# Development of a guideline for the selection of Vehicle Restraint Systems - identification of the key selection parameters

# Development of a guideline for the selection of Vehicle Restraint Systems - identification of the key selection parameters

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**Abstract**

“SAVeRS” (Selection of Appropriate Vehicle Restraint Systems) is a project funded within the CEDR 2012 Transnational Road Research Programme “Safety”. The first Work Package of the project is aimed at analysing the existing criteria for identifying the need for the placement of a vehicle restraint system and for the identification of the most appropriate performance class. For this aim both the existing national standards and guidelines and literature documents have been analysed in details. The comparative analysis of 33 national standards and guidelines covering most of Europe and several non-European Countries has shown that there are many commonalities and it is possible to identify the most frequently used parameters with reference to safety barriers. Whilst the majority of the countries have guidelines and/or standards related to safety barriers, there is generally limited guidance for other systems such as crash cushions, transitions and motorcycle protection systems. Life-cycle cost models are usually not included in the standards but few tools are available worldwide.

*Keywords:* Roadside safety; safety barriers; crash cushions; terminals; transitions.

**Résumé**

“SAVeRS” (Sélection de systèmes de retenue approprié) est un projet financé dans le CEDR 2012 transnationale Road Research Programme “Sécurité”. Le premier lot de travaux du projet vise à analyser les critères existants pour déterminer la nécessité de la mise en place d'un système de retenue du véhicule et pour l’identification de la classe de performance le plus approprié. Pour cet objectif les documents relatifs à la fois à la norme nationale et les lignes directrices ainsi que la littérature ont été analysés en détail. L'analyse comparative des 33 normes et directives nationales couvrant la majeure partie de l'Europe et plusieurs pays non européens a montré qu'il existe beaucoup de points communs et qu’il est possible d' identifier les paramètres les plus fréquemment utilisés en référence à des barrières de sécurité . Alors que la majorité des pays ont des directives et/ou normes relatives aux barrières de sécurité, il existe généralement peu d'indications pour d'autres systèmes tels que les atténuateurs de choc, les transitions et les systèmes de protection de moto. Les modèles de coûts du cycle de vie ne sont généralement pas inclus dans les normes, mais peu d'outils sont disponibles dans le monde entier.

*Mots-clé:* Sécurité routière, les barrières de sécurité, atténuateurs de choc; terminaux; transitions.

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## 1. Introduction

Run-Off-Road (ROR) crashes are extremely severe road accidents that can often result in severe injuries or fatalities. The accident analysis conducted within the RISER Project, funded by the EU, concluded in 2005, highlighted that even though only 10% of the total accidents are single vehicle accidents (SVA, typically associated to the run-off-road type accidents) the rate of SVA events increases to 45% when only fatal accidents are considered.

To reduce the severity of ROR crashes, "forgiving roadsides" need to be designed and this includes identifying where there is a need for a Vehicle Restraint System (VRS) and what appropriate VRS should be selected for specific location and traffic condition.

At the present time, whilst there are standards covering the testing, evaluation and classification of VRS within Europe (EN1317, EN12767 etc), their selection, location and installation are based upon national guidelines and standards, often produced by National Road Authorities (NRA) and/or overseeing organisations. Due to local conditions, these national guidelines vary across Europe.

To allow for the development of a uniform guideline for selecting the most appropriate VRS performance requirements for the given conditions a number of CEDR (the Conference of European Directors of Roads) members have collaborated to fund the research project "SAVeRS" (Selection of Appropriate Vehicle Restraint Systems) within the 2012 Transnational Road Research Programme Call "Safety". The aim of the SAVERS project is to produce a practical and readily understandable VRS guidance document and a user-friendly web-based tool that will allow the selection of the most appropriate solution in different road and traffic configurations for all types of VRS: safety barriers; crash cushions; terminals and transitions; motorcycle protection devices.

The guidance document and the web-based tool will have with the following goals:
- ensuring the safety of road users, road workers and third parties;
- optimising VRS performance in use;
- maximising VRS serviceable life;
- minimising VRS whole life costs.

The different solutions considered will be fully compatible with EN 1317 and related EN standards (for example the European passive safety standards EN12767, EN40 and EN12899).

To ensure that the SAVERS project output will be a useable, robust and realistic guidance tool to aid designers in their choice and selection of VRS, a specific evaluation Task will be performed to test the effectiveness of the guidelines and of the tool developed in the project The guideline and tool will be tested for application to new and current designs and against sites where VRS have been in use for some years and performance information is available.

This paper gives details of the findings from the first of the Work Packages within the SAVERS project, i.e. to define the different parameters which can influence the need and selection of VRS, from both a review of national guidelines and standards, and from an associated review of published literature.

## 2. Objectives of the first Work Package of the SAVERS project

In order to develop a robust and effective methodology for the appropriate selection of a VRS, it is necessary as a first step, to collate, review, fully understand and appreciate current (and proposed future) national guidelines and standards. The aim of Work Package (WP) 1 is:
- to analyse the differing national guidelines and standards to identify, review and categorise information which is currently available relating to the parameters associated with the choice of VRS to develop a single document outlining the approaches taken in each country.
- to collate, review and fully understand international research which has been carried out regarding the parameters considered when selecting a VRS. This may, or may not be related to the development of the NRAs' guidelines.

In order to achieve these objectives, the WP was split into two distinct Tasks, each investigating the areas outlined in the bulleted list above. The subsequent section will outline the aims, methodology and results from these activities.

## 3. Collation and examination of national guidelines and standards

### *3.1. Methodology*

Standards and guidelines from 33 countries covering most of Europe and several non-European Countries were collected in the SAVeRS project (Fig. 1). It was noted that some countries have adopted and/or adapted guidelines from other countries either neighbouring or with similar infrastructural conditions. More specifically it was observed that guidelines from the USA were adopted by countries around the Americas, whilst the German standard is the most widely adopted standard around Europe if countries have not developed their own requirements. Although the majority of European countries have their own dedicated guidelines and standards, they still have common approaches, decision processes, tables and graphs.

Each standard was then read and analysed in detail to identify the parameters related to:
- the choice of whether to install a VRS, or not;
- the selection of VRS performance.

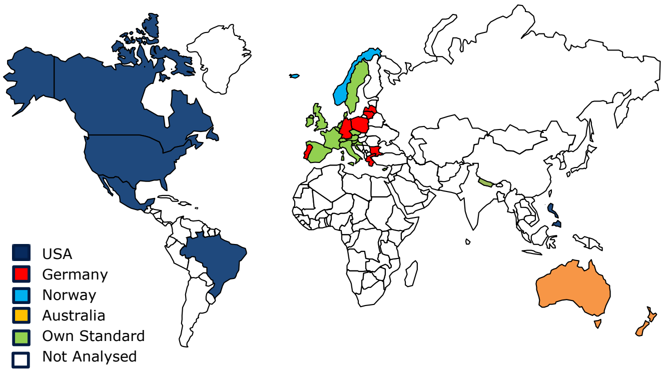


Fig. 1. collection on national standards and guidelines on VRS

A data matrix was prepared to store and present the identified parameters, by country. This was to allow easy identification of those parameters essential for the work within Work Package 2. As new parameters were identified within each of the items of documentation, it was decided whether to categorise these parameters under ‘Consequence’ or ‘Likelihood’, such that the elements of Risk (the product of consequence and likelihood) could be identified.

Once a complete set of robust parameters had been determined, the data matrix was divided into tabs, identifying those parameters related to the decisions for each VRS type, i.e. roadside safety barriers, median safety barriers, bridge parapets, crash cushions, transitions, terminals and motorcyclist protection systems (MPS). Due to low level of published guidance for terminals, transitions and MPS, these were removed from the data matrix. For each parameter, it was then determined whether it applied to the decision to install a VRS, or whether it was related to the selection of the performance for the VRS.

After the collation of data from National guidelines, the final matrix was transferred into SPSS, statistical analysis software, which was used to prepare frequency tables for each parameter for each VRS type. These frequency tables were then analysed to develop evidence-based conclusions on the most used parameters.

### *3.2. Results*

As each guideline was analysed, more detailed parameters were detected for some of the countries as compared to others. For example while some countries only mentioned the ‘existence of a tree’ as a parameter that leads to the decision of barrier installation, some countries went a step further and defined ‘trunk girth of a single tree’.

As one might anticipate it was observed that the parameters related to the consequences of an accident were used more often for the decision as to whether to install a VRS, or not since these are basically a list of hazards that would necessitate the installation of a VRS to mitigate the danger. Conversely, parameters related to the likelihood of a given type of accident were used more often to determine the level of performance required from the VRS, since these include parameters such as percentage of heavy goods vehicles.

Examination of those parameters most frequently referenced within national guidelines and standards has shown that in terms of the justification for roadside safety barrier, it is the risk to vehicle occupants, travelled speed, road geometry, the existence of risk to third parties and traffic which are the most frequently included parameters (in that order). For median barriers, the same factors are most frequently referenced, but with it is the existence of risk to third parties which is mentioned most frequently. When considering those factors which are used for determining the performance requirement of a roadside safety barrier, it is factors such as the existence of special risk to third parties, traffic and road alignment and/or geometry which are considered most frequently (in that order). For median barriers, again, these are factors which are frequently referenced, but with traffic being the most frequently referenced characteristic. When such factors are examined in further detail, it is the presence of embankments and cuttings (and their height and gradient), the presence and proximity of vulnerable road users (such as pedestrians and cyclists), railways, bodies of water and non-deformable roadside obstacles, the average annual daily traffic and actual speeds which are most prominent in determining the need for a roadside safety barrier. When selecting the performance of a roadside barrier, it is factors such as the presence of structures and railways lines, the presence and proximity of bodies of water and non-deformable roadside obstacles, the average annual daily traffic and actual speeds and the presence of adverse road geometry which are most prominent. Whilst factors such as aesthetics and cost are mentioned in some national guidelines and standards, their frequency is low.

For bridge parapets there is less specific guidance than for roadside and median safety barriers, however obstructions with a special risk to vehicle occupants and the height of the bridge, are the most common factors. When determining the performance of a bridge parapet, it is factors such as the existence of special risks to third parties (for example railways lines) and obstructions posing a risk to vehicle occupants which are referenced most frequently.

Guidance on the need to install crash cushions is very limited; however it is the presence of a non-deformable hazard which occurs most common (perhaps unsurprisingly). With regard to determining the performance level of the crash cushion, this is limited to the actual speed limit of the road. This is perhaps also as expected as the standards for the testing of crash cushions identify impact speed as one of the defining parameters for performance. For terminals, transitions and MPS, there is very limited guidance within national guidelines and standards and hence, there is insufficient data upon which to form any justifiable conclusions. It was also observed that, whilst the majority of the countries have guidelines and/or standards related to roadside and median barriers, there is generally limited guidance for other VRS systems such as crash cushions, transitions and MPS.

## 4. Collation and examination of published literature

### *4.1. Aim*

The goal of the literature review in the SAVeRS project is to find out how the placement and choice of suitable VRS is approached and assessed by researchers. In fact the actual decisions taken by NRAs are mostly based on national tradition and acknowledged studies while on-going research should be able to point out to changes driven by the development of the road infrastructures. For sake of simplicity the review has been approached by searching how different actors play a role in the decision making of VRS placement. The point of view of policy makers, vulnerable road users such as cyclist and pedestrians and motorcyclists were investigated and the available analyses of accidents involving safety barriers were assessed looking at both financial implications and safety.

### *4.2. Methodology*

Most of the studies available in the literature can be divided between in-depth accident analysis and commentaries and assessment of policies.

A large number of studies undertaken to allow optimisation of the number, length and location of vehicle restraint systems installed in the roadside and the central reserve of roads fall in the first category. Most of these studies have utilised collated incident data, although the number, quality and relevance of the incidents investigated should be understood, in all cases. The results of these studies will be reported in the next section.

Since Powered-Two-Wheels (PTW) safety and development of Motorcyclist Protection Systems (MPS) have become a specific issue in accidentology, several PTW research projects are dealing as well with crash reconstruction and the expected effects of MPS. Other papers are more general in terms of analysing common crash circumstances. When it comes to test procedures and standards regarding MPS, several FEMA (Motorcyclists`Associations, 2012) initiatives are available in European literature. The EU-project Smart VRS (IDIADA, 2012), together with results of the first naturalistic riding project (Saleh, 2010) offers deeper insights to various MPS aspects. On the other hand policy papers usually deal with vulnerable road users and cultural instances such as protection of public health and of the cultural and natural heritage. Pedestrians, cyclists and motorised two wheelers fall in the typical "vulnerable road user groups" but these groups are loosely defined without adherence to a strict classification. (Avenoso and Beckmann, 2005).

Another important issue in roadside crashes is related removing hazards placed in the clear zone. The decision regarding tree removal in the Clear zone and roadside barrier installation is strongly affected by the discussion on the relation between public health and road infrastructure design. According to (Naderi, 2003) the US Center for Disease Control and the Surgeon General's Office study all the variables which favour active lifestyle living such as pedestrian and bicycle use over the automobile and can improve national health by reducing obesity and related medical care costs. In this context it is believed that improving the aesthetic aspect of transportation corridors can be beneficial in a double way: by reducing accident frequency and severity and by increasing pedestrian activity.

Boulevard treatment and the introduction of green infrastructure within transportation corridors, however, have presented difficulties in relation to the treatment of the Safety Zone. In regard to this, although landscaping as a tool to achieve safer roads is socially recognized, researchers are trying to assess quantitatively its effect on driver behaviour. Several case studies have been produced: a study on five arterial roads in Toronto, between 1992 and 1995 (Rosenblatt and Bahar, 1998); a comparison between the safety performance of 12 couples of parkways and freeways, in four US states (Mok and Landphair, 2003); the crash rate before and after landscape improvement in 10 study sites in Texas (Mok et al., 2006), and a correlation analysis to identify weak relations between the quantity of car accidents and some aesthetic properties of road landscape in Lithuania (Matijošaitienė and Navickaitė, 2013). The Fatal Accident Rate (FAR) and the Accident Cost (AC) constituted the dependent variables for comparing the safety performance of parallel sections of selected parkways and freeways in Mok and Landphair (2003). Most these studies showed a positive correlation (although sometimes weak as in the case of Matijošaitienė and Navickaitė (2013)) between the aesthetic enhancement of the road landscape and the road collision rate. Also all the authors concluded that the research results were limited and more detailed analyses of accidents in relation to landscaping were needed.

The study by Mok et al., (2006) is particularly relevant due to the analysis of tree collisions before and after landscape improvements. The research hypotheses of this study were that crash rates significantly decreased after the landscape improvement at study sites and that a decrease in the number of tree collisions occurred after landscape improvements. Of the 61 study sites initially chosen only 10 could be used to evaluate the effects of landscaping on safety as the others included additional treatments that can have a direct effect on safety, such as pedestrian sidewalk widening, expansion of existing shoulders, or installation of bicycling path. Results showed a decrease in crash rate in eight of the ten study sites; in two sites an increase in crash rate after the landscape treatment was observed. The number of tree collisions showed a decrease of about 70.83% after landscape treatment but it should be noted that in 9 out of 10 locations only 0-2 crashes were observed in the before period and therefore the effect of landscaping is not so evident. In the single location where 18 crashes were reported in the before period only 3 crashes where reported in the after period with a significant reduction in tree collisions. The change was associated with a landscape treatment that occurred in 1992.

It is not possible to select a vehicle restraint system without considering the financial consequences of the selection. Unfortunately this is an area that is difficult to quantify due to the difficulty in collecting information covering the relevant costs and benefits for a particular system. There are notable attempts at developing tools to address roadside safety design costs, with the Roadside Assessment Program (RSAP) (Ray et al., 2012) in the

US being the most ambitious. This is a good example of a method to estimate the costs and benefits associated with different design concepts. A similar evaluation was applied in Sweden in the doctoral thesis of Karim (Karim and Magnusson, 2008) using Life-Cycle Costs (LCC). Similar approaches may be applied in other countries but no other published articles could be obtained in this review.

### *4.3. Results*

#### *4.3.1. Roadside hazards*

Running off the road doesn't necessarily results in injuries. If there is sufficient space available to slow down and stop the vehicle, most incidents will remain without consequences. Most often however, objects or terrain conditions can cause an abrupt slowdown or destabilization of the vehicle leading to injuries for the vehicle occupants. Trees heavily contribute (5% - 10%) to fatal accidents (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements, 2002). Tree crashes obviously are more frequent on roads other than motorways. From all fatal incidents with fixed obstacles on roads (but non motorways) outside urban areas in the Netherlands (2002), trees contributed for 85% of all roadside objects (2004b). Lighting columns and other isolated supports also represent an important share, varying around 7% of all fatal accidents (STATS19 database, period 1998-2002) (Lynam, 2005). On motorways, single vehicle ROR accidents involving Vehicle Restraint Systems VRS are responsible for 20% - 30% of fatal accidents (Lynam, 2005). Unfortunately, accident statistics generally are not sufficiently detailed to give information about the type of Vehicle Restraint System impacted or impact details. Generally speaking it should be noted that VRS safety effectiveness can be limited in case of inadequate installation, inappropriate maintenance or lack of repair.

Ditches can be considered as a special type of obstacle. Much depends on the cross-section of the ditch (depth, slope). Often however, entering a ditch will destabilize the vehicle (Thomson, 2002). In some cases, a vehicle that enters a ditch can be guided onto a rigid construction at the end of the ditch. Embankments represent a second type of 'special' obstacle. Cut slopes with a gradient below 1:3 are considered as relatively safe (AASHTO, 2011), although some countries allow higher gradients. For example the Netherlands allow cut slopes with a 1:2 gradient when the transition from horizontal to sloped surface is rounded (CROW, 2004b). Based on existing recommendations and numerical simulations, a gradient of 1:3 is the threshold to consider a slope as an obstacle or not (Pardillo-Mayora, 2010). Higher slopes could lead to a potential rollover risk. For fill slopes, slope and height determine whether this type of obstacle is acceptable or not. For steep slopes there is a risk that the vehicle leaving the road could lose contact with the surface when it enters the embankment and is 'launched'. In such cases the fall height should be reduced to limit possible consequences (CROW, 2004a) (SETRA Service d'Etudes sur les Transports les Routes et leurs Aménagements, 2002). Again, a rounded transition from horizontal surface to sloped surface increases the allowed slope (CROW, 2004a) in the Netherlands.

#### *4.3.2. Placement of safety barriers*

The available literature on the placement of VRS focuses on safety barriers. Most of the studies make comparative analyses on accident rate and severity on road segments before and after the placement of safety barriers. Information on terminals, transitions and attenuators is scarce. Analysis can be divided between studies on median and studies on roadside barriers. Often these analyses don’t discuss the containment level but rather the particular kind of safety barriers used (concrete, steel w-beam, steel cables, etc…) and make a distinction between rigid and flexible barriers. Results are often assessed in terms of containment, accident rates and accident severity.

The effectiveness of two safety barrier types prevalent in the US: the GA-type strong post, corrugated beam safety fence system and a wire rope median barrier have been examined by Alluri et al. (2012). In the case of the strong post system they identified that on a 1,652.3 km length of the barrier there were 8,674 cases in which the safety barrier was impacted. Of these impacts, 94.5% of the impacts resulted in the impacting vehicle being contained by the barrier system. It is important to note that some of the impacts with the barrier were outside of the design parameters of the barrier system (e.g. an impact in which the weight and/or speed and/or angle exceeds the level to which the system has been designed and tested). They noted that compared to roadside safety barrier, median barriers accounted for a slightly higher percentage of incidents in which the barrier was breached by the impacting vehicle. By comparison, when a 162.5 km long installation of wire rope median barrier was examined, it was reported that 549 impacts occurred and of these, containment occurred in 83.6% of cases. 98.1% of cars impacting the barrier and 95.5% of light trucks (whose containment is not part of the design considerations for this type of safety barrier) were contained.

In addition to the in-service performance of the central reserve rope barrier itself, Alluri et al. (2012) also examined the before and after effects of the central reserve rope barrier's installation. They found that the installation of the median barrier had reduced the fatal impact rate by 42.2%, the severe injury rate by 20.1% and the minor injury rate by 11.6%. However, the rate of incidents involving possible injury and property damage rose by 53.1% and 88.1% respectively, resulting in an overall impact rate increase of 37.8%. This emphasises that safety barriers are, in themselves, also hazards and hence, their use should only be as a last resort where other safety measures cannot be implemented. Similar results have been found by Bonneson et al. (2012), Elvik (1995) and Tarko et al. (2008) for different type of barriers.

Work by Candappa et al. (Candappa et al., 2009) has also examined the effectiveness of flexible barrier systems, this time on the Australian road network. In this case, a total of 101.6 km of road length was installed with wire rope safety fence. The study compared the impact frequency at road sections before and after treatment. The results indicated that the barriers could be associated with significant reductions in the risk to both casualty and serious casualty rates. These reductions varied from site-to-site, but were, on average, around 76% for all casualty impacts and 77% for serious casualty impacts. The report also states that these figures align closely with work from previous International studies citing, in particular, reports from Sweden and the US. The report concludes that the introduction of flexible barrier systems, such as wire rope is likely to produce substantial reductions in incident occurrence, in particular in cases of off-road and head-on impacts for both casualty and serious casualty impacts.

The effectiveness of median barriers on the French motorway network was evaluated by Martin and Quincy (2001). This study showed that the crossover incident was rare, identifying that in 0.5% of car incidents and in 7% of incidents in which the median barrier was struck by a truck, the vehicle was not contained by a safety barrier. The authors also conclude that crossover incidents are more serious than other types of incident with 19% resulting in fatalities and 43% resulting in some level of injury. As a word of warning, the authors state that in recent years in France, extra traffic lanes have been added to existing motorway sections, which has often led to a reduction in central reserve strip width. New motorways are being built with a maximum 5 m wide median barrier (to limit ground surface requirements and cost). According to the authors in these median-strip-width conditions, one possible strategy to reduce the number of median barrier crossings significantly is to place barriers with higher containment capacities (level H2 or over). This same issue is common in most European countries due to limited land availability and most National Road Authorities across Europe require therefore high containment barriers in the medians.

Whilst the safety benefits of vehicle restraint systems are therefore well documented, there are occasions where safety barriers are purposely not installed due in part to the hazard posed by their installation. Instead wide central reserves (9 m) have been used as a lane separator. Davis and Pei (Davis and Pei, 2005) reconstructed five incidents in the US where a wide central reserve (greater than 9 m) without an installed safety barrier was traversed, causing fatalities on the opposite carriageway. In the US, a 9 m (30 ft) wide central reserve is thought to be sufficiently wide for 80% of out-of-control drivers to regain control of their vehicle. Davis and Pei conclude that whilst the 9 m central reserve was in place, fatal incidents still occurred and could have been mitigated had a normal containment (TL3) safety barrier been in place.

The use of the clear central reserve has also been examined by Donnell et al. (Donnell et al., 2002). In this particular case, the Pennsylvanian Department of Transportation's design policy was reviewed which stated that safety barriers were not required for central reserves with a width of 10 m or more and with an average daily traffic of 20,000 vehicles per day. The report concluded that crossover incidents, whilst rare, result in fatal injuries in 15% of cases, with 72% incidents resulting in nonfatal injuries. The report also states that on earth-divided roads, crossover incidents decrease as the central reserve width increases (due to the increase in vehicle recovery time). In addition, it was found that crossover incidents occur more frequently downstream of interchange entrance ramps, and that they are more likely to occur during periods of adverse weather (wet or icy) than other types of incident.

Miaou et al. (Miaou et al., 2005) conducted similar work to Donnell et al. (Donnell et al., 2002), within the roads of Texas. Their research concentrated further on the modelling of incidents, basing this more directly on the benefit-cost relationship, rather than on the pure safety considerations in the Donnell et al study. They concluded that a positive cost-benefit could be achieved with clear wide central reserves. Similar studies were also developed by Elvik (1995) and Tarko et al. (2008) who concluded that median barriers are found to increase incident rate, but reduce incident severity. In general terms, Elvik also concluded that safety barriers and crash cushions reduce both incident rate and severity, adding that safety barriers reduce the chance of sustaining a fatal injury by about 45%, given that an accident has occurred. The chance of sustaining a personal injury is reduced by about 50%.

Whilst the central reserve has been the focus for many papers and research articles, there has been limited associated study for the use of roadside barriers. However one such study was that of Schneider et al. (2009). Their specific area of study was in the locating of safety barriers within horizontal curves on rural two-lane highways in Texas.

If a barrier is to be placed it is essential to define the appropriate length of the barrier considering that if a barrier is too short it may allow an errant vehicle to traverse behind the barrier, whilst a barrier too long in length will present an additional unnecessary hazard to road users. In order to ascertain guidelines for the minimum length of safety barrier to be installed, Tomasch et al. (2011) analysed the run off road crashes derived from a National Austrian crash database. The authors defined the required safety barrier length as the length that allows the vehicle speed to be reduced to an acceptable value upon impact with the obstacle, considering a maximum possible deceleration of 0.3 g behind the barrier. To determine the desired length of a barrier ahead of an hazard they developed a relationship between barrier length and the speed at which vehicles depart the roadway based on the Austrian database. The authors demonstrated that the application of this approach would reduce the number of fatalities among occupants of vehicles striking bridge abutments by approximately 8%.

*4.3.3. Motorcyclist Protection Systems (MPS)*

Most Run-Off-Road crashes in bends occur at radii between 50 - 150 m. Radii relations between subsequent curves (R1/R2>1) and disharmonic trace, high bendiness and high gradients are critical safety issues for PTW riders. Run-off-road accidents involving PTW are more likely to occur in left hand curves than right hand curves, for countries were standard driving is on the right side of the carriageway (Saleh, 2010). Most motorcycle collisions with crash barriers occur at angles between 10° and 45° although in the European standard (CEN, 2012) the prescribed crash test angle is 30°.

Impact of motorcyclists against a fixed object occurred in 4% of the cases in urban areas while variations between 10% and 20% can be observed in rural areas. The most important obstacles referring to particularly severe injuries, are trees/poles, roadside barriers and road infrastructure in general. Exposed guardrail posts are the most dangerous aspect of guardrails with respect to motorcyclists. The risk of injury due to hitting a fixed object is related to the impact area and rigidity of the object. Hence, small rigid objects such as support posts are most likely to cause the most severe injuries as they concentrate the impact forces on a small area of the human body (IDIADA, 2012).

Several studies as for example Berg et al. (2005) investigate both sliding and upright crash positions of riders. 2-BE-SAFE (Saleh, 2010) results show the same tendencies, that both crash types are equally relevant, especially from in-depth analysis of Spanish data. Also crashes with the rider still sitting on bike in an upright position should be considered. For riders remaining in an upright position when impacting a crash barrier, most injuries occur at shallow impact angles, i.e. the rider slides and tumbles into the top of the supporting posts. When a rider impacts with a barrier in an upright position, the motorcyclist is likely to be thrown over the guardrail system if the height of the barriers is too low (Duncan et al., 2000).

## 5. Conclusions

The review of the existing national standard and guidelines has shown that there are many commonalities and key parameters that are frequently used for identifying if there is a need for a vehicle restraint systems (VRS) and for selecting the performance of a VRS even though the parameters are typically different: the parameters related to the consequences of an accident were used more often for the decision as to whether to install a VRS, or not since these are basically a list of hazards that would necessitate the installation of a VRS to mitigate the danger.  Conversely, parameters related to the likelihood of a given type of accident were used more often to determine the level of performance required from the VRS, since these include parameters such as percentage of heavy goods vehicles.

For the most performance requirement in the most common VRS application (roadside barriers), it is factors such as the presence of structures and railways lines, the presence and proximity of bodies of water and non-deformable roadside obstacles, the average annual daily traffic and actual speeds and the presence of adverse road geometry which are most prominent. Whilst factors such as aesthetics and cost are mentioned in some national guidelines and standards, their frequency is low. Whilst the majority of the countries have guidelines and/or standards related to roadside and median barriers, there is generally limited guidance for other VRS systems such as crash cushions, transitions and MPS.

The available literature on the placement of VRS focuses on safety barriers. Information on terminals, transitions and attenuators is scarce. Most of the studies make comparative analyses on accident rate and severity on road segments before and after the placement of safety barriers. The discussion on median barriers focuses on the effectiveness in reducing accident rate and severity against the option of wider central reserves. In terms of variables for the placement and choice of VRS, these are not generally indicated since, as already stated, most of the studies analyse a same road, for the same traffic and geometrical conditions, before and after a safety treatment. Risk analysis and safety management tools such as 'safety-barrier diagrams' are suggested for identifying the risks associated with the installation of safety barrier systems.

Environment and pedestrian protection issues play a role also in the placement of roadside barriers in corridors and rural roads. In regard to this the in Europe some countries prefer minimizing interaction between different road users and between vehicles driving in different directions using central reserve and roadside barriers, while in US especially wide safety zone complemented by landscape and trees are preferred.

Studies on Motorcyclist Protection Systems use traffic volume variables such as AADT and percentages of different road users and recommend the installation of MPS in roads with high exposure of PTWs. In terms of road geometry, accident statistics and in-depth analyses point out roads with bends between 50 m and 150 m as specific areas of higher risks.

In regard to the influence of cost on the placement of VRS there are useful methodologies that can be exploited for a European economic assessment tool but the main current and future difficulty is to find financial data covering all aspects of a VRS installation and valid beyond a region or national level.

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