirements for regular reviews of the RoR crash statistics. Incident data collection forms should take RoR issues into consideration.

5.2 Design Phase

Based on the responses received, one out of four believes that the current design standard is not sufficient for a high level of safety. Concerning roadside maintenance nearly every second one responding is of this opinion. Even though nearly three quarters consider their road works design standard to be sufficient for a high level of roadside safety, several responses indicated that road works standards are currently being reviewed or updated. In addition, some responses suggested that standards are not always used or followed.

The fact that in Europe one third of the total fatalities are RoR crashes points out the relevance this kind of accident has on traffic safety. Thus, design standards/guidelines, covering all safety relevant aspects, are very important for a high level of roadside safety.

To consider aspects which are not constant over time, it is important to update these roadside safety guidelines regularly. To give an example based on the questionnaire responses, the changes of the general speed limit has not led to changes in the specifications of vehicle restraint systems. In addition to this example changes of the composition of the vehicle fleet, e.g. increase in the percentage of Sport Utility Vehicles (which differ in size and weight from ordinary cars) or the increased percentage of fully electric driven vehicles (which also differ in weight from ordinary cars), have not led to changes in standards and guidelines.

A further important point is the clarity of standards and guidelines. A specific roadside safety issue may be known to the NRA, however problems may be introduced in one of the design phases. For example, a design standard may state that motorcyclist protection systems should be considered at sites with a high risk for motorcycle accidents. However, the term "high risk site" could be open for interpretation if a precise definition of what constitutes a "high risk site" is not provided.

In addition to the clarity of standards and guidelines their level of detail is also an important aspect. To give an example, 6 out of 27 survey respondents said that provision for motorcyclists, cyclists, equestrians and pedestrians were not taken into consideration within their design standards/guidelines.

Another common theme within the survey responses was issues relating to a lack of consideration of site constraints within the design standards/guidelines. Examples of these issues included guidelines not aligning with typical road layouts and existing utilities not taken into consideration during VRS design.

Similarly, a lack of consideration given to VRS product constraints within the design standards was noted by the survey respondents. A typical example of this is the lack of detail in ground condition requirements for VRS. A VRS which was installed and crash tested on a concrete surface may not necessarily perform in the same way if it is installed on an actual roadside with loose soil. NRAs and designers have limited control over such unproven installations, if substantiated design advice related to VRS ground conditions are not included within the manufacturer's installation manual.

Another typical example is the deflection distances and the lack of roadside space available for VRS installation to accommodate deflection. Cable VRS are known to deflect less when crash tested in short lengths, as deflections are limited by the fixed anchors at the terminals. Longer installations of such VRS in the real world can result in higher deflections. In such cases the tested length is considered a constraint for the VRS in question. Lack of consideration of such product limitations within a design manual can lead to longer-than-tested lengths of cable VRS designs, which could result in unknown deflection properties that can cause injury in a RoR crash.

These findings led to the following recommendations:

It is recommended that NRAs should regularly update their roadside design standards/guidelines and to ensure consistency with their other design regulations.

It is recommended that the existing roadside design guidelines are reviewed regularly to ensure that the issues identified through the regular network safety performance monitoring are taken into consideration.

It is recommended the solutions/countermeasures within roadside design standards/guidelines are clearly defined to minimize personal interpretation. The solutions/countermeasures should also include sufficient technical detail so that the constraint of the site, the VRS products and the needs of different road users can be taken into consideration during the design phase.

The design standard/guideline may be comprehensive with an adequate level of detail to address the roadside safety issues inherent within the country. However, there is still the possibility of safety issues which may be introduced by the designer, due to misuse or misinterpretation of the design standard. Design stage road safety audits are often utilised to ensure that unsafe (which can include non-compliant) designs are not carried over to final implementation. However, it is still possible for a non-compliant design to reach the implementation stage, if it wasn't subject to a RSA, or if the auditors could not identify the issues during the audit. It is also possible that the RSA recommendations may not have been taken into consideration or adopted by the design team. This could also contribute to an unsafe design reaching the implementation stage.

These findings led to the following recommendations:

It is recommended that NRAs should implement processes for road safety audits during the design phase for all roads.

It is recommended that guidelines for the RSAs take common issues relating to the latest roadside safety requirements specific to their country into consideration.

In some cases, despite the design standard being understood and applied, a compliant design may not be achieved due to reasons such as site constraints, cost constraints and product availability. In such cases, the overseeing organisation may consider issuing a departure (variation) from the standard. A departure from standard should only be applied for following a comprehensive evaluation, which often includes risk assessment and cost/benefit analysis. Such departures may introduce increased (even though accepted) risks which may contribute to injury as a result of RoR crashes.

As part of the Work Package 1 activities, a database of roadside design related departures was provided by Highways England. Some of the more common types of departures featured within this list were VRS length of need issues caused by site restrictions, VRS transition issues cause by lack of product availability and provision of a lower containment level for central reservation VRS caused by cost issues.

While it is a challenge to come up with an overarching solution for all of the individual departures, one thing the NRAs can do is to have a process for regular review and analysis of the departures they have issued. Through these analyses, it may be possible to identify the underlying reasons for the most common departures. Through better understanding of these reasons, the NRA could develop a targeted strategy to minimise the need for the departures. These may include strategies such as improvement of the design standard, improvement of collaboration mechanisms with the other design parties, evaluation of the reasons and effects of budget constraints with wider NRA management, etc.

For example, one of the survey responses pointed out that "*Detailed planning of VRS starts after the road design has already been finalised - often too late to make necessary changes*". Such a systematic issue could easily lead to common VRS related departures. In such a case, perhaps the solution lies within an improvement of the design approach to ensure roadside design and roadside safety is incorporated within the road design process at an early stage.

These findings led to the following recommendation:

> *It is recommended that NRAs should implement a process for regular register, review and analysis of the roadside safety related departures from standard. This way, the underlying reasons for the most common types of departures could be understood, and the necessary strategies to minimise the need for these departures could be put in place.*

5.3 Implementation Phase

Analyses of the narratives of respondents suggest that installation errors and material properties of VRS are important topics.

VRS installation error was a common issue pointed out by a number of respondents within the survey. As a basic example, a w-beam VRS which is lapped in the wrong direction can impale an impacting vehicle; effectively transforming the VRS from a risk mitigation measure into a hazard. Similarly, other installation errors could convert VRS into a higher risk hazard, which may then contribute to injury as a result of a RoR crash.

Installation errors can be caused by lack of adequate training of the installers. To mitigate this risk, a number of NRAs have started to put in place obligatory training for VRS installers.

The installation errors should ideally be identified during the construction level RSA. However, it is possible that these errors are missed if the RSA is not carried out or if the issues were not identified by auditors during the RSA; effectively resulting in an unsafe roadside. Therefore, it is important to ensure the RSAs are carried out and the auditors are informed about the technical requirements of the project under audit.

Another potential issue that may be introduced during the construction phase is if the material properties of the VRS provided on site is not as tested. CE marking procedures have introduced mandatory factory production control; however these controls are carried out every six months and it may still be possible that sub-standard materials are provided on site, which could result in a VRS that is not capable of performing as intended. Furthermore, non-harmonised VRS products cannot yet be CE marked and therefore these products are not subject to mandatory factory production control inspections. NRAs could consider introducing additional processes to ensure the quality of both the VRS manufacture (for non CE marked products), and its installation.

These findings led to the following recommendations:

It is recommended that NRAs should put in place the processes to ensure VRS installers and inspectors are adequately trained, so that the risk of installation errors can be minimised.

It is recommended that NRAs should put in place processes for road safety audits following the construction phase for all roads.

It is recommended that NRAs consider processes to ensure the quality of VRS delivered and installed on site.

5.4 Operational Phase

Examples of issues that can occur throughout the operational life include, durability issues such as corrosion, loss of tension, loosening of bolts, which can increase the level of risk posed by a VRS. Similarly, if an impacted VRS is not repaired in time, it may fail to perform as expected in a subsequent impact. Sometimes changes in the road environment may have an effect on the existing VRS installation. For example, where pavement overlays are constructed without any adjustments to the height of a roadside VRS, the VRS may be too low relative to the road surface to perform as intended. Similarly changes to the roadside environment such as erosion around the VRS foundations or overgrown vegetation can turn a safe design into an unsafe one over time. All of these factors could become a contributor of injury as a result of a RoR crash.

NRAs often utilise RSIs to detect and rectify these issues over time. If RSIs are not carried out, these issues may not be detected. However, even when regular RSIs are carried out, some of these issues may be missed. For example, the issue may have occurred after the RSI was undertaken. If such cases are common, it may be a good idea to increase the frequency of RSIs. Another possibility is that the RSI is undertaken, but the problem is not detected. This could occur if the RSI methodology is not detailed enough to cover the specific roadside safety related issues or it may be that the inspectors may not have the necessary level of training or experience with the unique problems of roadside safety design. In such cases, the NRA may consider improving their RSI processes or improve the training requirements for road safety inspectors.

Issues may have been detected within the RSI; however, solutions for the identified problems may not have been applied adequately or in a timely manner. If such cases are a known issue, the NRA should consider reviewing the shortcomings of their processes which are causing these issues.

These findings led to the following recommendations:

> *It is recommended that NRAs should put in place processes for regular RSIs, preventative maintenance and inspections.*

> *It is recommended that guidelines for the RSIs take common issues relating to roadside safety requirements specific to that country into consideration.*

Finally, there could be other changes through the lifecycle of a roadside, which may have an effect on the overall safety but which may not be easily detectable through RSIs. For example, if there are significant changes to the traffic characteristics of the road over the years, such as a considerable increase in the percentage of heavy goods vehicles (HGVs), the original assumptions for the selection of the existing barrier may no longer be true. Therefore, the risk of a heavy vehicle impacting the VRS would be significantly higher than it was assumed at the design phase.

Another example is the changes in the vehicle fleet composition and vehicle characteristics over time. For example, a recent study has demonstrated the significance of the trend of increasing vehicle mass over time (Erginbas et al., 2017). In 2016 40% of the UK car fleet weighed over 1,500kg with two occupants on board. 1,500kg is the mass of the test vehicle used for the most commonly used VRS containment class of N2 in the UK. With all of these on-going changes, the level of safety provided by existing installations is decreasing over time. This is because the number of vehicles that fall outside of the original design assumptions of the roadside is increasing.

As these types of changes are unlikely to get picked up at RSI, they should be monitored at an NRA level through asset management, network monitoring and research activities.

These findings led to the following recommendation:

> *It is recommended that NRAs should put in place processes to monitor and assess the long-term effects of changes to road traffic and vehicle fleet on the safety of existing roadsides and foster greater intervention in coordinated decisions concerning future development in relevant truck and car making technical standards.*

6 Roadside Safety – Development of the "Roadside Safety Organisational Robustness Fault Tree"

Based on the content and structure of possible shortcomings visualised in a mind-map a model which presented them in a logical flow was generated. The logical flow of this model lead to a type of fault tree analysis (FTA). Therefore, it was decided to call this framework the "Roadside Safety Organisational Robustness Fault Tree" (Erginbas et al., 2019). This framework is presented in **Figure 10**.

The aim of this structure is to guide users (road authorities) through the assessment of roadside safety in a systematic and logical manner. It should help users in conducting expert reviews of the roadside safety of their road network by systematically addressing the many different aspects of the life cycle of roadsides (including the design, implementation and operational phases). Furthermore, it should help to identify where problems may occur, both from a management and an operational sense, and assist the user in developing remedial management actions and measures to address roadside safety issues operationally.

The starting point of the Roadside Safety Organisational Robustness Fault Tree is the definition of an undesirable outcome of the system. All of the possible ways that can lead to the undesirable outcome and the underlying contributory factors are then identified. These factors are then visually organised in a fault tree diagram so that the logical connections between the contributory factors that can lead to the undesirable outcome can be sequentially displayed and analysed. All factors which are considered are extracted from the questionnaire responses and are further developed during internal project team workshops. In line with the CEDR Call, it was decided to integrate only those aspects which road authorities are responsible for.

The approach behind the Organisational Robustness Fault Tree relates back to the original aims of the CEDR Call which led to this project. As described within the Call, despite the existing roadside design standards, guidelines, safety products and established processes, road users continue to get injured as a result of RoR crashes. While some solutions look good on paper, they may not always result in a safe, real-world application. There are many factors that may contribute to the ultimate undesired outcome of injury resulting from a RoR crash and these contributory factors may be introduced at different stages of the lifecycle of a roadside, such as the design, implementation and maintenance phases. For example, a roadside design which is compliant with existing guidelines may end up contributing to negative consequences in the event of a RoR crash if it is not implemented properly; a compliant VRS installation may end up contributing to negative consequences in a RoR crash if it is not maintained properly; or a roadside design guide may fail to prevent harm in the event of a RoR crash if the local problems are not understood properly due to lack of network monitoring.

NRAs must be aware of, and take into account, these potential failure mechanisms so that necessary countermeasures can be introduced in the form of more comprehensive standards, guidelines and processes. The more the potential failure mechanisms are countered, the greater the organisational robustness will be. The Roadside Safety Organisational Robustness Fault Tree is an attempt at classifying all of these potential roadside safety risk contributors, which relate to the organisational processes which are within the realm of influence of NRAs. Therefore, it constitutes a framework for future guidelines as the NRAs can use the fault tree to assess their own organisational robustness and identify the necessary countermeasures for the identified areas of shortcomings.

As can be seen in **Figure 10**, starting with the undesired final outcome of "injury resulting from a RoR crash" the fault tree then outlines the potential factors that may contribute to the undesired outcome and the associated stages of the roadside timeline. While developing the fault tree it turns out to be useful to differentiate the design phase further into 4 different chapters (**Figure 10** and **Figure 11**). The resulting structure is as follows:

1. Network Performance Monitoring,
2. Design,
    a. Standard writing and policy,
    b. Use of the standard,
    c. Departures from standard,
    d. RSA design,
3. Implementation/installation,
4. Operational life (including RSI).

Each and every phase includes positive conditions which can lead to a safe roadside and negative conditions, split by contributory factors, which can lead to an unsafe roadside. To support the user a colour labelling was introduced. The general logic of the chart is that:

- Green boxes represent ideal situations;
- Blue boxes represent factors which may have contributed to the undesired result of injury as a result of a RoR crash (most of these are based on the survey responses);
- Grey arrows represent the logical flow of how these contributory factors are related.

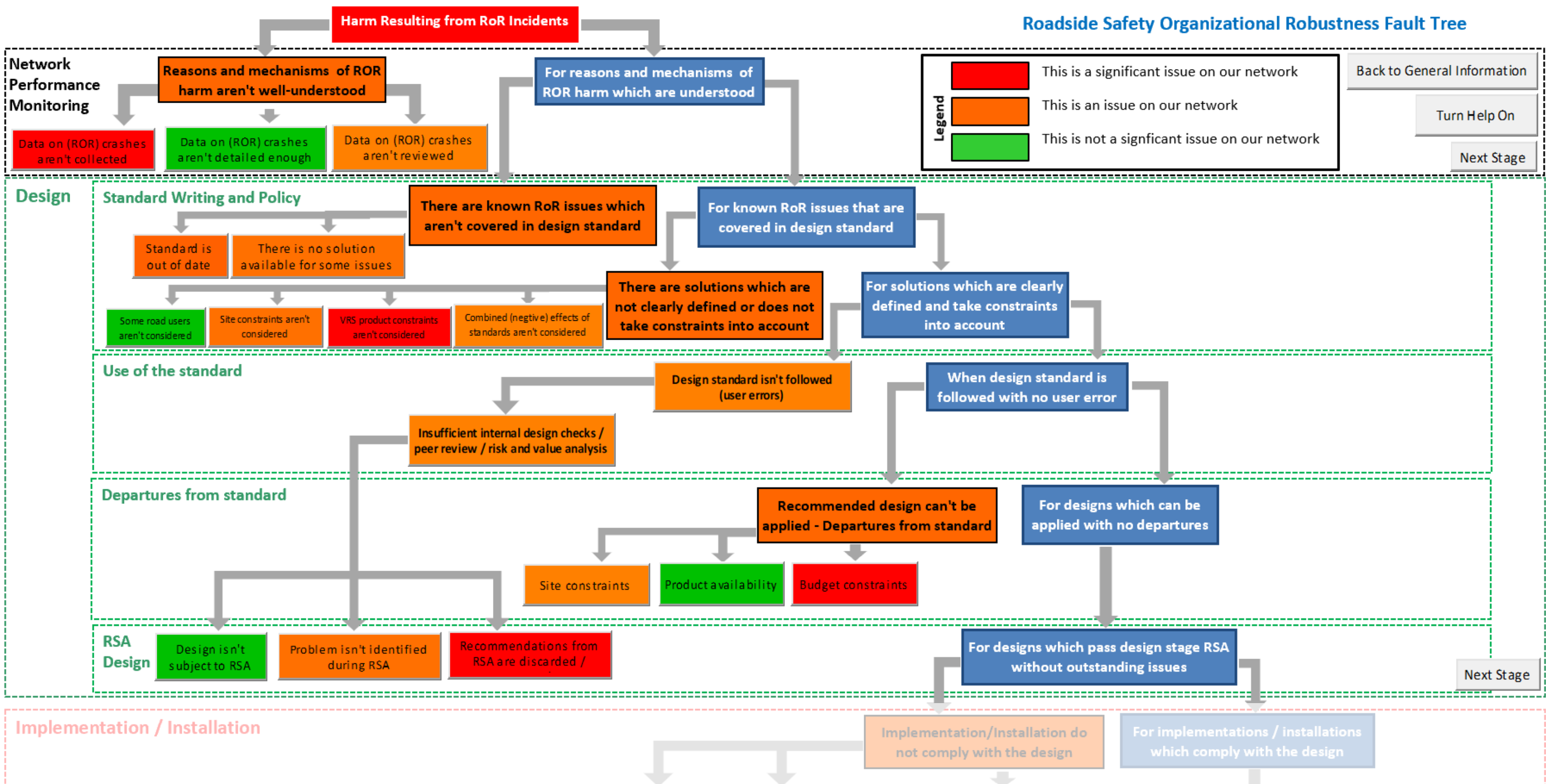


Figure 10: Roadside Safety Organisational Robustness Fault Tree (stage 1 and 2) (Erginbas et al., 2019)

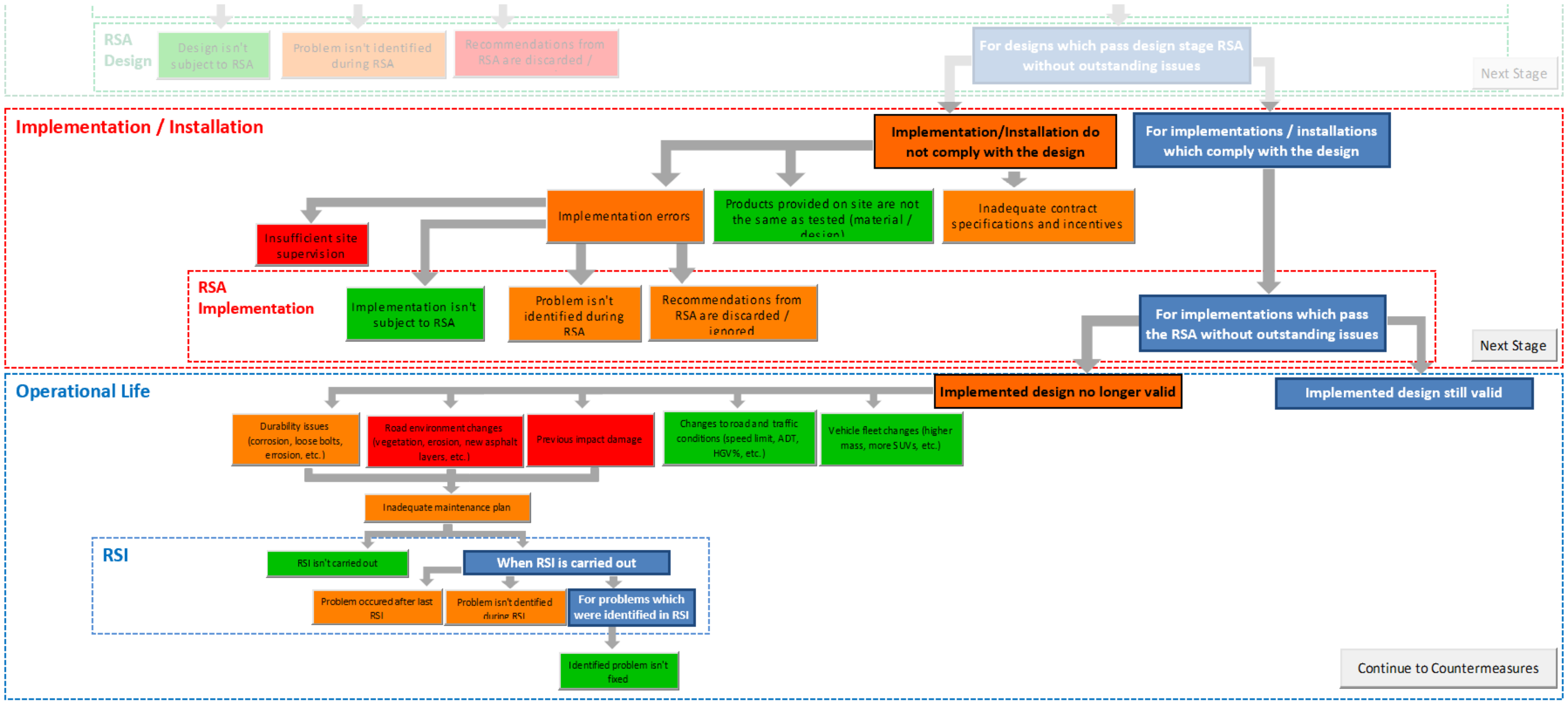


Figure 11: Roadside Safety Organisational Robustness Fault Tree (stage 3 and 4) (Erginbas et al., 2019)

6.1 Network Performance Monitoring

Based on the findings structured in the mind-map the first important section of the Organisational Robustness Fault Tree relates to the network performance monitoring phase (see **Figure 12**). As this step is a reactive one it is clear that the availability and reliability of data is the key.

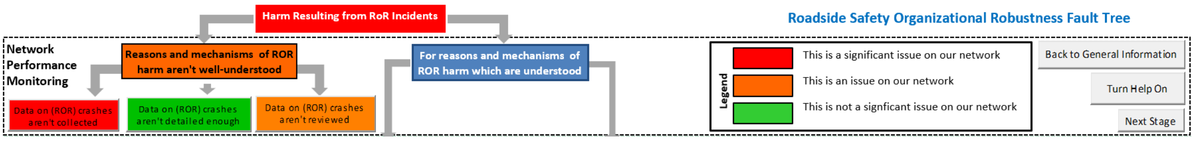


Figure 12: Network Performance Monitoring Phase of the Roadside Safety Organisational Robustness Fault Tree

6.2 Design Phase

As identified while developing the mind-map, the regular review and update of roadside design standards and guidelines is of importance. Furthermore, it was pointed out that the rules and regulations have to be clearly defined and should include sufficient technical details.

To deal with the possibility that safety issues which may be introduced by the designer, due to misuse or misinterpretation of the design standard, conducting road safety audits during the design phase is of importance.

Based on the responses one could conclude that in some cases departures from the standards/guidelines are unavoidable. To develop a targeted strategy to minimise the need for the departures by improvements of the design standard, improvements of collaboration mechanisms with the other design parties, evaluation of the reasons and effects of budget constraints, etc. is an important aspect within the design phase of the Organisational Robustness Fault Tree.

To include such topics, the second section of the Organisational Robustness Fault Tree, which relates to the design phase, is divided into four sub-phases of standard writing and policy, use of the standard, departures from standard and RSA (see **Figure 13**).

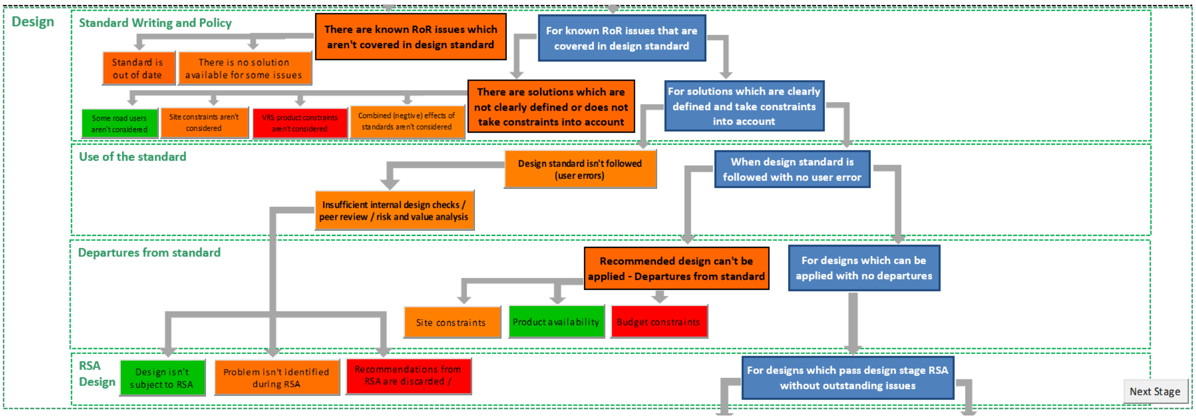


Figure 13: Design Phase of Roadside Safety Organisational Robustness Fault Tree

6.3 Implementation/Installation Phase

The analysis of the narratives of responses from the questionnaire suggested that installation errors and material properties of VRS are important topics. This leads to the development of the third section of the Organisational Robustness Fault Tree, which relates to the installation/implementation phase (see **Figure 14**). A compliant design may result in an unsafe roadside if it is not implemented/installed properly, e.g. , a W-beam VRS which is lapped in the wrong direct, or a VRS which is not installed in the correct height/distance to the carriageway. Another example is that the VRS does not match that which was tested.

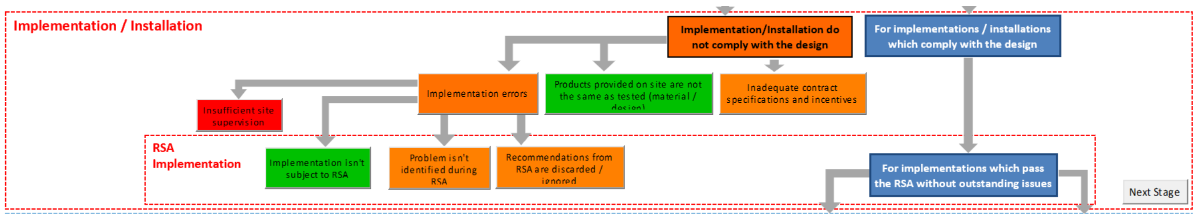


Figure 14: Implementation/Installation Phase of Roadside Safety Organisational Robustness Fault Tree

6.4 Operational Phase

The final section of the Organisational Robustness Fault Tree relates to the operational life phase (see **Figure 15**). A roadside may have been designed and constructed in accordance with the standards. However, even a compliant roadside may become unsafe within its life span if it is not maintained adequately. Furthermore, changes in the traffic characteristics, the fleet composition, the speed limit, etc. must be taken into consideration too.

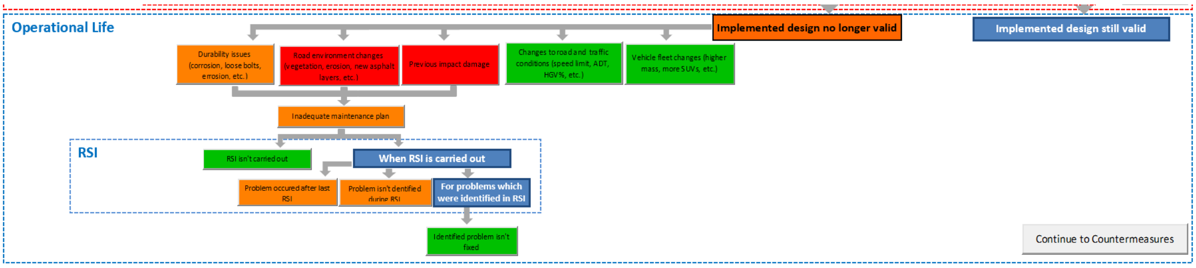


Figure 15: Operational Life Phase of Roadside Safety Organisational Robustness Fault Tree

As previously mentioned, the Roadside Safety Organisational Robustness Fault Tree is an attempt at classifying the potential organisational shortcomings which may contribute to injury as a result of RoR crashes. A NRA can utilise this fault tree to help assess their roadside safety organisational robustness. This can be done by identifying the existing issues, the stages at which they are introduced and then assessing if there are countermeasures in place to mitigate the identified shortcomings.

7 Roadside Safety – Use and Testing of the Support Tool

To support NRAs in increasing roadside safety an EXCEL-tool (TRL, 2019) was developed based on the Roadside Safety Organisational Robustness Fault Tree (see **Figure 16**).

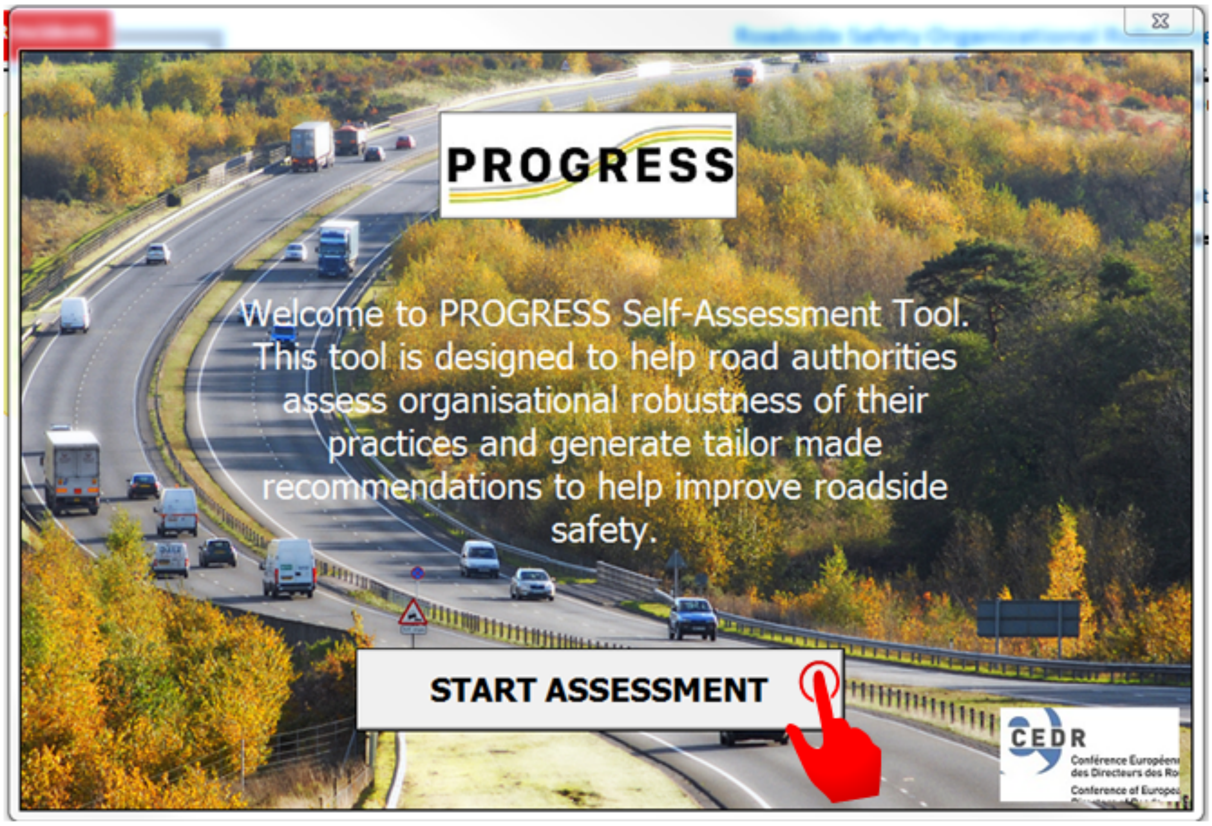


Figure 16: PROGReSS Self-Assessment Tool

The main output of the tool is a list of recommendations to improve an organisation's robustness with regard to roadside safety. This list is generated by a combination of the inputs to the FTA and the currently employed countermeasures. The list is sorted in the direction of descending priority, along with possible countermeasures.

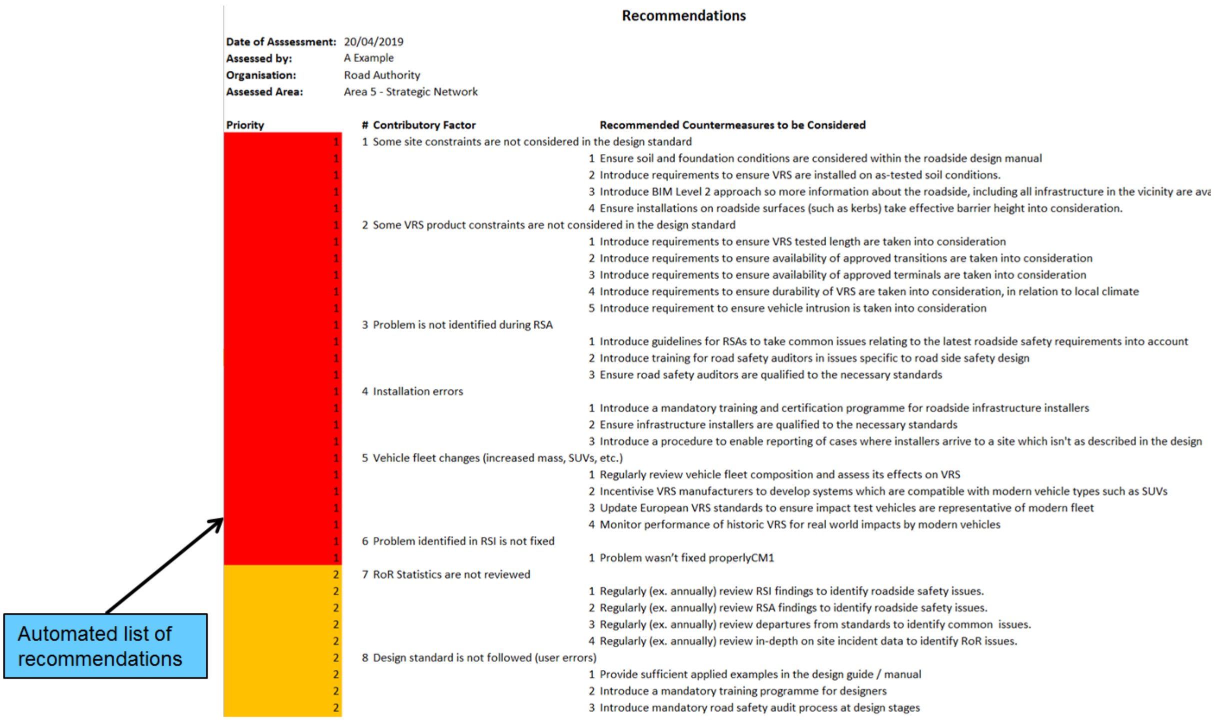
In order to allow the prioritisation, a risk based model was developed. Risk is categorised on a three-point (3, 2, 1) rating scale while countermeasures were also based on simple three-point (>1, 1, 0) scale, as detailed in

Table 1.

Table 1: Prioritization Matrix

		Number of Countermeasures Applied		
		>1	1	0
Contributory Factor Risk	1			
	2			
	3			

The main result is a colour coded list of recommendations which can be used by road authorities to consider the introduction of new processes to increase their organisational robustness, and to help improve roadside safety. To support the decision, a prioritisation is included in this list of recommendations. The combination of failure conditions with the highest risk (3) with lowest number of countermeasures (0) will be listed first and coloured in red (**see Figure 17**). Those with the lowest risk (1) and the highest number of countermeasures (>1) positioned at the bottom of the recommendation list, coloured in green.



Recommendations

Date of Asssessment: 20/04/2019
Assessed by: A Example
Organisation: Road Authority
Assessed Area: Area 5 - Strategic Network

Priority	#	Contributory Factor	#	Recommended Countermeasures to be Considered
1	1	Some site constraints are not considered in the design standard		
1			1	Ensure soil and foundation conditions are considered within the roadside design manual
1			2	Introduce requirements to ensure VRS are installed on as-tested soil conditions.
1			3	Introduce BIM Level 2 approach so more information about the roadside, including all infrastructure in the vicinity are ava
1			4	Ensure installations on roadside surfaces (such as kerbs) take effective barrier height into consideration.
1	2	Some VRS product constraints are not considered in the design standard		
1			1	Introduce requirements to ensure VRS tested length are taken into consideration
1			2	Introduce requirements to ensure availability of approved transitions are taken into consideration
1			3	Introduce requirements to ensure availability of approved terminals are taken into consideration
1			4	Introduce requirements to ensure durability of VRS are taken into consideration, in relation to local climate
1			5	Introduce requirement to ensure vehicle intrusion is taken into consideration
1	3	Problem is not identified during RSA		
1			1	Introduce guidelines for RSAs to take common issues relating to the latest roadside safety requirements into account
1			2	Introduce training for road safety auditors in issues specific to road side safety design
1			3	Ensure road safety auditors are qualified to the necessary standards
1	4	Installation errors		
1			1	Introduce a mandatory training and certification programme for roadside infrastructure installers
1			2	Ensure infrastructure installers are qualified to the necessary standards
1			3	Introduce a procedure to enable reporting of cases where installers arrive to a site which isn't as described in the design
1	5	Vehicle fleet changes (increased mass, SUVs, etc.)		
1			1	Regularly review vehicle fleet composition and assess its effects on VRS
1			2	Incentivise VRS manufacturers to develop systems which are compatible with modern vehicle types such as SUVs
1			3	Update European VRS standards to ensure impact test vehicles are representative of modern fleet
1			4	Monitor performance of historic VRS for real world impacts by modern vehicles
1	6	Problem identified in RSI is not fixed		
1			1	Problem wasn't fixed properlyCM1
2	7	RoR Statistics are not reviewed		
2			1	Regularly (ex. annually) review RSI findings to identify roadside safety issues.
2			2	Regularly (ex. annually) review RSA findings to identify roadside safety issues.
2			3	Regularly (ex. annually) review departures from standards to identify common issues.
2			4	Regularly (ex. annually) review in-depth on site incident data to identify RoR issues.
2	8	Design standard is not followed (user errors)		
2			1	Provide sufficient applied examples in the design guide / manual
2			2	Introduce a mandatory training programme for designers
2			3	Introduce mandatory road safety audit process at design stages

Figure 17: Colour coded list of recommendations

Whilst the tool has been developed based on known research and feedback from stakeholders it should be noted that this is not a detailed design tool for use at individual site locations.

Furthermore, the list of failure conditions, and potential countermeasures, is not an exhaustive list. Whilst every effort has been made to identify the most common failure conditions and countermeasures, based on the research performed, there are likely to be other conditions and further countermeasures than those detailed in the tool.

As the PROGReSS Self-Assessment Tool is based on the Roadside Safety Organisational Robustness Fault Tree each stage of the tool refers to a phase shown in **Figure 10/Figure 11**). The first heading relates to a negative condition for the stage with sub-headings provided that details the likely contributory factors affecting this stage. The positive condition has no sub-factors. This is shown for Stage 1 in **Figure 18** below which denotes:

- Both the negative and positive conditions;
- Contributory factors;
- Back to general information (allows access to Step 1, general information, and alteration if items have been miscoded);
- Access to help notes (turns on and off help notes) (this is not visible on the figures but is a feature integrated in the tool);
- Next stage button, allows progress to next stage in the fault tree.

In order to support the user, a user guide is available which includes all details necessary.

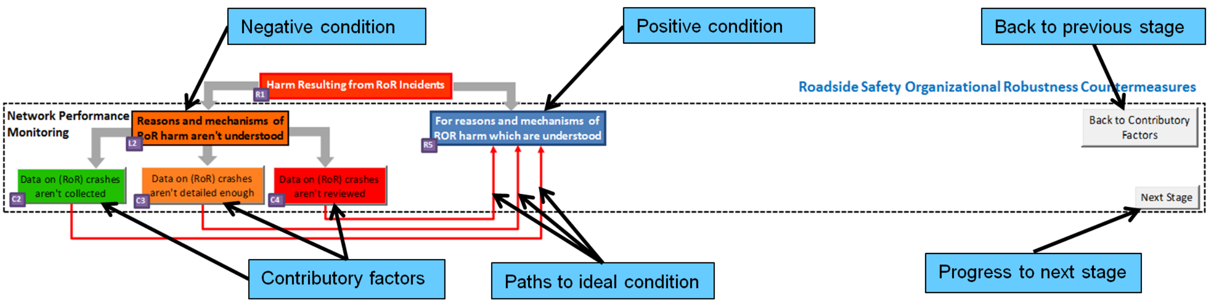


Figure 18: Example of given options and possible codes

For both, the PROGReSS Self-Assessment Tool as well as the User Guide a download free of charge is available at on the project website www.cedrprogress.eu and later on the CEDR website (www.cedr.eu).

Within the initial project plan it was proposed to test and gain insight in the use of the PROGReSS Self-Assessment tool, to further develop the first alpha version to a fully capable final version. For this purpose, a two stage pilot testing phase was adopted for testing the practicality, ease of use, de-bugging and the identification of other improvements.

- Pilot stage 1: a review and initial assessment of the tool without a real-life case. This aimed at getting input of the usability and comprehensibility before testing it in real life cases
- Pilot stage 2: Full scale test of the tool in real life cases. This aimed at getting feedback from participating NRA's applying the tool in practice to current and ongoing projects and work procedures.

It was anticipated that road authorities from different countries would be able to support these steps by giving input from their perspective. For several reasons the responses from NRAs was limited and thus the tool was mainly tested from members of the consortium.

8 Summary

8.1 Main Result

Analyses of crashes highlights the importance roadside safety has for road safety in general within Europe. Based on the CARE/CADaS database single-vehicle crashes constitute up to 40% of all fatalities resulting from traffic crashes. In selected countries one quarter up to one third of all fatalities are due to RoR crashes. Based on this importance, numerous standards have been produced aimed at making roads in particular, and roadsides specifically, more forgiving. In addition, several projects have been conducted to support road authorities to reduce the harm due to RoR accidents. Roadside safety remains an important topic and achieving the target of halving the number of traffic fatalities in the period of 2010 to 2020 will (in part) rely on the provision of safe roadsides. Based on analyses of literature, roadside safety projects and guidelines of the selected countries PROGReSS collated the existing knowledge in this field. Furthermore, road authorities, consultants and practitioners in Europe were invited to share their knowledge and experiences. Theses analyses where focussed on rural roads with speed limits higher than 70km/h (40mph) and generally including the higher order rural roads. Maintenance aspects and quality control procedures were analysed too. To support the efforts of road authorities to further increase traffic safety by safe roadsides the essence of theses analyses are documented in various work package reports. The main result of PROGReSS is the tool called "Roadside Safety Organisational Robustness Fault Tree". The purpose of this tool is to support Road Authorities with a systematic approach aimed at detecting potential shortcomings in existing approaches and to analyse potential weak points within the chain of road planning, design, implementation and operation. It starts by analysing the reasons and mechanisms of RoR crashes, analysing the design standards and their use, as well as the implementation/installation of VRS and possible impacts which might require the renewal of the systems or possible changes of aspects which might require different systems.

8.2 Conclusions and Recommendations

The analyses of roadside safety projects identified that a lot of knowledge exists in this area. As a result a comprehensive list of roadside design elements and design parameters and their effect on crashes could be compiled. However, based on the results of the literature study on the impact of guidelines and standards on roadside safety it became apparent that the effect of the application of guidelines and standards on roadside safety has not been sufficiently studied or reported in scientific journals in Europe or the rest of the world. This fact could explain why significant differences between countries exist, concerning the guidelines to be followed as well as concerning the content of guidelines, e.g. concerning the required clear zone.

As a starting point it is recommended that CEDR members should agree on a common definition of Roadside Hazards and a Forgiving Roadside. The project team proposes the following as definitions:

- *"A hazard is any physical element which may, in the event of an errant vehicle leaving the carriageway, result in serious injury to the occupants of the vehicle."*
- *"A forgiving roadside is a roadside that minimises the risk and consequences of driving errors".*

As pointed out in chapter 5, the results of Work Packages 1 and 2 lead to a couple of recommendations on network level as on project level.

On a network level the project team recommends that NRAs should put in place processes for efficient network safety performance monitoring, so that the local roadside safety issues can be better understood. In order to adjust the efforts necessary to achieve the national road safety target, the NRAs' safety performance should be analysed on a yearly basis. Furthermore, the related national guidelines dealing with roadside safety and VRS should include requirements for regular reviews of the RoR crash statistics. As a prerequisite for such an approach, crash incident data collection forms have to take RoR issues into consideration.

To improve roadside safety during the design phase the project team recommends that:

- NRAs should regularly update their roadside design standards/guidelines and ensure their consistency with other design regulations. The regular updates should take all issues identified through the regular network safety performance monitoring into consideration.

- the solutions/countermeasures within roadside design standards/guidelines are clearly defined to minimize personal interpretation. The solutions/countermeasures should also include sufficient technical detail so that the constraint of the site, the VRS products and the needs of different road users can be taken into consideration.
- NRAs should implement processes for road safety audits during the design phase for all roads. In addition, it is recommended that guidelines for the RSAs take common issues relating to the latest roadside safety requirements specific to their country into consideration.
- NRAs should implement a process for regular register, review and analysis of the roadside safety related departures from standard. This way, the underlying reasons for the most common types of departures could be understood, and the necessary strategies to minimise the need for these departures could be put in place.

Furthermore, the project team recommends the following roadside safety improvements during the implementation phase:

- NRAs should put in place the processes to ensure VRS installers and inspectors are adequately trained, so that the risk of installation errors can be minimised.
- NRAs should put in place processes for road safety audits following the construction phase for all roads.
- NRAs consider processes to ensure the quality of VRS delivered and installed on site.

Finally it is recommended that during the operational phase the following improvements in roadside safety are introduced:

- NRAs should put in place processes for regular RSIs, preventative maintenance and inspections.
- guidelines for the RSIs take common issues relating to roadside safety requirements specific to that country into consideration.
- NRAs should put in place processes to monitor and assess the long-term effects of changes to road traffic and vehicle fleet on the safety of existing roadsides and foster greater intervention in coordinated decisions concerning future development in relevant truck and car making technical standards.

To further improve roadside safety in an efficient manner, further systematic research on the relationship between the application of European guidelines and standards and roadside safety should be conducted, starting with a template for registering relevant design decisions as characteristics of operating roads. Analyses of the awareness and estimations of the usefulness of the output of previous research programmes financed by CEDR suggests greater communication relating to project outcomes is warranted on a European level. Once a greater understanding on this aspect exists this could lay the ground for a common European approach. The experiences with the implementation of EU Directive 2008/96/EC RISM demonstrated the potential of guidelines on a European level. Prior to RISM no more than 50% of funding countries employed any of the different procedures in question. The fact that RISM has now been extended is encouraging and further supports improved road safety by safe road infrastructure across EU Member States.

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