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SAVeRS

Guideline for the selection of the most appropriate Roadside Vehicle Restraint System

Deliverable D3.1
June 2015

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CEDR Call2012: Safety: Use of Vehicle Restraint Systems

SAVeRS
Selection of Appropriate Vehicle Restraint Systems

Guideline for the selection of the most appropriate Roadside Vehicle Restraint System

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List of acronyms

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway Officials (USA)
CEDR	Conference of European Directors of Roads
CMF	Crash Modification Factor
f+i	Fatal + injury crashes (crashes resulting in injuries)
HGV	Heavy Good Vehicle (includes buses, single unit trucks, multiple unit trucks and tractor-trailers)
IKE	Impact Kinetic Energy (kinetic energy of the vehicle at the moment of the impact against the barrier calculated considering only the speed component transversal to the barrier)
LON	Length of need of a barrier
MPS	Motorcycle protection system
NRA	National Road Authority
ROR	Run Off Road Crash
SDF	Severity Distribution Function
SPF	Safety Performance Function
SV	Single Vehicle Crash
SVROR	Single Vehicle Run Off Road Crash
VRS	Vehicle restraint system (barriers, including bridge parapets, crash cushions, terminals)
VRSCL	Vehicle restraint system (barrier) class as defined by EN1317:2 standard
WLC	Whole Life Costing
WP	Work Package

EXECUTIVE SUMMARY

SAVeRS (Selection of Appropriate Vehicle Restraint Systems) is a Research Project funded within the 2012 Call "Safety" of the Transnational Road Research Programme of CEDR (Conference of European Directors of Roads) by Belgium/Flanders, Germany, Ireland, Norway, Sweden, United Kingdom.

The aim of the SAVeRS project was to produce a practical and readily understandable Vehicle Restraint System (VRS) guidance document and a user-friendly tool that would allow the selection of the most appropriate solution in different road and traffic configurations for different types of VRS.

The partners of the SAVeRS Consortium, lead by the University of Florence (Italy), are: TRL (UK), VTI (Sweden), Trinity College Dublin (Ireland), ZAG (Slovenia), AIT (Austria), Parsons Brinckerhoff Ltd (UK), BRRC (Belgium, subcontractor of TRL).

This Guideline is the output of Work Package 3 of the project where the results of the activities of WP1 and WP2 have been combined and complemented. Further details on the background studies conducted in the SAVeRS project can be found in the deliverables D1.1 "Defining the Different Parameters which can influence the need and selection of VRS" and D2.1 "Analysing the Different Parameters which influence the need and selection of VRS" both available in the SAVeRS website (www.saversproject.com).

The final product of the SAVeRS project is the following set of documents that can be downloaded for the SAVeRS website (www.saversproject.com):

- Guideline for the selection of the most appropriate Roadside Vehicle Restraint System (this document);
- SAVeRS tool: an Excel spreadsheet with built-in macros where the models and selection criteria developed in the SAVeRS project and described in this Guide are implemented;
- SAVeRS tool user manual: a companion document that provides guidance for the use of the SAVeRS tool;
- Excel spreadsheet for the calibration of the crash prediction model for motorways (for users interested in calibrating the SAVeRS prediction model for a different motorway network);
- Excel spreadsheet for the calibration of the crash prediction model for two-lane two-ways rural roads (for users interested in calibrating the SAVeRS prediction model for a different two-lane two-ways rural roads network).

The document is structured in the following 5 chapters and 6 annexes where all the models implemented in the tool are described and additional guidance is provided to the user to select the most appropriate VRS:

- introduction
- identification of the need for a VRS (barrier placement guidance)

- safety barriers (including bridge parapets)
- recommendation for the implementation of the guideline by national road administrations
- crash cushions and terminals
- motorcycle protection systems
- annex 1 - glossary
- annex 2 - development of a base safety performance function
- annex 3 - calibration of the motorway run-off-road model
- annex 4 - calibration of the rural two-lane two-ways run-off-road model
- annex 5 - development of an HGV impact energy distribution
- annex 6 - severity distribution functions

The SAVeRS tool allows the user to compare different barriers classes (according to EN1317-2) and types in terms of potential penetrations, potential fatal crashes and whole life costing.

In selecting the most appropriate device it should be noted that often a safety barrier is not necessary and therefore, prior to applying the SAVeRS tool for defining the most appropriate barrier class or type, the designer should evaluate if there is actually the need for a barrier. Most of the national standards provide indications for the definition of the situations where a safety barrier is needed. A summary of these criteria is given in chapter 2 of this Guideline and implemented as separate function in the SAVeRS tool.

For crash cushions and terminals the SAVeRS tool allows the user to estimate the number of crashes that will potentially impact on the device in the analysis period and the potential number of crashes that will impact at a speed above the VRS class, as defined by EN1317-3 and ENV1317-4 (future EN1317-7).

Any inquiry related to the use of the SAVeRS tool should be addressed to francesca.latorre@unifi.it.

1 INTRODUCTION

Run Off Road (ROR) crashes are road accidents that can often result in severe injuries or fatalities. The accident analysis conducted within the RISER Project, funded by the EU and concluded in 2005, highlighted that even though only 10% of the total number of accidents are single vehicle accidents (SV, typically associated to the ROR crashes) the rate of SV 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 situations where there is a need for a Vehicle Restraint System (VRS) and defining what appropriate VRS should be selected for a specific location and traffic condition.

At this time, whilst there are standards covering testing, evaluation and classification of VRS within Europe (EN1317 part 1 to part 8, EN12767 etc.), their selection, location and installation requirements are typically 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.

As a result, the main objective of the SAVeRS project was to produce both a practical and readily understandable VRS guidance document and a user-friendly tool that would allow to select the most appropriate solution in different road and traffic configurations.

The guideline is structured in the following 4 main sections:

- *Identification of the need for a VRS (barrier placement guidance)*: this section is based on the result of previous projects, existing manuals and national standards to help the user to identify if there is a need for a VRS. This section of the Guideline also provides indications for the definition of the proper Length of Need (LON) to be used when a VRS is needed;
- *Safety barriers (including parapets)*: this section represents the core of the Guideline and provides guidance for selecting the most appropriate safety barrier class and type, assuming the device is tested and classified according to EN1317-2. Different types of road section configurations are considered and each specific project can be characterized by the designer in terms of a number of physical and traffic parameters. For dual carriageway roads both median barriers and lateral barriers have been assessed. This section of the Guideline has been implemented in a user friendly tool that provides not only an assessment of the risk factors associated with different performance classes (according to EN1317-2) but also an evaluation of the most cost effective type of barrier (steel, concrete, wood, cable etc).

- *Recommendations for the implementation of the guideline by National Road Administrations*: the selection of the appropriate VRS in different geometric and traffic conditions is strongly affected by national regulations and therefore an implementation procedure has been included in the Guide showing the issues that can be directly implemented by the NRAs in the form of an internal guidance document (e.g. setting the thresholds for the different risk indicators allowing also to identify the need for upgrading a VRS on an existing road section) and the issues that need to be tackled by revisiting national standards and regulations. As different European countries have different regulations it is not be possible to have a unique implementation plan. The required implementations to national regulations, considering the results of the SAVeRS project, have then been identified in Italy and in the UK to be used as a practical example for the usability of the research outputs and the implementation in different countries.
  In this section examples of application of the Guideline at the design stage are also given.
- *Crash cushions and terminals*: this section of the guide allows to assess the crash cushions classified according to EN1317-3. The guidelines for the selection of barrier terminals (according to the new EN1317-7 - to be published) are also included. The SAVeRS tool allows to estimate the number of expected crashes in the design lifetime for both. The crash cushions and terminals sections of the tool can be used on existing roads to define priorities for the replacement of non crashworthy terminals with new crashworthy ones or for upgrading existing crash cushions. Sections that are exposed to a higher risk of impact against the VRS should be considered with a higher priority.
- *Motorcycle restraint systems (MRS)*: this section of the guideline provides guidance to identify where an MRS tested according to EN Technical Specification CEN/TS 1317-8 ("Road restraint systems Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers") is recommended and in which conditions a specific assessment should be made.

2 IDENTIFICATION OF THE NEED FOR A VRS (BARRIER PLACEMENT GUIDANCE)

2.1 Methodology

Within Work Package 1 of this project, an extensive international search of the current state-of-the-art was undertaken to identify a list of the most influential parameters in the installation and selection of vehicle restraint systems. This was achieved through the examination and detailed analysis of National standards and guidelines, and also from a thorough review of existing literature (D1.1 Deliverable "Defining the Different Parameters which can influence the need and selection of VRS").

From the completion of this Work Package, a number of specific parameters were highlighted which were used predominately within National requirements for determining whether a vehicle restraint system should be installed at a particular location, or in front of a specific hazard.

However the most noticeably common underlying decision mechanism in most of the examined standards was a risk based model, as shown in Figure 1. Most of these standards based the decision of a VRS installation on the likelihood of a vehicle reaching a hazard and the consequences of the hazard being reached.

Figure 1: Risk Model

For assessing situations where a VRS is not in place the "likelihood" part of the equation can still be determined using the SAVeRS tool, which uses the "likelihood" related parameters identified within the WP1, such as AADT, %HGV, Road Geometry, etc. as described later.

However likelihood alone is not enough for the decision concerning a VRS installation, as a VRS would not be necessary if there are no hazards on the roadside that would pose any danger to errant motorists. For this reason, this section is dedicated to a non-exhaustive list of hazards that would necessitate the installation of VRS.

2.2 Forgiving Roadsides

The "forgiving roadside" approach is an inherent part of all the standards reviewed within WP1 and should always be followed as the main guideline in deciding if a VRS is required or not. The first priority of any designer should be to make the roadside as "forgiving" as reasonably possible. In order to achieve this, the following design options should be applied with an order of decreasing preference:

1. **remove the hazard:** if possible, a hazard should be removed to completely eliminate any risk of an errant vehicle reaching it;
2. **redesign the hazard to be safely traversable:** if the hazard cannot be removed, it should be made to be safely traversable by an errant vehicle;
3. **relocate the hazard further away from the road:** if the hazard cannot be made traversable, it should be located further away from the road, where it is less likely to be reached by errant vehicles;
4. **make the hazard passively safe:** if the hazard cannot be relocated, it should be made passively safe, in accordance with EN12767, to reduce the severity of a possible impact;
5. **install a VRS:** a VRS should only be installed if the options above are not possible or unreasonable from a cost-effectiveness perspective;
6. **delineate the hazard:** if none of the options above are applicable, the hazard should be delineated to warn road users of its existence.

It should always be remembered that, although designed and tested to decrease impact severity, collision with a VRS can also have undesired consequences. This is why it is presented as the 5th option on a list of decreasing priority. For this reason a VRS should only be used if reaching the hazard is likely to have more severe consequences than a collision with the VRS.

The hazards presented in the following section should be evaluated with the risk mitigation approach explained above.

2.3 Decision on where a roadside barrier is needed

2.3.1 Embankments (Falling Slopes)

Embankments (or Falling Slopes) may pose a rollover risk to the errant vehicles. The decision of a VRS need before an embankment should be made depending on the height and gradient of the embankment.

These are some examples from various standards:

- in Austria, a VRS is necessary on embankment slopes with a gradient steeper than 1:2 and height more than 4 m;
- in Ireland, the first stage is to provide embankment slopes that are 1:5 or flatter. If this is not feasible or cost effective the installation of a barrier may be appropriate. In all cases, the tops and toes of earthworks slopes should be rounded to a minimum radius of 4m;

- in Germany, a VRS is considered (depending on the speed and AADT) for embankments with a height over 3 m and a gradient steeper than 1:3;
- in UK, a VRS is considered for embankments/slopes with a height over 1 m and a gradient equal to or steeper than 1:1;
- in USA, a VRS may be considered (depending on the roughness of the surface) for embankments with a gradient steeper than 1:3;
- in Italy, a VRS is necessary on embankment slopes with a gradient steeper than 2:3 and height more than 1 m.

2.3.2 Cuts (Rising Slopes)

Cuts (or Rising Slopes) may pose a danger to the occupants of errant vehicles and may require shielding. The decision to install a VRS should be made depending on the gradient of the cut and the roughness of the surface. A VRS should be considered for cuts with steep slopes and rough surfaces. The base of the slope should also be curved smoothly.

These are some examples from various standards:

- in Germany, a VRS is considered (depending on the speed and AADT) for rising slopes with a gradient over 1:3;
- in Ireland, a cut slope is considered to be less of a hazard than a safety barrier provided the toe is rounded to a minimum radius of 4m. The exceptions are a slope steeper than 1:2 or a rock cut with a rough face that could cause vehicle snagging;
- in UK, installation of VRS is considered for soil cutting slopes and earth bunds greater than 1 m high and a gradient of 1:1 or steeper. A barrier is also considered for exposed rock faced cutting slopes regardless of the gradient;
- in Switzerland, installation of a VRS is considered for rising slopes with a gradient steeper than 1:3 when the slope foot is not rounded with a radius more than 5 m;
- in Italy no VRS are required in cuts.

2.3.3 Non-deformable Continuous Hazards

2.3.3.1 Retaining Walls

Retaining walls may pose a significant risk to occupants of errant vehicles, depending on the smoothness of the surface and possible impact angles. A VRS should be considered for retaining walls with a non-smooth surface.

These are some examples from various standards:

- in USA, a VRS is considered for retaining walls with a non-smooth surface and where the anticipated maximum level of impact is considerably high.

- in UK, a VRS is considered for a retaining wall which does not have a smooth face adjacent to traffic extending for at least 1.5 m above the adjacent carriageway;
- in Italy no VRS are required in front of retaining walls.

2.3.3.2 Noise Barriers

Noise barriers, if not designed in accordance to EN1317, may pose a significant threat to the occupants of errant vehicles. A VRS should generally be considered before noise barriers which are not designed and tested in accordance with EN1317.

2.3.3.3 Other Continuous Hazards

Other continuous roadside hazards, such as fencing or walls along the edge of land located near the road, may require shielding. Installation of a VRS may be considered.

2.3.4 Non-deformable Individual Hazards

2.3.4.1 The clear zone concept

Non-deformable individual hazards need to be protected if the structure is potentially harmful and if they are placed at a distance from the travelled way not larger that a given distance called “clear zone”. There are several possible methods to define the Clear Zone width as described in the Deliverable D1 of the IRDES Project (Nitsche et al, 2010) and in deliverable D1.1 of SAVeRS.

In the SAVeRS tool the AASHTO Roadside Design Guide procedure (AASHTO, 2011) is implemented (based on traffic, design speed, geometric layout and roadside configuration) and the compatibility of the available distance between the travelled road and obstacle with the requirements of the different national standards and guidelines analysed in deliverable D1.1 is also analysed. More details on the different methods applied in different countries can be found in D1.1 deliverable.

The tool procedure is not intended to replace national standards but to provide design indications for those countries that do not have a national standard (e.g. Italy) as well as practical indications for identifying outliers (situations where one country would have a very different requirement as compared to most of the others) when a country is revising already existing guidelines.

2.3.4.2 Trees

Collision with a tree is known to be one of the most common causes of injury in ROR crashes. Installation of a VRS should be considered for trees, especially for the ones expected to have a trunk girth of 100 mm or more at maturity.

These are some examples from various standards:

- in UK, a VRS is considered for trees having, or expected to have trunk girths of 250 mm or more (measured at a height of 300 mm above ground) at maturity;
- in France, a VRS is considered for trees having a trunk diameter of 100 mm or more and stumps protruding by more than 200 mm;
- in Denmark, a VRS is considered for trees with a diameter of 100 mm or more, measured 400 mm above ground;
- in Ireland, a VRS is required if it has a girth of 175mm or more measured at 1m above the ground;
- in Switzerland no protective device is needed for trees with diameter less than 80 mm.

2.3.4.3 Lighting Columns

Installation of a VRS is generally needed for High Mast or regular Lighting Columns, unless they are designed to be passively safe and tested in accordance with EN12767. More details on the use of passively safe structures can be found in the CEDR Forgiving Roadside Design Guide (www.cedr.fr).

2.3.4.4 Sign / Signal and Gantry Supports

Installation of a VRS is generally needed for Sign / signal and gantry supports, unless they are designed to be passively safe and tested in accordance with EN12767. More details on the use of passively safe structures can be found in the CEDR Forgiving Roadside Design Guide (www.cedr.fr). Specific consideration should be given for non-passively safe support posts with larger diameters.

These are some examples from various standards:

- in France, a VRS is needed for sign supports with a restraint moment exceeding 5.70 kN·m. This same value has been adopted also in the new revised Italian Standard;
- in UK and Ireland a VRS is considered for sign posts not meeting requirements of EN12767 which exceed the equivalent section properties of a tubular steel post having an external diameter of 89 mm and a nominal wall thickness of 3.2 mm. This limitation is slightly more conservative than the one adopted in France and in Italy;
- in Denmark, installation of a VRS is needed for steel posts with a diameter greater than or equal to 76 mm.

2.3.4.5 Intersecting / Transverse Ditches

Intersecting / Transverse ditches, if not covered properly, may cause high severity outcomes due to high angle impacts. Installation of a VRS should generally be considered, if the ditch cannot be made traversable, and if a head-on impact is likely.

These are some examples from various standards:

- in USA, a VRS is generally needed if likelihood of head-on impact is high;
- in Denmark, a VRS is generally needed for transverse ditches;

2.3.4.6 Culverts, Pipes, Headwalls

Installation of a VRS is generally considered for drainage pipes, culverts and headwalls. The decision should include engineering judgment based on the size and shape of the obstacle.

These are some examples from various standards:

- in USA, a VRS is considered based on size, shape and location of culverts, pipes and headwalls;
- in UK, a VRS is general considered for drainage culvert headwalls;
- in France, a VRS is necessary for culvert heads, except those implemented along the road or fitted with crash worth terminals or crash cushions.

2.3.4.7 Bridge Piers, Abutments, Railing Ends

A VRS is generally needed for bridge piers, abutments and railing ends.

2.3.4.8 Other Non-Deformable Single Hazards

Installation of a VRS should also be considered for the following non-deformable select individual objects:

- boulders;
- above ground equipment:
  - emergency telephones;
  - CCTV masts;
  - communication control cabinets;
  - stores for signs;
  - etc.;
- ends of concrete barriers, retaining walls, etc;
- wooden poles or posts with cross sectional area greater than 25,000mm^2 that do not have breakaway features;
- timber post and rail fences if not being used as a road boundary;
- substantial fixed obstacles extending above the ground by more than 150mm;
- concrete posts with cross sectional area greater than 15,000mm^2.

2.3.5 Permanent Bodies or Streams of Water

Getting submerged in a permanent body of water can have high severity consequences for the occupants of an errant vehicle. In case of sensitive bodies of water, such as reservoirs and sources of drinking water, contamination caused by an errant vehicle can also have dire consequences for other people using the source. Installation of a VRS should generally be considered for current or potential bodies of water, depending on the depth of water and significance.

These are some examples from various standards:

- in UK and Ireland a VRS is considered for permanent or expected water hazards with a depth of water 0.6 m or more; such as rivers, reservoirs, stilling ponds or lakes;
- in Austria, a VRS is necessary in areas adjacent to bodies of water, where the depth of water, channel cross section, etc. pose a particular risk;
- in Finland, a VRS is warranted for bodies of water deeper than 1 m, for at least one month per year;
- in Slovenia, a VRS is needed for road running parallel to a stream with a mean water level deeper than 2 m; near protected streams (regardless of the depth) and through water protection area (Zone2), where permitted speed is more than 90 km/h.

2.3.6 Chemical Works, Petroleum Storage Tanks, Locations of Hazardous Material

Chemical Plants, Petroleum Storage Tanks and facilities manufacturing or storing other hazardous materials in bulk may have catastrophic effects after an impact by an errant vehicle. This is mentioned in almost all of the standards examined in WP1. A roadside barrier should be installed along such locations.

2.3.7 Heavily Used Walkways, Locations of Public Gathering

An errant vehicle going into a busy public location with frequent pedestrian activity (including playgrounds) can cause a high number of casualties. The risk is higher for locations with a higher volume of pedestrian traffic and if the average time each person exposed to risk is longer. A VRS is generally considered for heavily used walkways and locations of public gathering.

2.3.8 Heavily Used Bicycle Paths

Similar to heavily used public locations, heavily used bicycle paths are under risk to errant vehicles. A VRS should generally be considered depending on the AADT of bicycles on the paths.

2.3.9 Adjacent Rail Lines

The collision of an errant vehicle with a train can have severe consequences; as it was the case in the Selby rail crash in England (2001) where 10 people died and 82 people suffered serious injuries. Unlike other stationary 3rd party hazards, the likelihood of an impact with a train is also dependent on the average number of trains on the tracks. Busier rail tracks pose a higher risk. A VRS should generally be considered along adjacent rail lines, depending on the frequency and speed of trains on the tracks.

These are some examples from various standards:

- in Germany, a VRS is needed for adjacent rail lines with more than 30 trains every 24 hours;
- in Spain, a VRS is needed for high-speed rail lines with an annual average of more than 6 trains per hour. A VRS is also needed for high-speed rail lined with an annual average of more than 6 trains per week, which contains at least one wagon loaded with flammable materials or toxic gasses;
- in Italy (in the new revised standard), a VRS is required if the rail line is closer than 12 m measured from the base of the road embankment.

2.3.10 Adjacent Roads

An errant vehicle going into another stream of traffic can cause serious traffic crashes with catastrophic consequences. The risk is higher for adjacent roads with a higher AADT and faster traffic flow speed. A VRS should generally be considered for adjacent roads, depending on the speed and AADT.

These are some examples from various standards:

- in Germany, a VRS is considered for adjacent roads with an AADT over 500 vehicles per day;
- in Italy (in the new revised standard), a VRS is required on the edge of the main road if the adjacent line is closer than 12 m measured from the base of the road embankment only for adjacent roads with an AADT over 1000 vehicles per day or a carriageway width above 5 m;
- in Finland, a VRS is warranted along adjacent roads with an AADT between 350 to 3000 vehicles per day.

2.3.11 Structures at Risk of Collapse

Some structures, such as bridge support elements or gantry supports have a risk of collapsing on other road users after an impact by an errant vehicle, particularly a heavy goods vehicle. These structures should generally be shielded by a VRS.

2.3.12 Objects which can Cause Severe Traffic Disruptions if Damaged

Some roadside objects or structures can be vital for the free flow of traffic. If damaged, these may take a long time to repair or replace, which could cause severe traffic disruptions. In such cases, the cost of a VRS may be less than the potential cost of traffic disruption. A VRS should generally be considered along such objects/structures.

2.3.13 Environmental Concern Such as Source of Drinking Water

An errant vehicle going into an environmentally sensitive area such as a source of drinking water can have serious environmental impacts. A VRS is generally considered along areas of environmental concern.

2.4 Risk assessment methods for identifying the need for a VRS

Within all of the countries examined in D1.1. Deliverable, risk assessment processes are undertaken, to varying degrees, to ascertain when and where a barrier is required.

In all cases, this starts with an examination of the features of the local site and the subsequent application of the clear zone concept (i.e. remove, relocate, make passively safe, and/or delineate). Hazards remaining within the clear zone are then assessed using a risk based approach to determine how the risk associated to these hazards should be dealt with. If it is financially viable, there is the option of protecting road users from the hazard with a vehicle restraint system.

The assessment of the remaining hazard varies from country to country, and further details of the methods used are given within deliverable D1.1. However, by way of a summary the approaches can range from the use of simple statements regarding requirements at specific hazards to complex computer systems:

Simple statements such as ‘Use barriers in front of dangerous point or lateral hazards’ are used in Croatia and in Italy.

Similarly in Cyprus, the requirements is to use a VRS ‘Where any of the following highway design features occur at or within 4.5 m from the edge of the paved carriageway:

- Retaining walls with a non-smooth traffic face up to 1.5 m above the carriageway level;
- Exposed rock faced cuttings slopes, rock filled gabions, crib walling or similar structures and which are less than 1.5 m above the carriageway level;
- Reinforced soil cutting slopes or earth banks greater than 1 m high and with a side slope gradient of 1:1 or steeper;
- Environmental noise barriers or screens;
- Structural supports such as overbridge piers, columns and abutments, etc.

Furthermore statements and bulleted lists such as these are also used within countries including Denmark, France, Israel, Slovenia and Switzerland.

Risk Classification models, such as those used in Belgium (Flanders), and Germany provide guidance for a pictorial view of risk assessment which then give further guidance on the containment and/or use of barrier systems with a particular level of performance as shown in Figure 2 and in Figure 3.

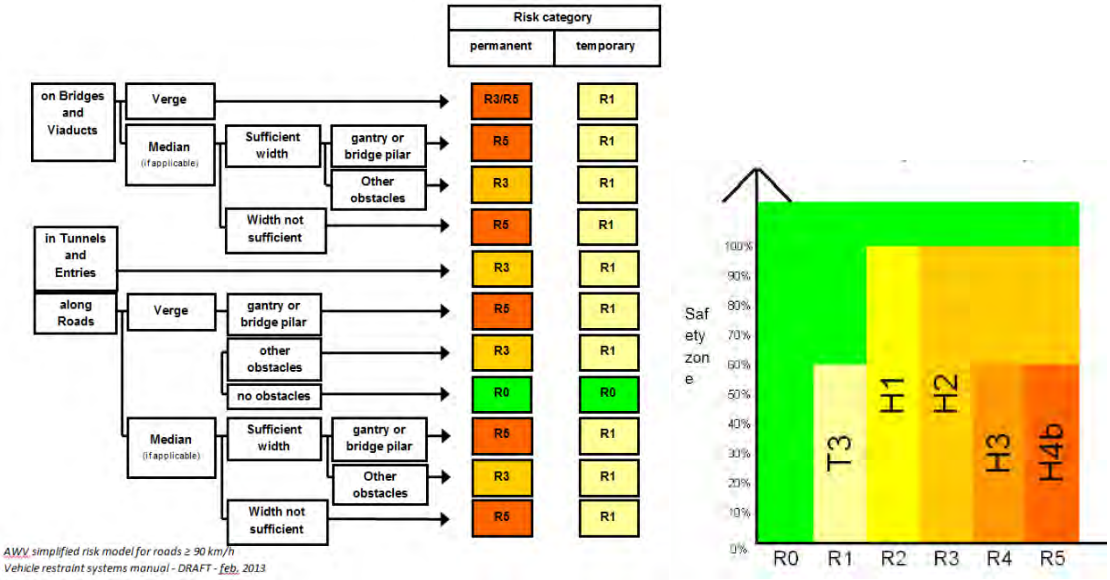


Figure 2: Risk classification processes used in Belgium (Flanders)

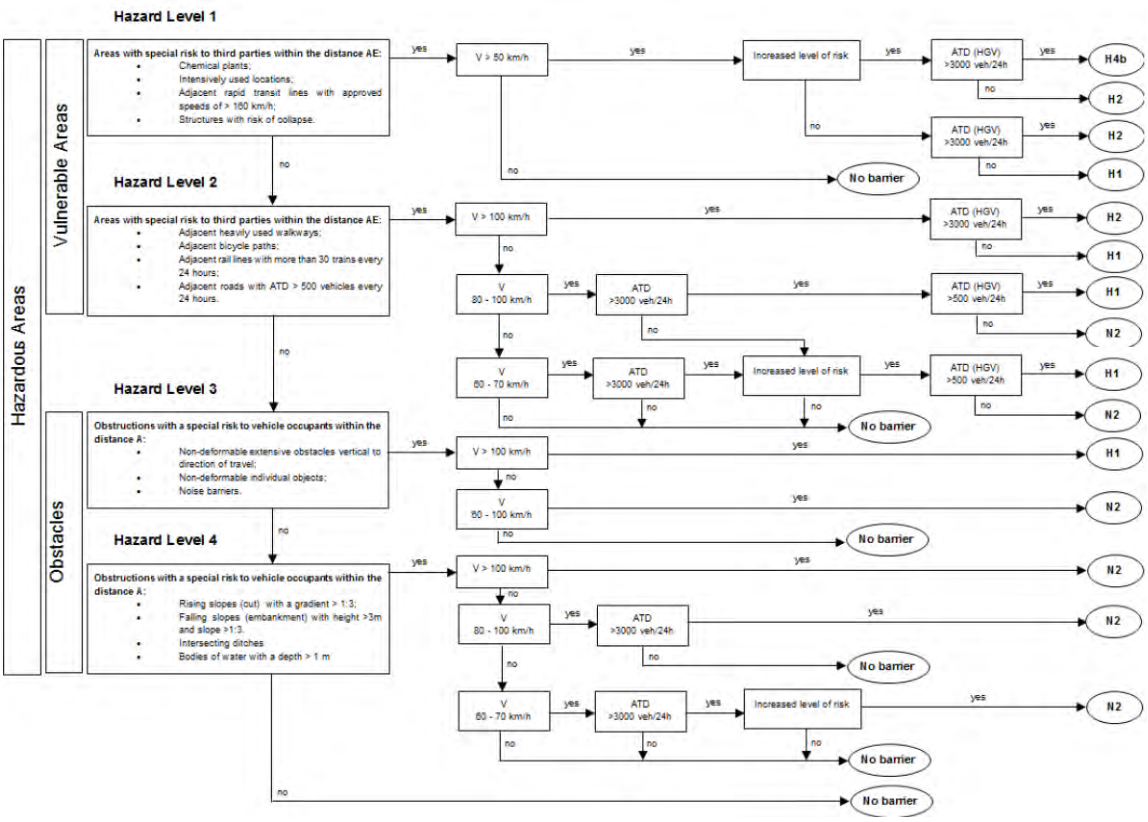


Figure 3: Risk classification processes used in Germany

In Spain, a tabulated view is used for determining the accident risk at any particular site, taking into account the local features and characteristics of the site, as shown in Figure 4.

Road Type	Type of Alignment	Side slope (Vertical : Horizontal)	Accident Risk	
			Very Serious or Serious	Normal
Single Carriageway	Straight or curve of radius> 1 500 m	<1:8	7.5	4.5
		1:8 to 1:5	9	6
		>1:5	12	8
	Outside of a curve of radius <1500 m	<1:8	12	10
		1:8 to 1:5	14	12
		>1:5	16	14
Dual Carriageway	Straight or curve of radius> 1 500 m	<1:8	10	6
		1:8 to 1:5	12	8
		>1:5	14	10
	Outside of a curve of radius <1500 m	<1:8	12	10
		1:8 to 1:5	14	12
		>1:5	16	14

Figure 4: Tabulated assessment of risk, as used in Spain

The hazards at the site are then assessed for their level of hazardousness, and an overall risk ranking for the site is determined. The containment level of the barriers to be provided is then subsequently specified, as shown in Figure 5.

Accident Risk	Containment level	$AADT_{HGV}$	Containment Level
Very Serious	Very High		H3 - H2 - H1
Serious	High	$AADT_{HGV} \geq 5000$	H2 - H1
		$400 \leq AADT_{HGV} < 5000$	H1
		$AADT_{HGV} < 400$	H1 - N2
Normal	Normal		H1 - N2

Figure 5: Determination of barrier containment level, based on accident risk in Spain

In a similar way, the new risk assessment procedure contained within the Irish TD19/13, requires the designer to establish if there is a hazard within the clear zone and if so, whether it can be mitigated. The hazard is then ranked as having a high, medium or low severity level. Next the sinuosity of that section of road is calculated and the collision rate threshold for that section of road is established. The risk of a vehicle leaving the road based on sinuosity ranking and collision rate ranking is then established. The hazard ranking and the risk of a vehicle leaving the road are then used to determine an overall risk ranking for the hazard. If the overall risk ranking is high, a barrier must be installed; if medium risk than a barrier must be used if the hazard is within 2 m of the edge of the carriageway, and the hazard must be further assessed if the hazard is 2 m or more away from the edge of the carriageway. If the overall risk is low, no safety barrier is required. As part of the overall process, it is greatly emphasised by the Irish requirements that an on-site review of the hazards is required.

The RRRAP system developed within the UK, and the RSAP programme used within the US and Australia are both examples of complex 'black box' systems which automatically undertake the risk assessment process, providing advice and information relating to the effectiveness of certain vehicle restraint systems. In the case of the RRRAP, the full details of a site, such as road type and classification, traffic flow, percentage of HGVs, the presence, location, size and type of hazards are inputted into the system. Options for treatment of the hazards in the form of VRS provision can then be entered, and the resulting level of risk is then received as an output. The aim of the process is to reduce the level of risk to As Low As Reasonably Practicable (ALARP principals). Whilst providing a complete and traceable methodology for auditing purposes, such systems often require a great deal of complex and detailed information to be entered into the systems.

2.5 Decision on Where a Median Barrier is needed

Crossover crashes often have catastrophic consequences. The risk of an errant vehicle colliding with other vehicle on the opposite stream goes higher as the AADT on the adjacent road goes up, and as the distance between two carriageways goes down. More severe consequences are also likely for higher traffic speeds on each direction of the road.

A VRS should be considered for medians depending on the, median width, the AADT on each side of the road, the speed limit and the topography of the terrain in between.

These are some examples from various standards:

- in USA, a median barrier is recommended on high-speed, fully controlled access roadways for locations where the median is 9.1 m in width or less, and the AADT is greater than 2000 vehicles per day. For locations with median widths less than 15.2 m and where the AADT is less than 20000 vehicles per day, a median barrier is optional;
- in UK, a safety barrier must be provided on dual carriageways where the width of the central reserve measured between opposing edges of carriageway road markings (or kerb faces where no markings) is 10 m or less;
- in Austria, a VRS is necessary on medians of dual carriageways with a speed limit above 70 km/h;
- in Italy, a median barrier is required for median widths (excluding the shoulders) below 12 m;
- in Sweden, a barrier is always required in the median.

2.6 Decision on Where a Bridge Parapet / Barrier is needed:

A VRS should be installed along all bridges.
It should be noted that protection needs to be extended beyond the bridge parapet in both approach and departure. Different criteria can be found to define these extensions: as an example in Ireland the protection needs to be extended for a minimum of 30 m in advance of the approach end and 15 m after the departure end of a vehicle parapet or vehicle/pedestrian parapet while in Italy a length of 1/3 of the minimum device length is required on both edges, in the revised standard.

2.7 Definition of the Length of Need

2.7.1 The Length of Need concept

The length of roadside that must be protected by a VRS depends on the size of the hazard and its placement relative to the road edge. This is usually called Length of Need (LON). The geometrical characteristics of the hazard do not influence the containment class of a VRS but they do influence the length of the installation and thereby the costs. The SAVeRS project investigates the type of VRS to be installed and provides information to support estimated the lifecycle costs but calculating the exact length of need for a VRS is beyond the project's scope. The information in this section is provided for the SAVeRS user to understand the implication of segment lengths used as an input in the tool.

2.7.2 Length of Need Background

Many national guidelines contain guidance on the length needed for a VRS depending on the roadside hazards. Most guidance documents use the approach and data developed in the US which are based on an assumed vehicle trajectory depicted in Figure 6. If the vehicle leaves the road and continues along a straight, the length "b" upstream from the hazard can be determined. The length "a" represents the projection of the hazard's length onto the road. If there is two way traffic, then a vehicle could cross over the centreline and strike the hazard from the other direction. This would generate a distance "c" downstream from the obstacle. As there is a lateral offset (or shy distance) of the barrier from the travel lane (Y_s), the length of need starts downstream a distance (d) from the point where the vehicle leaves the edge the travelled way. The length b+d is also known as the *runout length* of the vehicle.

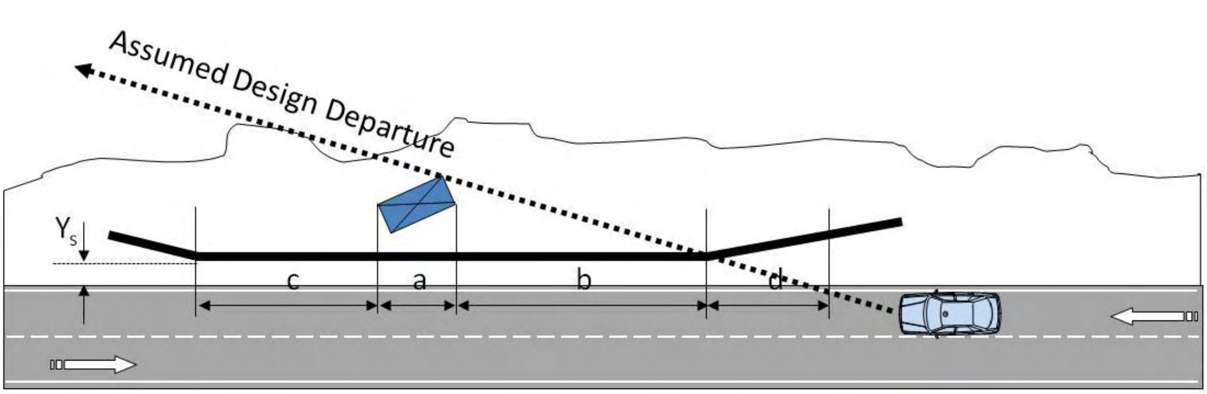


Figure 6: Length of Need

The length of a VRS to protect the hazard in the example in Figure 6 would be:

$$LON = a + b + c$$

The additional sections of VRS seen in the figure refer to the barrier anchoring sections (if required[1]) and barrier terminals. Unless the end terminal is specifically designed for redirecting an impacting vehicle, its length should not be included in the LON calculation.
The length defined in this analysis is a geometric requirement that has not been linked to the VRS selection. Type approved VRS have a minimum installation length specified in their type approval testing. The installed length of a VRS must always be greater than or equal to minimum installation length.

2.7.3 LON Specification

The following section provides information regarding LON calculation utilising information available in research literature. The purpose of the following summary is to provide information so the user understands the importance of an appropriate segment length for analysis. In all applications of the SAVeRS tool, the user's local guidelines and policies should be applied.
AASHTO has a well developed reference, the Roadside Design Guide (AASHTO, 2011), with updated LON information from the different sources, most significantly Coon et al, 1984. The approach used in this document is to determine the LON from the runout length for a roadside area. The lengths are based on observations of vehicle tracks from earlier studies in the 1960 and 1970s and more recently re-evaluated in Coon et al, 1984 and Sicking et al., 2010. The data is tabulated for different speed limits and road types and presented in Table

[1] As an example the new Italian draft standard requires 1/3 of the minimum barrier length to be placed prior to the section "b" to allow the barrier to have the full required containment at the beginning of section "b". This anchoring section could include the terminal or not depending on the terminal configuration.

1. The information in the Roadside Design Guide has been developed without reference to the hazard’s lateral offset from the road edge. This can result in longer LON calculations if a single hazard is close to road. In this case the trajectory of the vehicle leaving the road is not explicitly used.

Table 1: Runout Lengths recommended by Coon, et. al., 1984

	AADT			
Design Speed km/h	Over 10,000	5,000 to 10,000	1,000 to 5,000	Under 1,000
113	110	91	79	67
97	79	64	55	52
80	64	52	46	40
64	49	40	34	30
48	34	27	24	21

In an ongoing project, NCHRP 17-43 (NCHRP, ongoing), estimates of LON are being investigated using the trajectory of the vehicles and the lateral position of the hazards. The trajectories of the vehicles have been documented from US crashes and collected into a database which includes the actual vehicle paths.

Using the vehicle trajectories, corridors of the vehicle excursions can be created which then identify the runout length and resulting LON on the roadside. Figure 7 shows the trajectory envelopes (coloured areas) encompassing different percentiles of excursions that would strike a hazard placed 10 m from the road. The new analysis suggests that the AASHTO recommendations reflect the 85th-90th percentile of the trajectories. The two AASHTO curves shown in Figure 7 represent the lowest and highest values recommended for a road based on traffic volumes.

The influence of explicitly using the vehicle trajectories is demonstrated in Figure 8 where a 3 m obstacle distance is used for a reference. The actual trajectories suggest a much smaller LON is needed to shield a hazard, about 20 m (for the 85th percentile coverage level) compared to over 60 m for the lowest protection level suggested by AASHTO. The AASHTO lengths are seen to be unaffected by the hazard position when comparing this figure to Figure 7 for a 10 m hazard distance.

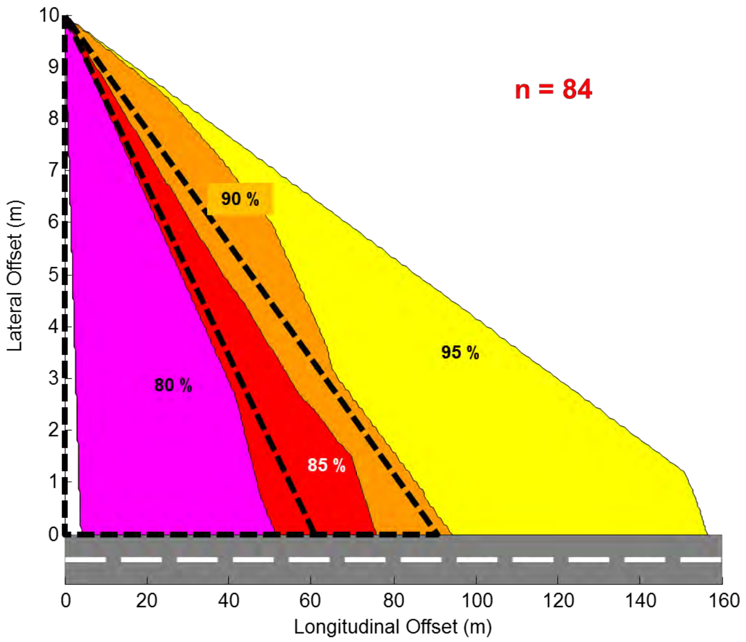


Figure 7: Upstream LON Requirements Based on Actual Trajectories and Compared to AASHTO 2011 Recommendations (dashed lines) for 96 km/h (60 mph) Roads [source: NCHRP 17-43 project]

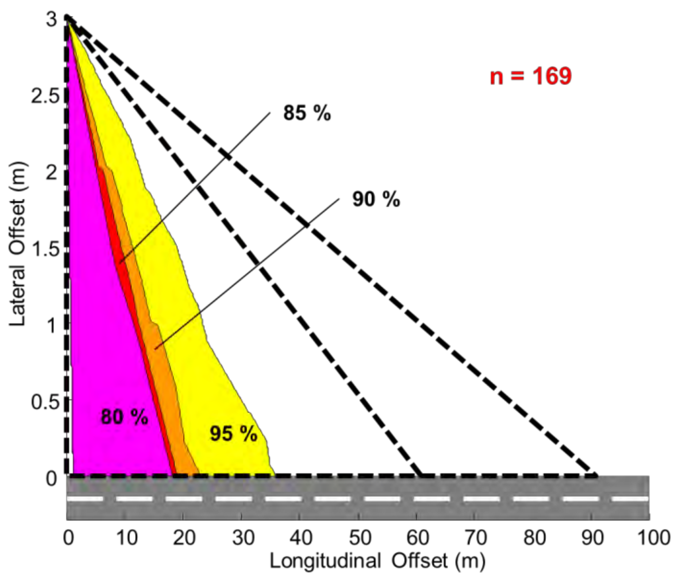


Figure 8: Influence of the Hazard Position on the LON [source: NCHRP 17-43 project]

2.7.4 Application to the SAVeRS Guideline

The SAVeRS analysis tool considers user defined segment lengths to identify the crash risks of a specific site. An example of a roadside with 2 point hazards (in red) is shown in Figure 9. Two point hazards with their associated LON (in blue) are shown. The SAVeRS tool does not use the position or number of the point hazards in the calculation, thus the user must know how the LON influences the assessment. If the reference length shown in the figure is used, the entire length of roadside will be used to calculate the accident rate and costs. As shown in the figure, not all the roadside necessarily needs protection and this may lead to longer installations than needed. The user can select to reduce the analysis length to just include both hazards or even divide the segment into two separate analyses.

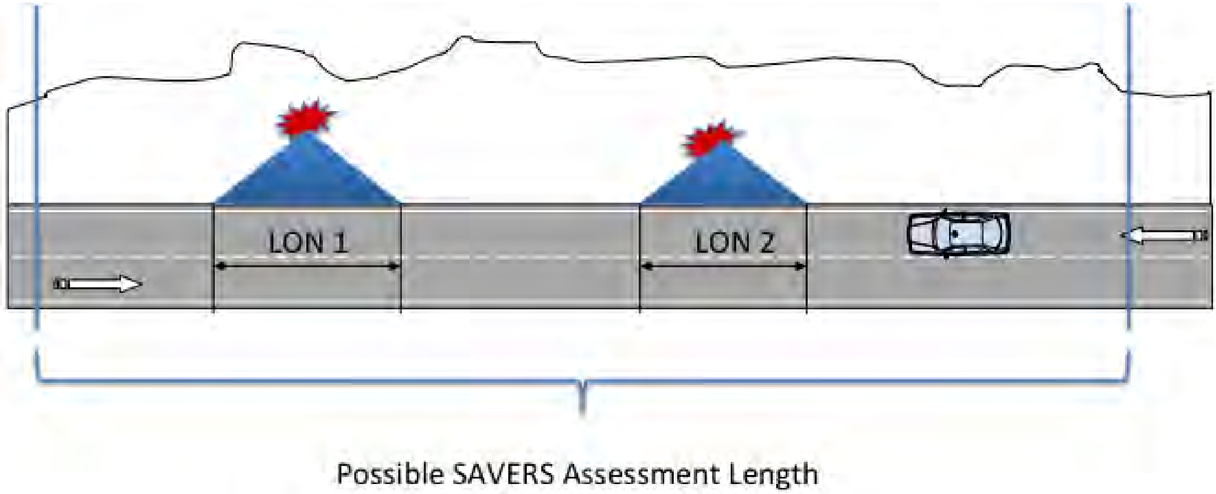


Figure 9: Roadside Design Case

Another case is shown in Figure 10 where the long obstacle is longer than the assessment length. The SAVeRS tool can analyse the crash rate and relative risk of the distributed hazard in terms of injury risk, but the tool will not detect if the assessment length is too short. This will result in an underestimation of the number of crashes on the segment and an underestimation of the costs for the VRS.

The user should know in advance what type of obstacles and where they are placed (laterally and longitudinally) along the roadside. As shown in Figure 9 and Figure 10, the user should identify the area to be addressed by the VRS before setting the analysis length in the tool. As a conservative estimate, the AASHTO approach can be used to estimate the LON, ignoring the lateral offset of the hazards. Information on the AASHTO approach is documented in full in the Roadside Design Guide (AASHTO, 2011).

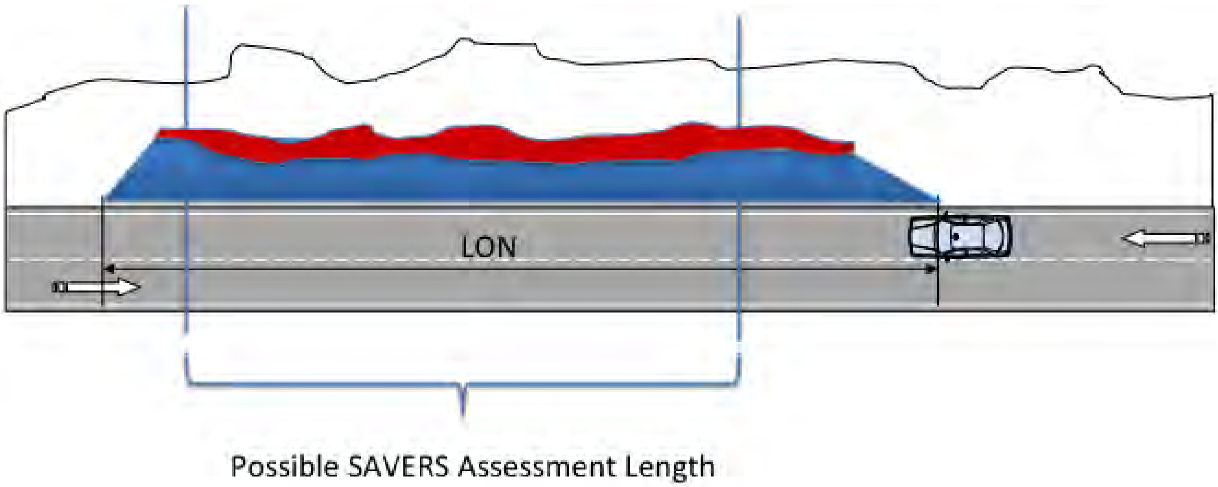


Figure 10: Example of Short Assessment Length

In the SAVeRS tool the "b" and "c" values of the LON are given. To obtain the total LON the designer needs to consider if it is a single isolated hazard or e series of hazards with overlapping LONs.

If the VRS installation length should be as small as possible, the approach being developed in NCHRP 17-43 Project can be applied but the full range of LON for different road categories is not available at the time of writing. Given that the 85th-90th percentile values for the 10 m hazard distance estimated in the NCHRP 17-43 project show a very good agreement with the AASHTO Roadside Design Guide while for shorter offsets the LON is proportionally reduced (given the same design speed), the AASHTO values (evaluated for the specific design speed and AADT) could be scaled with the offset distance, for example a 5 m hazard offset would require half the LON length as a 10 m hazard. Note that this should not be extended to case where a hazard on the road edge has a zero LON. In the tool both the AASHTO value and the reduced value are given and the evaluation is limited to a distance from the front of the barrier (considered at the edge of the shoulder) equal to the barrier working width. If the distance is smaller the interaction between the barrier and the obstacle needs to be assessed as shown in La Torre et al., 2015 with reference to the presence of a Variable Message Sign in the working width of the barrier. This study has shown that if the distance between the barrier and the obstacle is reduced below a certain value (to be determined for the specific barrier/obstacle configuration) the system will not offer the full performance for which it is designed.

3 SAFETY BARRIERS (INCLUDING BRIDGE PARAPETS)

3.1 The multi-level approach

As different countries, as well as different designers within a country, have different level of expertise and different data availability, the SAVeRS procedure has been structured with different possible application levels, as shown in Table 2.

Table 2: SAVeRS Multilevel approach

LEVEL	DATA AVAILABILITY	SAVeRS APPROACH
1	Very detailed data available	Full SAVeRS selection procedure
2	Limited data available	Reduced SAVeRS Selection procedure
3	No data available	Default selection criteria

Each model in the SAVeRS tool is designed allowing the user to change the calculation parameters as compared to the default ones. Where possible different default parameters sets are given for different conditions in order to allow the user to select the one that fits better the specific case analysed.

One of the core parts of the SAVeRS procedure is the estimation of the Single Vehicle Run Off Road crashes (SVROR) where, as an example, the user can:

- develop a specific base function and calibrate the overall model based on local data (Level 1);
- adopt one of the default base models and calibrate the full model based on local data (Level 2);
- select one of the default distributions (Level 3).

The different components of the SAVeRS tool are described in this guide together with the default values included in the tool.

3.2 Decision process

As indicated earlier the widely used definition of ‘Risk’ is a product of ‘Likelihood’ and ‘Consequences’, as shown in Figure 11.

Figure 11: The risk model used to categorize the parameters

In the SAVeRS approach the likelihood is estimated by means of a SVROR model that has been developed in WP2 based on the data from:

- UK, Ireland, Italy, Sweden and Austria (for motorways);
- Ireland and Sweden (for two-lane two-way rural roads).

The SVROR model, as implemented in the tool, is described in section 3.3 of this Guideline. A more detailed description of the model development can be found in WP 2 Deliverable (D2.1 "Analysing the Different Parameters which influence the need and selection of VRS").

To evaluate the possible consequences of a SVROR crash two different conditions has been identified:

- crashes where the vehicle is contained and the VRS is not penetrated;
- crashes where the vehicle is not contained and the VRS is penetrated.

To identify the conditions where the VRS can be penetrated a set of "impact kinetic energy" (IKE) distribution functions have been defined as described in section 3.2.

The "impact kinetic energy" is defined as:

$$IKE = \frac{M[V\sin(\theta)]^2}{2} \text{ [kJ]}$$

where:

M = the vehicle mass [tonnes]

V = speed of the vehicle at the time of impact [m/s]

θ = the angle of impact

Conceptually this is the kinetic energy that the VRS is exposed to in the crash if only the lateral component of the impact velocity is considered. This is a simplified expression that captures the basic physics of the crash but does not consider the complex contact phenomena that are also part of the crash between different structures.

Considering the VRS containment levels defined by EN1317-2 the following IKE values can be associated to each containment level (Table 3). If a vehicle is tested in H4 class with TB81 testing conditions (with a tractor-trailer instead than with a rigid truck) the H4a IKE value need to be considered as the tractor-trailer IKE is not directly comparable with the rigid truck IKE values. Low angle devices are not considered in the SAVeRS procedure as these are applied to work zones and temporary protections.

Table 3: IKE values for EN1317-2 test conditions

Application	Test Level	Mass [kg]	Speed [km/h]	Angle [deg]	IKE [kJ]
Low Angle	*T1*	*1300*	*80*	*8*	*6.2*
	T2	*1500*	*80*	*15*	*24.8*
	T3	*10000*	*70*	*8*	*36.6*
Normal	**N1**	1500	80	20	43.3
	N2	1500	110	20	81.9
High	**H1**	10000	70	15	126.6
	H2	13000	70	20	287.5
	H3	16000	80	20	462.1
Very High	**H4a**	30000	65	20	572.0
	H4b	*38000*	*65*	*20*	*724.6*

In the SAVeRS procedure different sets of impact energy distributions are given for Passenger Cars (PC) and for Heavy Goods Vehicles (HGV) as described in section 3.4 but the user can define different IKE distribution functions.

The Severity Distribution Functions (SDF) are implemented in the SAVeRS tool to estimate the consequences of each crash. The consequences of injury crashes are classified according to the KABC scale with the following definitions:

K	Fatal crash
A	Incapacitating injury crash
B	Non incapacitating injury crash
C	Possible injury crash

Property damage only crashes are not considered in the SAVeRS model as these are generally underreported and do not represent a critical crash for road restraint system.

For the definition of the SDFs the following conditions are considered in the SAVeRS tool (see section 3.5):

- crashes with impact energy below or to equal the VRS containment level (VRSCL). Even though there is no immediate relation between the IKE and the VRSCL as the actual containment depends on the combination of mass, angle and speed, this type of crash is conventionally considered to be contained by the VRS and the consequences are set to different values for different VRSCL as defined by EN1317-2. It should be noted, anyhow, that crashes with the same IKE can have completely different dynamics and therefore there is no guarantee that a crash with IKE below the VRSCL is actually contained or vice versa;
- crashes with an impact energy above the VRS containment level (VRSCL). This type of crash is conventionally considered to potentially lead to a barrier penetration. For high risk bridge decks and median barriers the consequences have been considered always fatal with a conservative assumption. For other installations a SDF function has been implemented in the SAVeRS tool considering also the hazard that the VRS is shielding.

All the default SDFs implemented in the SAVeRS tool can be modified by the user.

Based on the outcome of the accident evaluation a Whole Life Cost (WLC) evaluation is then performed considering:

- societal costs due to crash consequences;
- hardware related costs (construction, maintenance and repair);

as described in section 3.6.

The current version of the SAVeRS Tool doesn’t account explicitly for the traffic management cost due to the repair work zone (the cost is given per unit length). This could be added in future releases as a fixed figure per each crash provided that these figures can be made available as a fixed value independently of the traffic during the event.

The WLC analysis allows to compare directly in one single run different alternatives for the same VRS class. For comparing the user risk associated with different VRS classes for the same project different runs of the Tool need to be performed and the results compared off-line.

The overall SAVeRS procedure for selecting the most appropriate VRS with respect to safety barriers and bridge parapets is described in Figure 12.

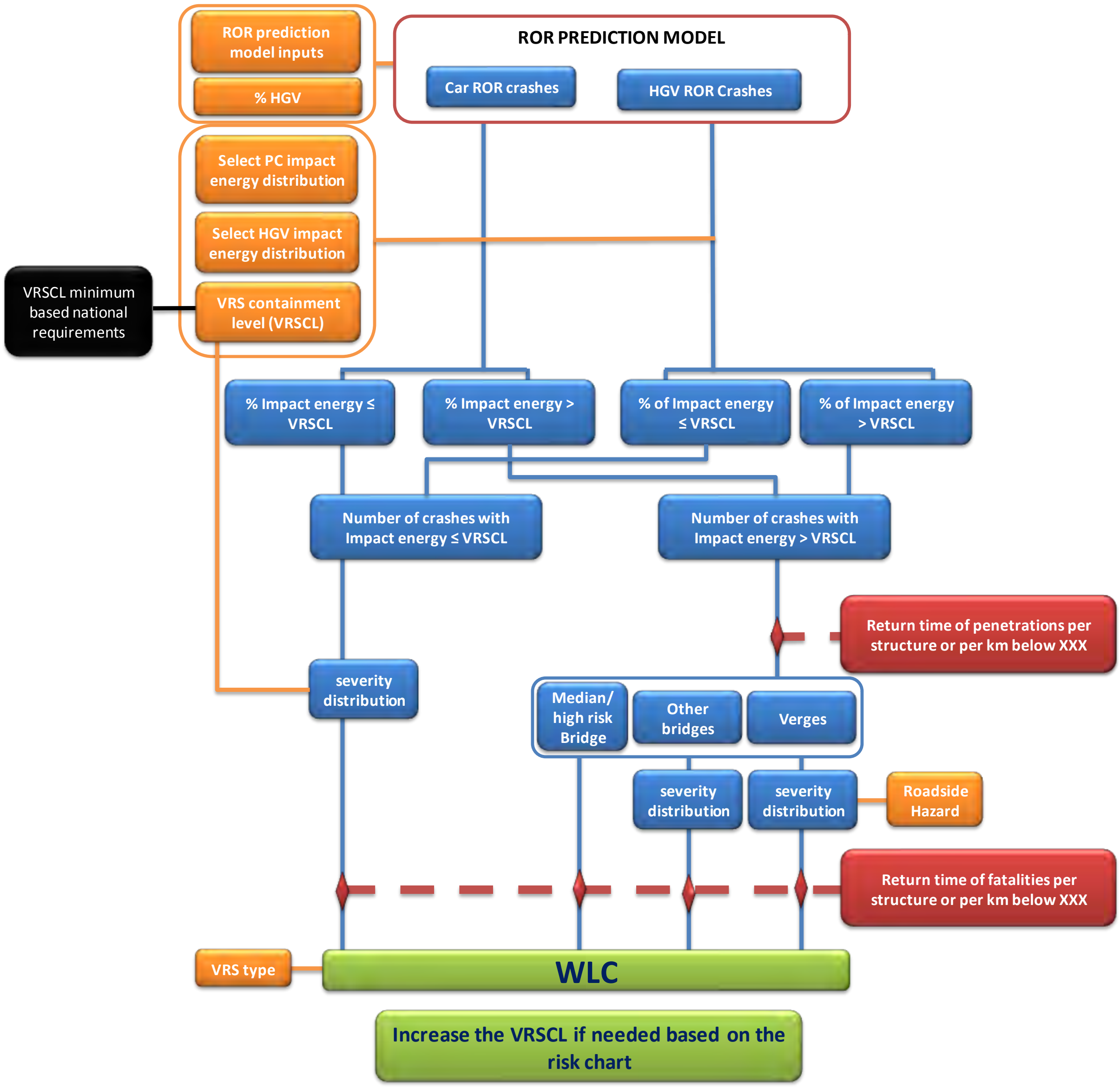


Figure 12: SAVeRS procedure for selecting the most appropriate VRS (for safety barriers and bridge parapets)

To account for third party risk a separate analysis has been performed comparing the requirement of different national in order to develop a “risk matrix”.

Consequences Likelihood	Normal	Relevant (relevant risk to third parties)	High (high risk to third parties)
Low	L	M	H
Moderate	L	H	H
High	L	H	VH

When the roadside configuration can be rated as "normal" (without special hazards for third parties) the selection is based solely on the results of the WLC calculations.

When additional risk factors for third parties are present:

- When a Medium (M) risk condition is estimated increasing the optimal WLC VRS class by one level should be considered with a minimum performance class of H2;
- When an High (H) risk condition is estimated increasing the optimal WLC VRS class by one level should be considered with a minimum performance class of H3;
- When a Very High (VH) risk condition is estimated increasing the optimal WLC VRS class by one level should be considered with a minimum performance class of H4.

The criteria to define the high and very high third party risk situations are based on the worldwide review of the different national standards conducted in WP1 (see Deliverable D2.1 for more details).

The likelihood classes (low/medium/High) have been defined in the SAVeRS tool based on following assumption:

- For long span conditions (e.g. railways running parallel to the road under evaluation)
    - Low Likelihood = 1 barrier penetration/km every 100 years[2];
    - Moderate Likelihood = 1 barrier penetration/km every 50-100 years;
    - High Likelihood = 1 barrier penetration/km every 0-50 years.
- For local conditions limited to an extension below 1000 m (e.g. a high risk structure adjacent to the road under evaluation)

[2] This return time is based on the 100 year fatalities return time threshold defined in section 4.1. Even assuming a 100% fatality rate, if the penetrations return time is above 100 years the fatality return time would still be above 100 years. If a different threshold is considered these risk levels should be adapted accordingly.

- Low Likelihood = 1 barrier penetration every 100 years or more;
- Moderate Likelihood = 1 barrier penetration every 50-100 years;
- High Likelihood = 1 barrier penetration every 0-50 years;

These frequency values can be defined by the different NRAs for application in each country.

Based on the indications gathered in WP2 the following definitions of Relevant Risk and High Risk to third parties has been given in the SAVeRS procedure but this can be adapted in national regulations.

High risk to third parties:

- chemical plants within the clear zone or a fixed distance (e.g. 12 m in Italy);
- intensively used locations;
- high speed rails or rapid transit lines (overpassed or within the clear zone or a fixed distance, e.g. 12 m in Italy);
- structures not designed to bear the impact of an errant vehicle the collapse of which could have severe consequences on third parties (within the clear zone or a fixed distance).

Relevant risk to third parties:

- motorways, primary highways or roads with and AADT above a nationally defined value (e.g. Italy 1000, Germany 500) (overpassed or within the clear zone or a fixed distance, e.g. 12 m in Italy);
- public areas with frequent pedestrian activities (including playgrounds) within the clear zone or a fixed distance;
- environmental concern such as a source of drinking water overpassed or within the clear zone or a fixed distance (e.g. 12 m in Italy).

3.3 Run Off Road model

3.3.1 Structure of the Run Off Road Model

The Run Off Road model implemented in the SAVeRS tool has been developed in WP2 (see D2.1 “Analysing the Different Parameters which influence the need and selection of VRS” for more details) with a structure allowing for the maximum flexibility and adaptability to local conditions. The crash prediction model has the following structure.

$$N_{pred\_i} = N_{SPF,i} \times \left(CMF_{1,i} \times CMF_{2,i} \times \dots iCMF_{y,i}\right) \times C$$

where:

$N_{pred,i}$ is the predicted average SVROR crash frequency for a specific year for a site i;

$N_{SPF,i}$	is the predicted average SVROR crash frequency determined for base conditions for site i (base model);
$CMF_{y,i}$	are the Crash Modification factors specific to site i;
C	is the calibration coefficient to adjust the prediction for local conditions (national, regional, by network etc).

This structure has the advantage to allow for a very high degree of flexibility and adaptability to different conditions. The SAVeRS tool user can:

- select one of the models already available in the SAVeRS tool;
- select one of the base models already available in the SAVeRS tool and perform an overall calibration to the local network as described in Annex 3 (for motorways) and Annex 4 (for two-lane two-ways rural roads);
- fit the base model functional form to local data as described in Annex 2 and perform an overall calibration to the local network as described in Annex 3 (for motorways) and Annex 4 (for two-lane two-ways rural roads);
- replace the number of crashes estimated by the SAVeRS SVROR model with locally derived crash values (typically based on an Empirical-Bayes evaluation). The statistical methods to derive local crash data are not discussed in this Guideline. More details can be found in the AASHTO Highway Safety Manual (AASHTO, 2010 and AASHTO, 2014).

In the following sections the SAVeRS SVROR models for motorways and rural two-lane two-ways roads are summarized. More details on the model development can be found in D2.1 "Analysing the Different Parameters which influence the need and selection of VRS".

3.3.2 Motorways

3.3.2.1 Base model

The functional form used in SAVeRS for the prediction of the number of SVROR in "base conditions" is:

$$N_{SPF,i} = \mathrm{Sec}_{\mathrm{Length}} \cdot e^{\beta_0 + \beta_1 \log(AADT)}$$

where:

Sec_Length is the section length (in m);

AADT is the annual average daily traffic (vehicles/day).

This functional form has been calibrated for the motorway networks of Austria, Ireland, Italy, Sweden, UK extracting from the accident database a set of sections with the following characteristics:

- Road type: median divided dual carriageway

- Roadway type: segments (not including intersections, interchanges, driveways etc.)
- Area type: rural
- Terrain: level (between -2 and 2% longitudinal gradient)
- Alignment: straight roads
- Number of lanes: 2
- Hard shoulder: yes
- lane width between 3.50 m and 3.75 m
- outside shoulder width between 2.51 m and 3.00 m
- inside shoulder width between 0.51 m and 0.75 m;
- no rumble strips.

In Table 4 the models' coefficients for the different countries are given together with a summary of the characteristics of the road networks used for fitting the base model.

Table 4: parameters of the base models included in the SAVeRS tool and network characteristics for motorways

Variables	Austria	Ireland	UK	Italy	Sweden
β_0	-14.300	-12.540	-12.760	-14.470	-11.857
β_1	0.742	0.514	0.527	0.616	0.244
Type of roads	Motorways	Motorways	Motorways	Motorways	Motorways
Number of sections used	567	280	912	99	6799
Total number of km used	1434	278	829	327	2806
Analysis period	2007–2011	2007-2011	2007-2011	2007-2011	2003-2009
Total number of crashes	1008	131	668	671	1527
AADT range	3300/46150	3875/54401	5850/155400	3989/31186	4600-21250
Weighted average of AADT	19097	17835	42294	15832	9160
% HGV range	3.2-36.1	0-11.8	4.0-33.0 (*)	15.0-30.0	7.2-18.6
Weighted average of %HGV	8.8	6.9	15.9	24.1	14.2

(*) few outliers with higher HGV percentages can be found in the UK database. These are not considered in the normal application range given in this table

3.3.2.2 Selection of Crash Modification Factors (CMFs)

To account for the specific condition of a given project a set of Crash Modification Factors (CMF) are given for the following aspects:

- number of lanes;
- outside shoulder width (shoulder adjacent to the slow moving traffic);
- inside shoulder width (shoulder adjacent to the median);
- longitudinal gradient;
- shoulder rumble strips;
- lane width;
- horizontal curvature.

To allow for a simpler use of the tool the CMF values are given by ranges allowing the user to define an average value within a given range without the need for a very narrow segmentation in homogenous sections. For the horizontal curvature CMF, a function is given and the user will have to describe the geometric layout in the tool (in terms of radius and length of each curve).

The following tables show the CMF values implemented in the SAVeRS tool. More details on these CMF are given in D2.1 deliverable.

The user can modify the CMF values in the tools after activating the "Show CMF sheets to modify SAVeRS default CMF calculations" option but in doing this it is important to remember that all the CMFs are referred to a specific set of base condition. A CMF derived with base conditions different from the ones listed above shall not be used.

Table 5: CMF for increasing the number of lanes

Base condition	Specific design	CMF_L
2 lanes	3 lanes	**1.00**
2 lanes	3 lanes	**1.21**
2 lanes	4 lanes	**1.31**

Table 6: CMF for increasing the outside shoulder width

Shoulder width [m]	Median [m]	Median [feet]	CMF_{OSW}
< 1.00	not applicable		
1.00–1.50	1.25	4.10	**1.37**
1.51–2.00	1.75	5.74	**1.24**

2.01–2.50	2.25	7.38	**1.11**
2.51–3.00	2.75	9.02	**1.00**
3.01–3.50	3.25	10.66	**0.90**

Table 7: CMF for increasing the inside shoulder width

Shoulder width [m]	Median [m]	Median [feet]	CMF_{ISW}
< 0.50	not applicable		
0.50–0.74	0.620	2.03	**1.00**
0.75–0.99	0.870	2.85	**0.99**
1.00–1.24	1.120	3.67	**0.97**
1.25–1.49	1.370	4.49	**0.96**
1.50–1.74	1.620	5.31	**0.95**
1.75–2.00	1.870	6.14	**0.93**

Table 8: CMF for gradient classes

Gradient range [%]	Median [%]	CMF_G
$x \leq -4$	-4.5	**1.44**
$-4 < x \leq -3$	-3.5	**1.33**
$-3 < x \leq -2$	-2.5	**1.23**
$-2 < x \leq 2$	0.0	**1.00**
$2 < x \leq 3$	2.5	**0.82**
$3 < x \leq 4$	3.5	**0.75**
$x > 4$	4.5	**0.69**

Table 9: CMFs for shoulder rumble strips

Proportion of straight segment length (P_{OR})	CMF_{RS}
No rumble strips	**1.00**
10% of segment	**0.99**
20% of segment	**0.98**
30% of segment	**0.97**
40% of segment	**0.96**
50% of segment	**0.95**
60% of segment	**0.94**

70% of segment	**0.93**
80% of segment	**0.92**
> 90% of segment	**0.91**

Table 10: CMF for lane width

Lane width [m]	Median [m]	Feet	CMF_{LW}
< 3.00	Not applicable		
3.00–3.24	3.12	10.24	**1.07**
3.25–3.49	3.37	11.06	**1.04**
3.50–3.75	3.62	11.89	**1.00**
3.76–4.00	3.88	12.73	**0.97**

For the horizontal curvature effect a Crash Modification Function is given as shown below:

$$CMF_{HC} = 1.0 + 0.0719\ x \left[\sum_{i=1}^{m} \left(\frac{5{,}730}{R_i} \right)^2 \cdot P_{c,i} \right]$$

where:

CMF_{HC} = Crash Modification Factor for horizontal curvature in a freeway segment with any cross section for fatal-and-injury single-vehicle crashes

R_i = Radius of curve i (feet)

$P_{c,i}$ = Proportion of segment length with curve i

m = Number of horizontal curves in the segment

This function is already implemented in the SAVeRS tool and the user is only required to describe the geometry in terms of number of curves and their extension in the project length.

3.3.2.3 Calibration Coefficients for Run-Off-Road crashes on motorways

In most cases, CMFs from the literature do not reflect the actual road and traffic situation in the respective countries. Hence, so called calibration factors (C-values) need to be calculated to account for differences in the jurisdiction and time period to which they are applied.

The calibration coefficient in the prediction model accounts for all the factors that lead to safety differences and are not already considered by the crash prediction model.

The C-value is defined as the simple ratio between the total number of predicted (N_{pred}) and observed (N_{obs}) number of crashes defines the calibration factor (C):

$$C = \frac{\sum_{i=1}^{all\ sites} N_{obs,i}}{\sum_{i=1}^{all\ sites} N_{pred,i}}$$

In Table 11, the C-values for Austria, Italy, Sweden and the UK are given together with a summary of the characteristics of the road network used for calibrating the overall ROR model. Due to lack of sample data, no calibration factor for Irish motorways can be provided.

The guidelines for calibrating the SVROR model to a different network are given in Annex 3.

Table 11: parameters of the full models included in the SAVeRS tool and network characteristics for motorways

Variables	Austria	UK	Italy	Sweden
C	0.793	0.544	0.872	0.863
Type of roads	Motorways	Motorways	Motorways	Motorways
Number of sections used	567	454	100	7848
Total number of km used	1434	532	100	3663
Analysis period	2007–2011	2007-2011	2007-2011	2003-2009
Total number of crashes	1008	372	280	1524
AADT range	3300/46150	5892/107200	3700/62740	4600/21276
Weighted average of AADT	19097	11290	21652	9417
% HGV range	3.2/36.1	0.1/31.0	12.6/35.1	7.1/18.5
Weighted average % HGV	8.8	19.3	24.5	-
Number of lanes range	2-3	2-4	2-4	-
Lane width range (m)	3.0/3.75	3.1/4.1	3.75	-
Minimum curve radius (m)	890	-	445 (*)	1072

inside shoulder width range (m)	1.0–1.50	0.50-1.97	0.50	-
outside shoulder width range (m)	0.50/3.00	1.16-3.5	1.00/4.00	-
Longitudinal grade range	-2/+2	-3.76/+3.19	-2.85/+2.85	-1.63/+1.53
Rumble strips (Y/N)	N	N	N	Y

The model is calibrated considering the total SVROR crashes while the SAVeRS tool requires to split the crashes in passenger car crashes and HGV (trucks and buses) crashes. A common assumption is that the accident risk is the same and therefore the number of crashes with HGV (N_{HGV}) would be given by:

$$N_{HGV} = N \cdot \%HGV$$

where %HGV is the percentage of HGVs in the traffic mix.

Recent studies show that this assumption is not valid for ROR crashes. In the NCHRP 22-27 project (Ray et al, 2012) a correction factor of 0.3 has been introduced to account for the reduced ROR risk of HGVs.

Using the Italian, UK and Irish entire fatal+injury SVROR crash dataset the following statistics have been derived for motorways:

- in UK a 0.5 HGV risk correction factor was estimated;
- in Italy a 0.61 HGV risk correction factor is was estimated;
- in Ireland a 0.51 HGV risk correction factor is was estimated.

This extensive evaluation confirms that there is a correction factor to HGV crash estimates and therefore for each country as well as for the user defined model a correction factor is allowed.

For the counties for which the HGV crash risk correction factor is not yet available the value of 0.61 as been adopted being the highest of the values calculated.

3.3.3 Two-lane, two-ways rural roads

3.3.3.1 Base model

Smaller, non-motorway road types were modelled in a similar fashion as motorways. Only two partners, VTI (Sweden) and TCD (Ireland), had data available for conducting this analysis. The Irish data were constrained to state roads with speed limits of 100 km/h.

Swedish data was available for most road types but a lack of crash data and diversity of road configurations required that a pragmatic constraint to two-lane two-ways rural roads with carriageway widths between 9 and 10 m were used. More details on the respective country models are presented in the deliverable D2.1.
The two base models are slightly different as the Swedish model includes also the posted speed as an explanatory variable in the base model.

The base model for two-lane two-ways rural roads has therefore the following form:

$$N_{SPF,i} = \text{Sec\_Length} \cdot e^{\beta_0+\beta_1 \log(AADT)+\beta_s \text{speed}}$$

where:

Sec_Length	is the section length (in m);
AADT	is the annual average daily traffic (vehicles/day);
speed	is the local speed limit (km/h).

This functional form has been calibrated extracting from the accident database a set of sections with the following characteristics:

- road type: two-lane two-ways single carriageway
- roadway type: segments (not including intersections, interchanges, driveways etc.)
- area type: rural
- terrain: level (between -3 and 3% longitudinal gradient)
- alignment: straight roads
- hard shoulder: yes
- lane width not below 3.50 m
- outside shoulder width between 1.50 m and 2.10 m

In Table 12 the models coefficient for the different countries are given together with a summary of the characteristics of the road network used for fitting the base model.

Table 12: parameters of the base models included in the SAVeRS tool and network characteristics for two-lanes two-ways rural roads

Variables	Ireland	Sweden
β_0	-11.164	-14.252
β_1	0.385	0.549
β_2	0 (not used in the model)	$0.445\text{x}10^{-2}$
Type of roads	Rural two-lane two-ways	Rural two-lane two-ways

Number of sections used	283	155
Total number of km used	287	97
Analysis period	2007-2011	2003-2009
Total number of crashes	109	31
AADT range	1490-15100	2200-7400
Weighted average of AADT	5483	7400
HGV Range	/	7-24
Number of lanes range	2	2

3.3.3.2 Selection of Crash Modification Factors (CMFs)

The application of the crash prediction model to the specific condition of a given project requires a set of Crash Modification Factors (CMF). The CMFs for motorways cannot be applied to rural roads and a set of appropriately derived CMFs for rural roads were obtained from the AASHTO Highway Safety Manual (AASHTO, 2010). The following CMFs were identified and implemented into the model:

- outside shoulder width;
- longitudinal gradient;
- lane width;
- horizontal curvature.

The CMF for the shoulder width is given in Table 13 which uses a 1.8 m (6 ft) paved shoulder as a reference. The CMFs in Table 13 are taken for AADT over 2000 which are the highest values.

Table 13: CMF for the outside shoulder width

Shoulder width [m]	Median [m]	Median [feet]	CMF_{OSW}
x < 0.30	0.15	0.5	1.45
0.30 ≤ x < 0.90	0.60	2	1.3
0.90 ≤ x < 1.50	1.20	4	1.15
1.50 ≤ x < 2.10	1.80	6	1.00
2.10 ≤ x ≤ 2.70	2.40	8	0.87

The CMF to account for the grade of the road is given in Table 14 and is independent of AADT. The baseline condition is a road with gradient between -3% and 3%.

Table 14: CMF for longitudinal gradient

Gradient range [%]	Median [%]	CMF_G
x < -6	-7.0	**1.16**
-6 ≤ x < -3	-4.5	**1.10**
-3 ≤ x < 3	0.0	**1.00**
3 ≤ x < 6	4.5	**1.10**
x ≥ 6	7.0	**1.16**

Lane width can be modified by the CMFs listed in Table 15. These values are based on AADTs greater than 2000.

Table 15: CMF for Lane Width

Lane width [m]	Median [m]	Median [feet]	CMF_{OSW}
x < 2.90	2.75	0.5	1.45
2.90 ≤ x < 3.20	3.05	10	1.3
3.20 ≤ x < 3.50	3.35	11	1.15
≥ 3.50	3.65	12	1.00

The CMF that accounts for horizontal curvature is given by the equation

$$CMF_{HC} = \frac{(1.55 * L_c) + \left(\frac{80.2}{R}\right) - (0.012S)}{1.55 \cdot L_c}$$

Where L_c and R are the curve length (in feet) and curve radius (in miles) and S is the presence of a spiral transition (no transitions S=0, transition at one end S=0.5, transitions at both ends S=1.0).

3.3.3.3 Calibration Coefficients for Run-Off-Road crashes on two-lane, two-ways rural roads

The calibration coefficient for Ireland was not calculated since no data for road segments not complying to the baseline criteria were available but the tool allows to input a calibration coefficient. The Swedish model was calibrated with only with the inclusion of grade and only marginally increased the sample size. The Calibration constant for Sweden was C= 0.9577.

The calibration coefficient can be derived from crash, traffic and infrastructural data with the same procedure described in Annex 4.

For two-lane two-ways rural roads the evaluation of the HGV correction factor was not as extensive as for the motorways due to the fact that the overall crash data were available only from Ireland and the traffic data was not coupled with the detailed crash database. Considering an average HGV percentage in the mix a correction factor of 0.19 was estimated but this should be further investigated.

3.4 Impact energy distribution models

The selection of a VRS has several components but one critical parameter to understand is the structural capacity, or containment level, of a VRS. To compare a specific crash with a given VRS containment level the Impact Kinetic Energy (IKE) is considered, as described in section 3.2.

To identify the distribution of IKE values there are very limited datasets and mostly referred to passenger cars.

For this type of vehicles the IKE distributions available in the SAVeRS tool are:

- the US RSAP3 distributions (NCHRP Project 22-27) for single carriageways and dual carriageways;
- the German GIDAS distributions (German In Depth Accident Survey) for Motorway - Dual carriageways, Highway - Dual carriageways and Rural - Single carriageway roads.

For each distribution curve, the probability of having an IKE not higher than a given IKE* can be calculated as shown in Figure 13. In the SAVeRS tool the probability of having an IKE not higher than the IKE corresponding to the different VRSCL indicated in Table 3 is given for each of these curves. The user can add a user defined curve in the tool based on different datasets.

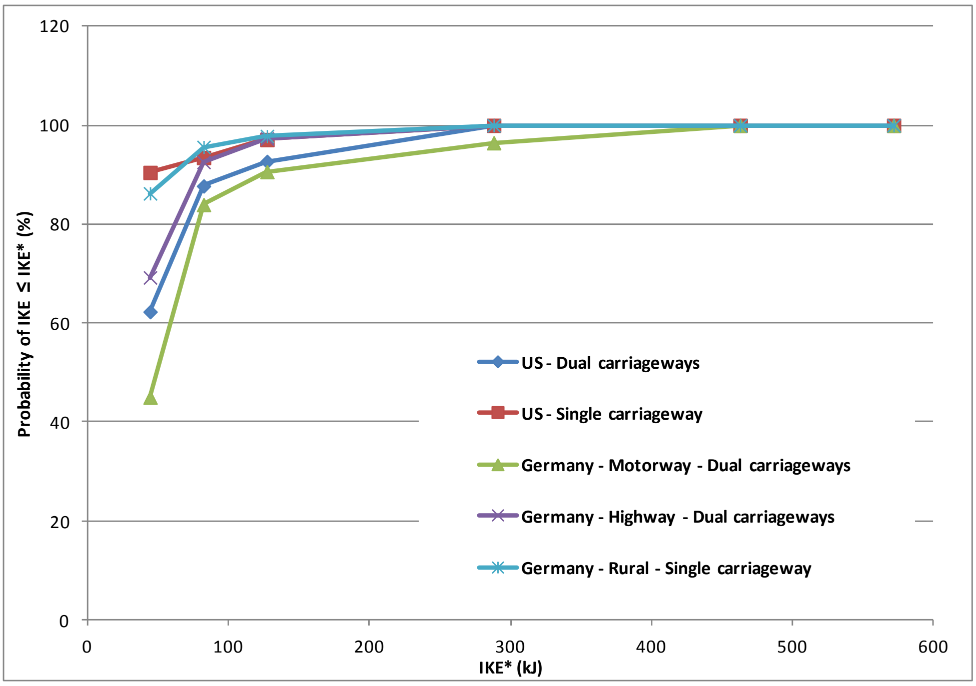


Figure 13: comparison between passenger cars Impact Kinetic Energy in the SAVeRS tool

To complete the understanding of applied loading on the VRS in real world conditions, the expected departure conditions for heavy trucks must be included. Unfortunately there are no databases with HGV crashes available to create similar exit condition plots as for passenger cars.

Generally speaking the HGV impact angle distribution would be lower than the passenger car distribution and therefore in the RSAP3 model (RSAP3, 2013) the approach was to select all the trajectories that are compatible with the sliding conditions of a single unit truck or with a tractor-trailer/multiple units truck.

A study conducted by the University of Florence with Cepav Uno in Italy (Domenichini L., La Torre F., Giordano G., 2004), developed a predictive model based on the handling performance of vehicles, position in a travel lane, observed vehicle speed distributions by vehicle type and vehicle type distribution in the mix. This model allows to estimate the distribution of the upper threshold of IKE values assuming that all the crashes will occur at the maximum sliding equilibrium condition for a given vehicle and speed. This assumption is extremely conservative and has been applied for very critical risk evaluations but for VRS design these distributions should be adjusted.

Based on the trajectory data given by RSAP3 the following "base" distributions have been defined excluding from each subset any record where the combination of speed and angle was not compatible with the equilibrium of a single unit truck (or bus) or with a tractor-trailer/multiple unit truck. The equilibrium evaluation criterion is defined in Annex 5 where the original procedure has been adjusted to be applied to the SAVeRS procedure. Different limiting conditions are defined depending on the number of lanes (2 or 3), the position on the lane (lane 1 is the outer, lane 3 is the closest to the median) and the edge to be considered (roadside or median). In all the evaluations a 3 m wide outside shoulder has been considered and a 0.70 m wide inside shoulder has been considered. Figure 14 shows that majority of impact angles is between 5° and 10°. The full procedure defined in Annex 5 has been applied using 2 different datasets from 2 sections on the Italian motorway network: one for a 3 lane section and one for a 2 lane section. Based on the observed mix, lane occupancy for the different vehicle types and speed distribution per lane and per vehicle type the probability of having a vehicle running off with a given combination of speed, mass and maximum impact angle is calculated. The probability distributions calculated with the procedure shown in Annex 5 have been adjusted weighing each impact angle class (0-5, 5-10, 10-15, 10-15, 15-20, above 20) according to the “base” distributions shown in Figure 14.

In the SAVeRS tool the user can define a different distribution that can be derived from experimental data or by applying the Annex 5 procedure to local data.

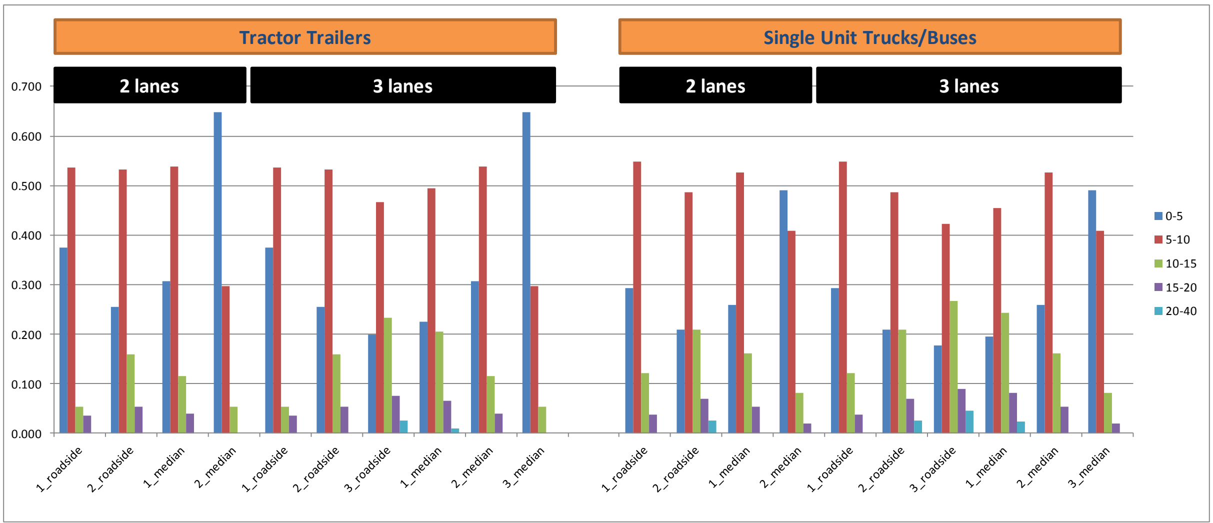


Figure 14: distribution of impact angle for a given travelling lane, HGV type and road configuration (number of lanes)

The different HGV distribution curves are shown in Figure 15 (for roadsides) and in Figure 16 (for medians). The distribution curves calculated with the threshold values (physical upper limit of the impact angles) can be calculated based on the procedure in Annex 5 but, as indicated earlier, this should not be used for design purposes unless very critical conditions have to be analysed (e.g. possible impact with an extremely high risk structure close to the roadway).

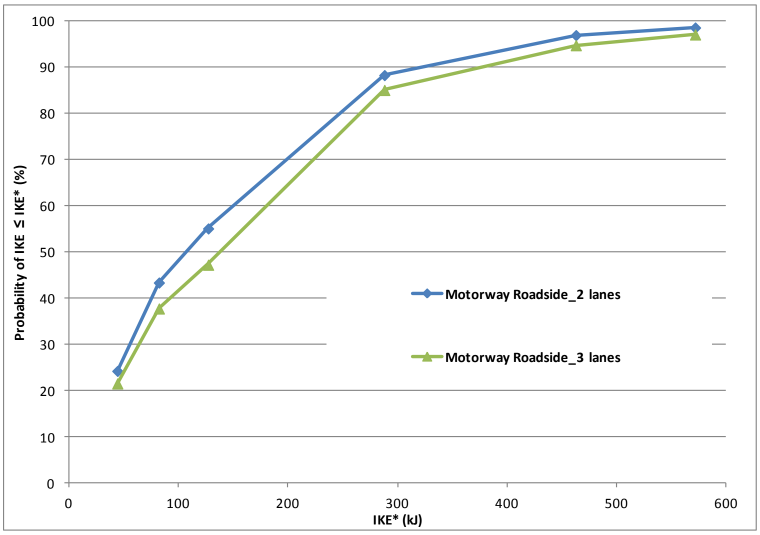


Figure 15: distribution of HGV Impact Kinetic Energy for roadsides (outer edge)

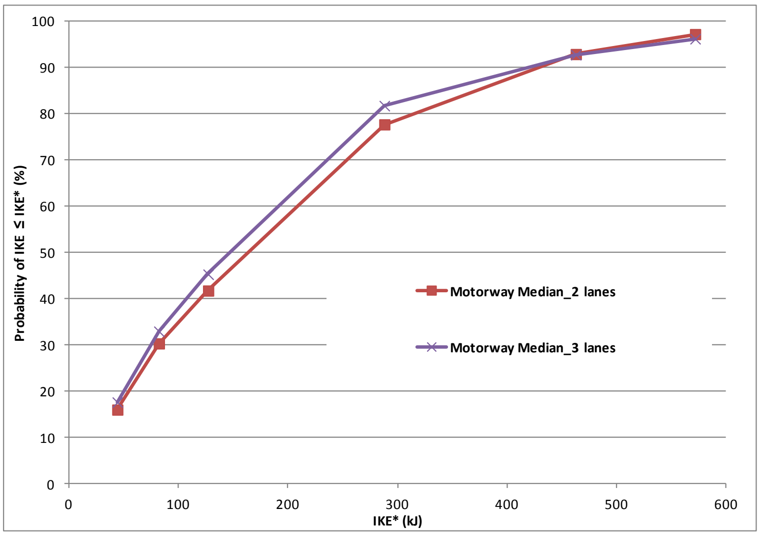


Figure 16: distribution of HGV Impact Kinetic Energy for medians

For rural two-lane two-way roads the experimental data to run the full model are not available and the RSAP3 distribution for single carriageway roads (Figure 17) has been implemented. More details on the mass, speed and angle distributions adopted in RSAP3 can be found at http:// rsap.roadsafellc.com. The limitation is that this assumes the standard traffic mix of the RSAP3 tool. Specific curves can be developed with the full procedure in Annex 5 if speed and traffic mix distributions are made available also for this type of roads.

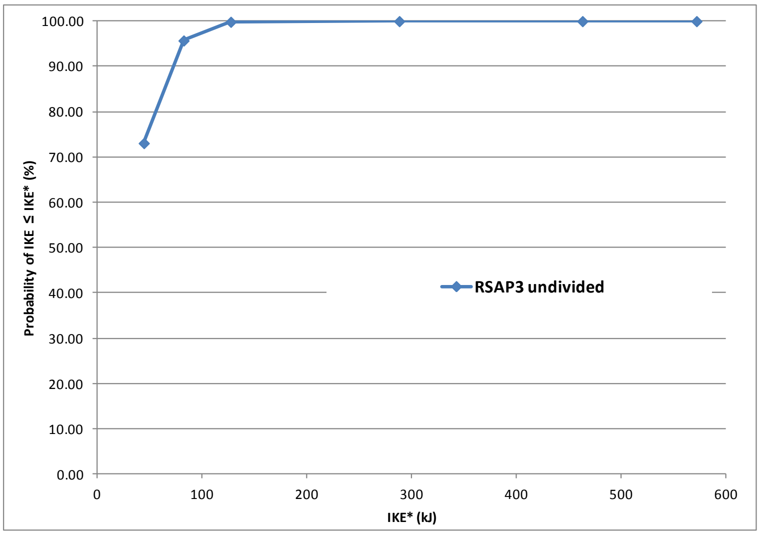


Figure 17: distribution of HGV Impact Kinetic Energy for two-lane two-way rural roads (based on RSAP3 distributions).

3.5 Severity distribution functions

The Severity Distribution Functions are used in the SAVeRS tool to split the injury+fatal crashes in the KABC scale, as discussed in section 3.2.

In the SAVeRS tool the following criteria have been applied for the definition of the severity distributions:

- when a vehicle potentially penetrates the VRS (IKE above VRSCL):
  - in case of a median or a high risk bridge (tall bridges - with a drop of 10 m or more, important water streams, highly traffic roads, structures behind) a 100% fatality rate is assumed as a safe estimate;
  - for other bridges the data from NCHRP 12-22(03) (Ray and Carrigan, 2014) have been applied showing that out of 38 fatal+injury crashes involving a VRS penetration: 5 were fatal (17.2%), 13 where A injuries (44.8%), 5 where B injuries (20.7%), and only 6 (20% resulted in C injuries);
  - for verges the HSM freeway model distributions without a safety barrier have been applied (HSM, 2014). A correction factor to K, A, B crashes has then been applied based on the UK RRRAP model to account for the different risk related to the hazard that is shielded by the VRS (http://www.standardsforhighways.co.uk/tech_info/rrrap.htm). Table 16 shows the default hazard risk factors included in the SAVeRS tool. The user can

adopt these or define a “user defined” hazard. C type crashes are derived as a difference between the total crashes and the K+A+B crashes;

- when a vehicle is potentially contained by the VRS (IKE below or equal to the VRSCL) the HSM freeway model SDF has been applied with a correction factor to account for the different VRS class in place. Due to a lack of experimental data the latter is based in the work conducted in 2010 by U. Ehlers, 2010 that compared the potential severity of impacts of N2, H1 and H2 barriers. The correction factors applied in the SAVeRS tools are shown in Table 18 where increasing the VRSCL leads to an increase of severe crashes (K and A) and, consequently, a reduction in the less severe (B and C). The values for H3 and H4 are extrapolated for the H2 to H1 ratio but a specific study to evaluate the severity of impacts with different classes of barriers (including H3 and H4) is deemed necessary.

As no direct correlation has been found between the distribution of injury crashes and the EN1317 severity class (based on ASI and THIV indices) in the current version of the SAVeRS tool there are no correction coefficients to account for this. This differentiation could be added in future releases when different severity distributions will be available.

Table 16: Default hazard correction factor for barriers penetrations in the SAVeRS tool

Hazard type	K/A/B
No specific hazard	1
Brick/Masonry Wall	1.3
Bridge structure/abutment/rigid wall	1.7
Cabinets (communications/power/electricity supply)	2
Chain link/Welded Mesh/Palisade	0.8
Close boarded fence	0.9
Culvert	1.8
Ditch	0.8
Environmental/noise Barrier (concrete/timber)	1.8
Environmental/noise Barrier (earth)	0.8
Lagoon/Water > 1.00 m depth	1.5
Rigid sign/lighting/electricity post/pole and similar (non passively safe)	1.8
Rock	2.5

Slope_Steep/high slope	1.5
Slope_Very steep/high slope	2
Slope_Extremely steep/high slope	2.5
Tree	2

For the definition of the slope configuration the criteria given in Table 17 could be used (based on the UK RRRAP) but different definitions could be applied adjusted lo different national standards.

Table 17: slope risk based on the definitions used RRRAP (UK)

Slope	**Height equal or above (m)**	**Slope risk**
Falling 1:1 or steeper	1.0	**Slope_Extremely steep/high slope**
Falling 1:1.5 - 1:1	1.5	**Slope_Very steep/high slope**
Falling 1:2 - 1:1.5	2.0	**Slope_Very steep/high slope**
Falling 1:2.5 - 1:2	2.5	**Slope_Very steep/high slope**
Falling 1:2 - 1:3	5.0	**Slope_Steep/high slope**
Rising 1:1.5 or steeper	0.5	**Slope_Steep/high slope**

All other conditions, if a barrier is required, can be considered as “no specific hazard”.

Table 18: Default VRSCL correction factor for barriers containments in the SAVeRS tool

VRSCL	K	A	B
Passenger cars			
N1	0.907	0.973	1.005
N2	0.950	0.985	1.003
H1	1.000	1.000	1.000
H2	1.000	1.000	1.000
H3	1.000	1.000	1.000
H4	1.000	1.000	1.000
HGV (truck and buses)			
N1	0.980	0.980	1.009
N2	0.989	0.989	1.003

H1	1.000	1.000	1.000
H2	1.005	1.005	0.998
H3	1.011	1.011	0.997
H4	1.014	1.014	0.996

3.6 Whole life cost model

The economic impact of a VRS must be based on all costs and benefits that can be grouped into several categories. These different financial elements are defined by the construction and operational costs for the systems and the impact on traffic safety which is a result of the change in injury and societal costs.

The following cost categories are considered in the SAVeRS tool:

- Societal costs (obtained multiplying the number of expected crashes per each category for the unit cost of accidents for a given severity). As the unit cost per crash severity can vary considerably amongst the different countries this value is included in the barriers worksheet for each country;
- Equipment cost. This is dependent on the specific VRS used and accounts for the following costs items:
    - construction costs (only the first year of analysis) and is given per unit length (m);
    - reconstruction cost that is calculated automatically after the expected design life (that needs to be defined for each specific barrier);
    - maintenance cost (every year) and is given per unit length (m);
    - repair cost: this is based in the repair cost per unit length (m) and estimated length of barrier (m) to be repaired after a crash that depends on the type of vehicle (passenger car or HGV) and the type of crash (contained or penetrated). If the traffic management cost (installing the work zone and manpower) is paid separately when a repair is executed then this should be added dividing the total cost per the average repair length). Even though the repair cost are typically at discrete years this is spread over the analysis period considering the potential annual crash frequency (that is typically below 1 and is not to be intended as a specific intervention).

In the “Barrier” sheet of the SAVeRS tool a set of different VRS have been already included. The current version of the tool contains barrier cost information for the following countries:

- Austria;

- Great Britain;
- Ireland;
- Italy;
- Slovenia;
- Sweden.

Additional barriers from these countries can be added to the list as well as new countries can be included in the dataset in the “barriers” worksheet of the tool.

If a new barrier is added the unit costs for construction, maintenance and repair have to be included as well as the repair length (that could also be based on similar barriers already in the list).

If a new country dataset is defined by the user then a new set of societal costs have to be defined in the same worksheet.

As indicated earlier the SAVeRS tool allows to compare directly in one single run different alternatives for the same VRS class. For comparing the WLC associated with different VRS classes for the same project different runs of the tool need to be performed and the results compared off-line.

4 RECOMMENDATION FOR THE IMPLEMENTATION OF THE GUIDELINE BY NATIONAL ROADS AUTHORITIES

4.1 Selection Procedure

The SAVeRS tool can be applied at a national level in the definition of national standard allowing the different NRAs to identify:

- the minimum return time of a penetration per km that can be accepted in the design phase;
- the minimum return time of a fatal crash per km that can be accepted in the design phase;
- the default parameters that should be used in the design phase;
- the minimum VRS class for different traffic conditions and infrastructure layouts that to be included in the national standard. This would be used in preliminary design phases and in where a site specific analysis is not conducted;
- the situations where a maximum VRS class should be set unless special circumstances justify a higher VRS class.

For high risk bridges a target per bridge could be considered instead than a target per km as it is unlikely that a bridge would have an extension of above one km.

Different target values in terms of minimum return times of penetrations and of fatal crashes could be established for new designs and for existing roads. The tool could be used to assess the potential risk of existing situations considering the specific traffic, geometric layout and hazard characteristics in order to identify the need for a barrier replacement and a priority list of the replacements. This is extremely relevant where a new national standard is issued requiring a different VRS class as compared to the previous one.

This activity is extremely important to make sure that the target values do not lead to unrealistic applications (e.g. a maximum number of fatal crashes that cannot be achieved even by using the H4 VRS class).

This same approach is proposed in the RSAP procedure as described in the Ray and Carrigan, 2015. In this case a possible base condition for setting the return time of fatal crashes is defined as the number of ROR fatal crashes per edge-mile per year that have occurred in the previous observation period. In the same paper a target risk of less than a 1/100 severe or fatal crashes in 30 yrs/1000-ft of bridge rail is recommended. This is equivalent to a risk of less than 1/600 severe or fatal crash/edge-mi/yr on roadways (a return time of fatal + severe crashes of 375 years per edge-km). To define the number of fatal only crashes the ratio of fatal Vs fatal + severe injury crashes (K/(K+A) ratio) can be calculated based on the figures applied in the SAVeRS tool (see section 3.5).

Considering the base conditions, a K/(K+A) ratio has been estimated in section 3.5 with the Highway Safety Manual severity distribution functions but this ratio could be adapted to the severity distribution of any specific country.

With the K/(K+A) ratio set to 0.3, the return time of one severe event every 375 years per km of road edge leads to a return time of 1 fatal crash every 110 years per km of road edge. As a preliminary estimate a minimum return time of 1 fatal crash every 100 year per km of road edge where a barrier is installed could be considered unless different considerations are provided. The minimum fatal crash return time is only applied to conditions where no risk to third parties occurs. If there is an additional risk to third parties the protection will have to be increased according to the risk chart given in section 3.2.

In the UK the RRRAP approach uses the “equivalent fatalities per 100 million vehicle km” approach (1 fatal = 10 serious = 100 slight accidents). For each road type two thresholds are given to define the “acceptable”, “tolerable” and “unacceptable” risk. Given the fact that the risk is given per 100 million vehicle km, the thresholds in terms of number of “equivalent fatal crashes” per year per km is different for different AADT volumes as shown, as an example, in Figure 18 for 2 lane motorways (D2M) and in Figure 19 for 3 lane motorways (D3M).

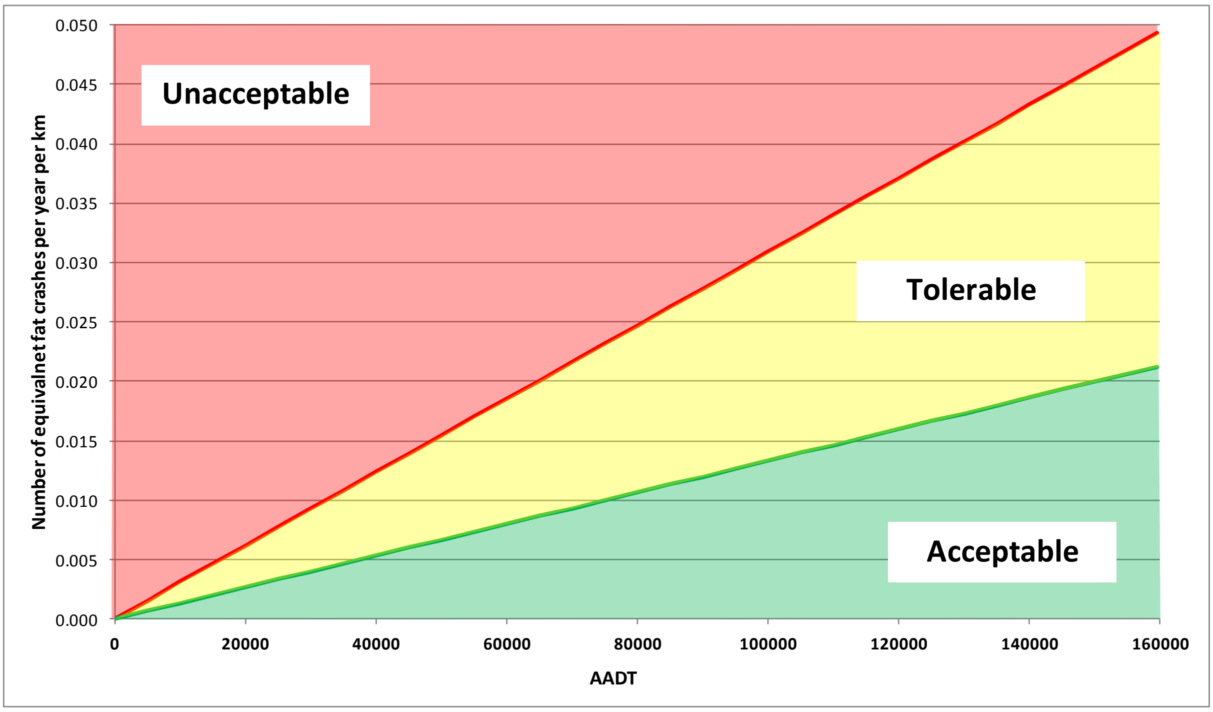


Figure 18: risk thresholds in RRRAP (UK) for 2 lane motorways

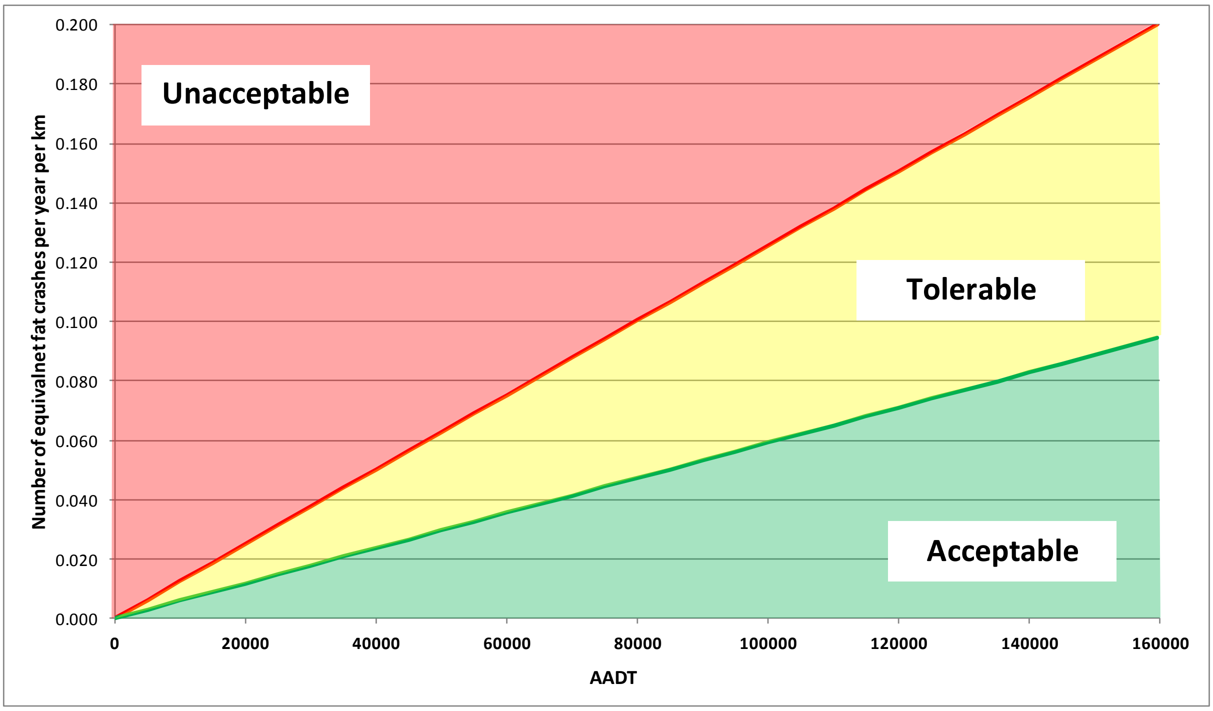
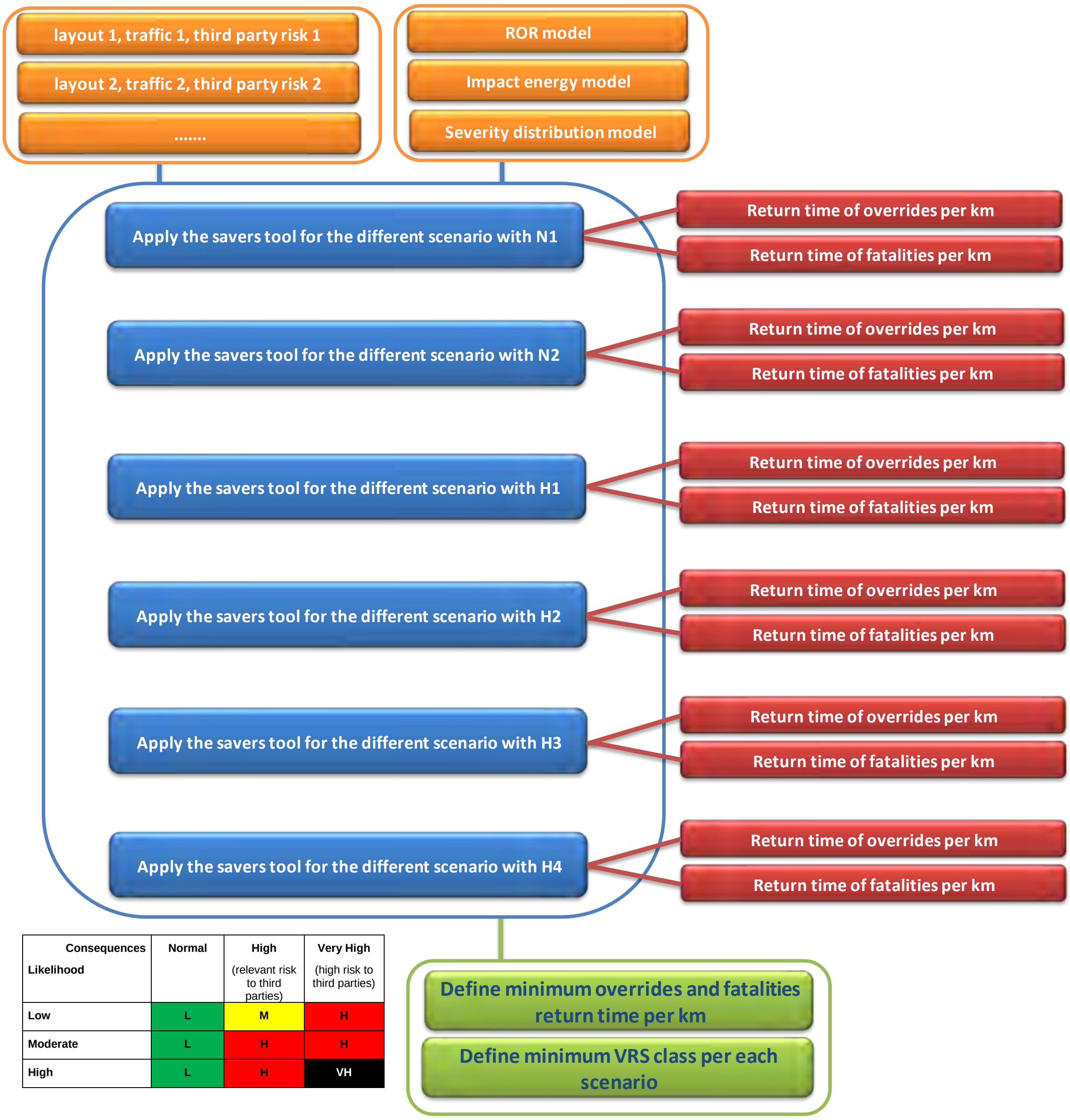


Figure 19: risk thresholds in RRRAP (UK) for 3 lane motorways

The number of “equivalent fatal crashes” is obviously higher than the number of fatal crashes alone and therefore, to allow for an easier comparison with RRRAP, the SAVeRS Tool provides also an estimate the frequency and return time of the equivalent fatal crashes defined as: total injury costs/single fatal crash cost.

In this phase the user should consider a set of reference conditions that could either be the most critical ones or the ones corresponding to different infrastructure and traffic conditions that are already considered in national standards.

The process is described in Figure 20 and an application to two specific national standards (from Italy and UK) is then given as examples in section 4.2.



Consequences / Likelihood	Normal	High (relevant risk to third parties)	Very High (high risk to third parties)
Low	L	M	H
Moderate	L	H	H
High	L	H	VH

Figure 20: procedure implementation of the SAVeRS tool at the NRA level.

4.2 Application to selected EU Countries

4.2.1 Italy

The outcome of the SAVeRS model has been applied to the Italian motorway network considering a set of typical scenarios, as shown in Table 19 where the classes required by the new draft Italian standard have been highlighted (in orange the class required if the road passes over or adjacent to another infrastructure or a sensitive structure, in yellow the minimum class required without relevant third party risk, if different).

Table 19: evaluation different roadside configurations in Italian motorways typical scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
AADT (per direction)	10000	20000	30000	40000
%HGV	20 %	25%	30 %	30 %
AADT HGV	2000	5000	9000	12000
Local conditions	base	base	base	base
Length	1 km	1 km	1 km	1 km
Penetration return times (roadside)				
N1	26	17	13	11
N2	72	45	33	28
H1	111	67	49	41
H2	**335**	**207**	**154**	**129**
H3	**4102**	**2141**	**1390**	**1164**
H4	8972	4683	3040	2546
Fatal crashes return times (verge with steep slope)				
N1	549	356	276	231
N2	723	466	359	301

H1	747	483	372	312
H2	**813**	**529**	**411**	**344**
H3	**847**	**552**	**429**	**360**
H4	848	553	431	361
Fatal crashes return times (verge with rock)				
N1	366	237	183	154
N2	583	373	284	238
H1	643	411	314	263
H2	**769**	**499**	**386**	**324**
H3	**843**	**549**	**426**	**357**
H4	847	552	429	359
Fatal crashes return times (high risk bridge)				
N1	26	17	13	11
N2	68	42	31	26
H1	100	61	44	37
H2	**244**	153	115	96
H3	**706**	**442**	**331**	**277 (*)**
H4	778	497	379	**317 (*)**
Fatal crashes return times (other bridges)				
N1	143	92	71	60
N2	306	192	144	121
H1	389	243	182	152
H2	611	393	301	252

H3	824	533	412	345
H4	838	544	422	354
Penetration return times (median)				
N1	26	17	13	11
N2	67	41	30	25
H1	99	59	42	35
H2	261	155	111	93
H3	**1761**	**919**	597	500
H4	4535	2367	**1537**	**1287**
Fatal crashes return times (median)				
N1	26	16	13	11
N2	63	39	28	24
H1	90	54	39	33
H2	202	123	89	75
H3	**577**	**348**	252	211
H4	718	451	**338**	**283**
(*) for bridges shorter than 100 m H3 becomes H4 if the road passes over or adjacent to another infrastructure or a sensitive structure; for bridges longer than 100 m always H4				

For the evaluation of high risk bridges an evaluation length of 200 m has also been considered to test the model, as shown in Table 20, but in this case the most severe conditions found in the calibration dataset, considering a standard section design have been considered (downhill slope -2.85% and average curvature 1/445 m).

Table 20: evaluation of a 200 m high risk bridge in Italian motorways typical scenarios

AADT (per direction)	10000	20000	30000	40000
%HGV	20 %	25%	30 %	30 %
AADT HGV	2000	5000	9000	12000
Local conditions				
Average curvature	1/445	1/445	1/445	1/445
grade	-2.85%	-2.85%	-2.85%	-2.85%
lanes	3	3	3	3
Length	0.2 km	0.2 km	0.2 km	0.2 km
Fatal crashes return times (high risk bridge)				
N1	41	27	21	17
N2	105	65	48	40
H1	149	90	65	55
H2	**366**	227	169	141
H3	**1004**	**615**	**451**	378
H4	1135	711	533	**447**

This risk assessment shows that the VRS classes required by the Italian standard lead to extremely high return times of fatal crashes (in some cases above a 1000 years per km) much higher than typical return times of any civil engineering structure. This confirms the results of the study conducted by ERF in 2012 (ERF, 2012) that showed that the Italian requirements represented an outlier as compared with the other national standards. The draft revision of the standard tailored the different VRS requirements to the actual HGV traffic but still the requirements are extremely high. In a future revision of the standard a reduction of the VRS requirements should be considered using the SAVeRS tool to identify the minimum VRS class that allows to achieve a given risk level.

4.2.2 UK

The outcome of the SAVeRS model has been applied to the motorway network of the UK considering a set of typical scenarios, as shown in Table 21 where the classes required by the UK standards have been highlighted (in orange, the class required if the road passes over or adjacent to another infrastructure or a sensitive structure, in yellow the minimum class required without relevant third party risk for the verge, and in cyan, the minimum class required for the median).

Table 21: evaluation different roadside configurations on UK motorways typical scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
AADT (per direction)	10000	20000	30000	40000
%HGV	5 %	10%	15 %	15 %
AADT HGV	500	2000	4500	6000
Local conditions	base except for the number of lanes	base except for the number of lanes	base except for the number of lanes	base except for the number of lanes
lanes	3	3	3	3
Length	1 km	1 km	1 km	1 km
Penetration return times (roadside);				
N1	15	10	8	7
N2	**48**	**31**	**24**	**20**
H1	79	50	37	31
H2	217	140	106	91
H3	6330	2196	1183	1016
H4	**11428**	**3966**	**2135**	**1835**
Fatal crashes return times (verge with steep slope)				
N1	303	210	168	145
N2	**408**	**280**	**224**	**192**

H1	418	288	230	198
H2	446	308	248	213
H3	462	320	258	222
H4	**463**	**321**	**259**	**222**
Fatal crashes return times (verge with rock)				
N1	203	140	113	97
N2	**339**	**230**	**182**	**157**
H1	271	252	200	172
H2	425	293	235	202
H3	462	319	257	221
H4	**462**	**320**	**258**	**222**
Fatal crashes return times (high risk bridge)				
N1	15	10	8	7
N2	**44**	**29**	**22**	**19**
H1	69	44	33	28
H2	149	99	76	65
H3	432	281	213	183
H4	**445**	**298**	**232**	**199**
Fatal crashes return times (other bridges)				
N1	80	55	44	38
N2	**189**	**126**	**98**	**84**
H1	243	161	124	106
H2	348	237	188	162

H3	458	314	251	216
H4	**460**	**317**	**255**	**219**
Penetration return times (median)				
N1	15	10	8	7
N2	48	31	23	20
H1	**79**	**49**	**36**	**31**
H2	212	134	100	86
H3	4580	1589	856	735
H4	8808	3056	1646	1414
Fatal crashes return times (median)				
N1	80	55	44	38
N2	188	125	97	83
H1	**242**	**160**	**123**	**106**
H2	346	235	185	160
H3	456	312	248	213
H4	459	316	253	218

4.3 Application at the design stage

4.3.1 Use of the tool at the design stage

The designer has to identify that there is a requirement for VRS before using the selection tool and determine the length and containment level of the barrier. As a support for this preliminary activity the “Barrier Placement” section of the tool could be used unless specific national regulations are already available. For UK roads the VRS would be designed using the Road Restraints Risk Assessment Process (RRRAP). The selection tool can then be used to compare difference VRS types from an economic stance.

The length of road analysed by the selection tool equates to the length of the barrier. Information relating to the alignment, road profile and traffic characteristics at the site are required to be input along with the containment level required for the VRS. These are used in the tool to assess the predicted number of crashes over the period analysed. The tool then requires some basic information about the nature of the hazard that would be encountered should a vehicle penetrate the barrier to be selected in the 'Severity Distribution Function' section. From this the severity of the predicted accidents and the resulting injury costs are calculated.

Finally, in the 'Cost Benefit' section of the selection tool the user selects the types of barriers to be compared for the containment class used for the analysis from the selections available in the tool and the costs associated with the barrier types for that site are displayed and compared. Only barrier types with the same containment level entered in to the first section of the selection tool are available in the drop down menu.

4.3.2 Worked examples

To test the SAVeRS model a set of 6 pilot applications with different characteristics have been analysed in the UK. The summary of the characteristics are given in Table 25. For each of these pilot projects a worksheet has been produced that can also serve as a worked example for new users to guide them through the use of the tool.

Six sections of road (pilot sites) in the UK have been analysed using the VRS selection tool to assess how it could be used by highway engineers for selecting a VRS type to use for a particular site.

The pilot sites are listed in Table 22 at the end of this section of the report with key characteristics used by the VRS selection tool. All are located in the south east of England and, with the exception on the A325, are on the Strategic Road Network managed by the Highways Agency. The sites are a mixture of single carriageway, dual carriageway and motorway.

The following scenarios are represented by the pilot sites:

- Single and dual carriageways
- Two and three lane dual carriageways
- Urban and semi-urban road environments
- Different horizontal and vertical alignments
- Different traffic flows (and densities) and HGV proportions
- A variety of hazards including those identified as 'high risk' and 'lower risk' in the selection tool.

Information on each of the pilot sites is recorded in the Pilot Site Reports. These contain site context, the parameters input for analysis in the selection tool and the 'Lifetime Cost' result calculated by the selection tool.

The selection tool can be used to indicate the most cost effective barrier type for the site taking into account construction and maintenance costs of a barrier and the cost of repairs following a crash for a variety of barrier types. Currently in highway design and maintenance the type of barrier selected is based on the designer's experience and professional judgement.

Table 22: Pilot Sites

No.	Owner (HA/TfL)	Site Description	Road Type (Motorway/ High status other)	Status (Planned/ existing)	Carriageway layout (Single/ Dual)	Speed Limit (kph)	Roadside configuration/ features	Barrier type installed/ considered?
1	Local Authority	A325 Farnham Road	Non-strategic	Existing	Single	95	Single carriageway road with semi-rural characteristics. Segment is on tight radius bend on downhill section. There is little or no existing safety barrier provision.	No VRS
2	HA	A282 - A1090 London Road overbridge to Stonehouse Lane	High Status	Existing	Dual	80	The A282 forms part of the M25 and provides access to and from the Dartford Tunnel and Queen Elizabeth II bridge. The anticlockwise carriageway has just been installed with CSB, DROBB and SSOBB to provide protection on an overbridge and from adjacent quarry face and chalk bunds. There is TSB along the central reserve.	CSB, DROBB, SSOBB and TSB
3	HA	A282 – approach to Junction 31	High Status	Existing	Dual	80	The A282 forms part of the M25 and provides access to and from the Dartford Tunnel and Queen Elizabeth II bridge. The anticlockwise carriageway has DROBB and SSOBB to provide protection from adjacent quarry face and chalk bunds.	CSB, DROBB, SSOBB and TSB
4	HA	A21 Pembury Road	High status	Existing	Single	95	The A21 along this section is a single carriageway with relatively straight profile. There is little or no existing safety barrier provision.	No VRS
5	HA	M4 - Junction 4 to 4A Heathrow Spur road	Motorway	Existing	Dual	112	The Heathrow Spur Road connects Heathrow Airport to the M4 motorway. There is SSOBB both sides within the central reserve and SSOBB to provide protection from large street furniture; traffic signs, gantries, airport communications equipment and bridge abutments. The majority of the carriageway verges are unprotected.	SSOBB
6	HA	M4 - Junction 3 to Junction 4	Motorway	Existing	Dual	112	The M4 motorway provides the primary access from the west to central London and, aside from the M25, is one of the most heavily used and congested motorways. There is SSOBB both sides within the central reserve and SSOBB to provide protection from large street furniture; traffic signs, gantries, airport communications equipment and bridge abutments. The majority of the carriageway verges are unprotected.	SSOBB

4.3.3 Conclusions from the Pilot Sites Analysis

For the analysis the output used for evaluation was the Lifetime Cost of a barrier type. The number of run-off road accidents predicted by the analysis for each Pilot Site and their severity has also been summarised in Table 23 at the end of this section. All sites have been analysed for a 20 year period as being the expected life span of a barrier used in the RRRAP. Some sites were also analysed for a 50/60 year period to compare the cost effectiveness of barriers over a longer lifespan as concrete barriers have high installation costs but up to twice the lifespan of metal barriers with lower maintenance and repair costs.

The selection tool considers barrier types from a monetary cost-benefit for the specified containment level and varying working widths. However, in selecting a barrier type consideration also needs to be given to the practical suitability of a barrier type for a site and the available working width of barriers or clearance from the safety hazard. In this situation practical issues need to be considered alongside the Lifetime Cost.

For example, in the analysis of sites requiring barriers with N2 containment class, the N2W5 steel barrier always came out as the most economic steel barrier type due to largely to the lower installation and repair costs coupled with the relative eases of undertaking these tasks. However, on some of the pilot sites (particularly the single carriageway sites) the offset to the hazard is too narrow for a safety barrier requiring this amount of working width. Similarly, for the A325 site wire rope was included in the barrier selection and the analysis showed it to be the most cost effective solution even though it would not be suitable for this site as some trees would be within the working width.

Currently the tool relies on the user's knowledge of the site and physical constraints to include suitable barrier types for comparison. It doesn't warn the designer of the practical limitations of certain barrier types.

Future development of the selection tool could consider the offset to the hazard and the working width of the barrier to be input in the road details section and the selection of barrier types restricted to those that meet the working width criteria to avoid recommendation of a barrier type that is unsuitable for a particular location.

Direct comparison can only be done for those barrier types having the same containment class specified by the user so multiple runs of the selection tool were carried out for each pilot site to compare the cost effectiveness of higher containment barriers.

For the single carriageways sites with 'lower risk' hazards in the verge, where a barrier with N2 containment is required, the most cost effective barriers is confirmed to be N2.

For dual carriageways roads the selection tool indicated that a high containment barrier was the most cost effective solution (H2 for verges and H4 for medians). The difference in lifetime cost was particularly marked for sites with a 'high risk' feature, for example tall bridges or medians. For medians with a lower traffic volume (Site 5) H2 and H4 solutions are comparable but still extremely more cost effective then the N2. It should be noted, in analysing these results, that in the standard SAVeRS Severity Distribution Function (see paragraph 3.5) every penetration of the median barrier is considered as fatal. If different Severity Distributions are available for specific conditions these can be implemented in the tool.

The pilot site analysis was carried out for UK roads and therefore only information on barriers for the UK has been considered in the analysis of barrier types. The selection tool was configured with examples of common barrier types encountered in the UK and typical costs associated with them. Data sets for other countries are available, and users can add further barrier types together with associated costs. This allows adjustment to more accurately reflect the cost of provision entailed for a particular site or region.

Presently, there is a list of hazards that can be selected in the tool for analysis. However, the tool does contain the facility to add a ‘user defined’ hazard to include a hazard type that is not included in the pre-configured list. Selection of the hazard determines the severity of predicted crashes if the barrier is penetrated and is not applicable in ‘high risk’ situations where the assumption is that all barrier penetrations will result in a fatality.

Table 24 below summarises the results of using the selection tool on the trial sites highlighting the type of hazard and containment level and the types of barrier considered for predicting the lifetime costs.

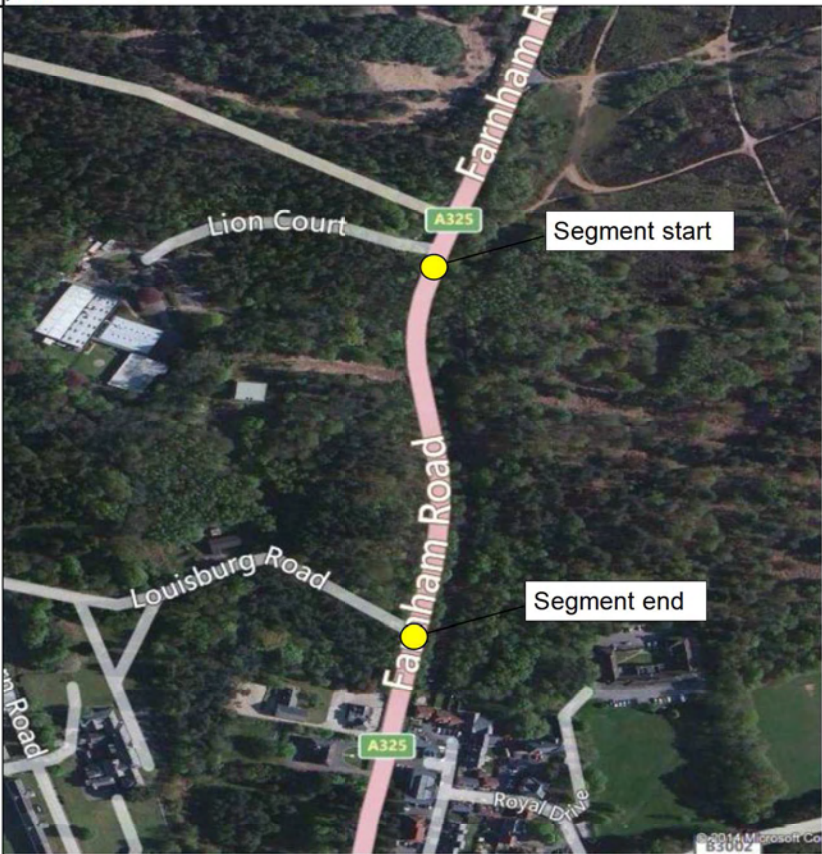
Table 23: Predicted Accident Summary for Sites

Pilot Site		ROR crashes Cars	ROR crashes HGVs	% of events:	Contained	Penetrated	N. of events in design life	Return time of a fatal crash (years)	Return time of a fatal crash/km (years)
1	A325 (with N2 barrier)	5.12	0.05	Fatality (K)	3.85%	8.10%	0.20863	96	29
				Incapacitating injury (A)	16.58%	33.64%	0.89566		
				Non incapacitating injury (B)	34.05%	58.26%	1.81562		
				Possible injury (C)	45.52%	0.00%	2.25118		
2	A282 - A1090 Northbound (with H2 barrier)	1.22	0.11	Fatality (K)	1.93%	100.00%	0.0802	249	69
				Incapacitating injury (A)	4.79%	0.00%	0.0611		
				Non incapacitating injury (B)	23.45%	0.00%	0.2991		
				Possible injury (C)	69.83%	0.00%	0.8907		
3	A282 - Approach to J31 Northbound (with H1 barrier)	0.25	0.02	Fatality (K)	1.93%	6.49%	0.0068	3040	182
				Incapacitating injury (A)	4.79%	15.14%	0.0166		
				Non incapacitating injury (B)	23.45%	68.81%	0.0794		
				Possible injury (C)	69.83%	9.56%	0.1711		
4	A21 - Pembury Road (with N2 barrier)	3.54	0.03	Fatality (K)	3.85%	8.10%	0.1440	139	51
				Incapacitating injury (A)	16.82%	33.64%	0.6271		
				Non incapacitating injury (B)	33.96%	58.26%	1.2508		
				Possible injury (C)	45.37%	0.00%	1.5499		
5	M4 Heathrow Spur (with N2 barrier)	0.41	0.006	Fatality (K)	1.83%	100.00%	0.0757	264	25
				Incapacitating injury (A)	4.79%	0.00%	0.0165		
				Non incapacitating injury (B)	23.45%	0.00%	0.0808		
				Possible injury (C)	69.93%	0.00%	0.2410		
6	M4 - J3 -4 (with N2 barrier)	8.86	0.18	Fatality (K)	1.83%	100.00%	1.6775	12	21
				Incapacitating injury (A)	4.79%	0.00%	0.3592		
				Non incapacitating injury (B)	23.45%	0.00%	1.7595		
				Possible injury (C)	69.93%	0.00%	5.2466		

Table 24: Sites Analysed using the Selection Tool

No.	Site Description	Road Type (Motorway/ High status other)	Carriageway layout (Single/ Dual)	Hazard considered in Analysis	Containment Level	Barrier Types selected in analysis (GB types only)	Barrier type installed/ considered?
1	A325 Farnham Road	High status	Single	Trees	N2	N2W2 Steel, OBB, TCB, Concrete Step Barrier, H2W4 Steel, H4 Concrete	No VRS
2	A282 - A1090 London Road overbridge to Stonehouse Lane	High Status	Dual	High bridge	H2	Concrete Step Barrier, H2W4 Steel, H4 Concrete	CSB, DROBB, SSOBB and TSB
3	A282 - Approach to M25 Junction 31	High Status	Dual	Gantry foundation (rock)	H1	DROBB, H1W4 Steel, Concrete Step Barrier, H2W4 Steel, H4 Concrete	CSB, DROBB, SSOBB and TSB
4	A21 Pembury Road	High status	Single	Tree	N2	N2W2 Steel, N2W3 Steel, N2W4 Steel, N2W5 Steel, OBB, TCB, Wire rope, DROBB, H1W4 Steel, Concrete Step Barrier, H2W4 Steel, H4 Concrete	No VRS
5	M4 - Junction 4 to 4A Heathrow Spur road	Motorway	Dual	Median	N2	N2W2 Steel, N2W3 Steel, N2W4 Steel, OBB, TCB, Wire rope, H2W4 Steel, H4 Concrete	SSOBB
6	M4 - Junction 3 to Junction 4	Motorway	Dual	Median	N2	N2W2 Steel, N2W3 Steel, N2W4 Steel, OBB, TCB, Wire rope, H2W4 Steel, H4 Concrete	SSOBB

SaVERS	Pilot Site Data Form		Site No. 1
Road Number:	A325	Road Name:	Farnham Road
Location			
Start OS Grid Reference:	SU 79980 37051	End OS Grid Reference:	SU 79976 36750
Speed Limit (mph):	60 (97kph)		
General Site Description:	Single carriageway road with semi-rural characteristics (non-trunk road). Segment is on tight radius bend on downhill section with mature trees and shrubs close to the east side of the road. There is no safety barrier on this section of road however, RRRAP analysis in connection with a new junction close by indicated that a safety barrier could be justified due to the trees.		
Location Map:			



Page 2	Pilot Site Data Form	Site No. 1

Carriageway Characteristics

Type of road: (single / dual carriageway)	Single (Ireland used as reference country)	No. of Lanes in carriageway:	2
Segment length :	307m	Curvature 1 (m. to 0dp):	264m (142m length)
Average Gradient (% to 2dp):	3.47	Curvature 2 (m. to 0dp):	287m (106m length)
		Spirals	YES
Outside shoulder width (m to 2 dp):	0	Percentage of rumble strips (% to 0dp):	0
Inside shoulder width (m to 2 dp):	n/a	Average Lane Width (m. to 2dp):	3.48

Traffic Characteristics

Traffic Flow (AADT) (see note 2):	20329
HGV Proportion (% to 1 dp):	5.4
Annual Traffic Growth:	0.73% (see note 5)
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):	n/a

Predicted Crash Condition

Reference country:	Ireland
Crash distribution (Cars):	Germany Single Carriageways
Crash distribution (HGVs):	RSAPV3 Undivided_fric=0.45-0.6
Containment Class:	N2

Hazards Occuring within Segment Analysed

		Comments
Roadside type:	Verge (roadside)	Hazards occuring in segment: Trees less than 250mm girth Embankment 1:3 or steeper
Type of Hazard:	Tree	

Recorded Accident History (see note 3)

Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)

Existing VRS Provision (where applicable)

Location(s):	None
Extents:	n/a
Barrier type:	n/a

Cost benefit analysis

Start year:	2018	End year:	2037
Interest rate (% to 2 dp) (see note 4):	3.5		

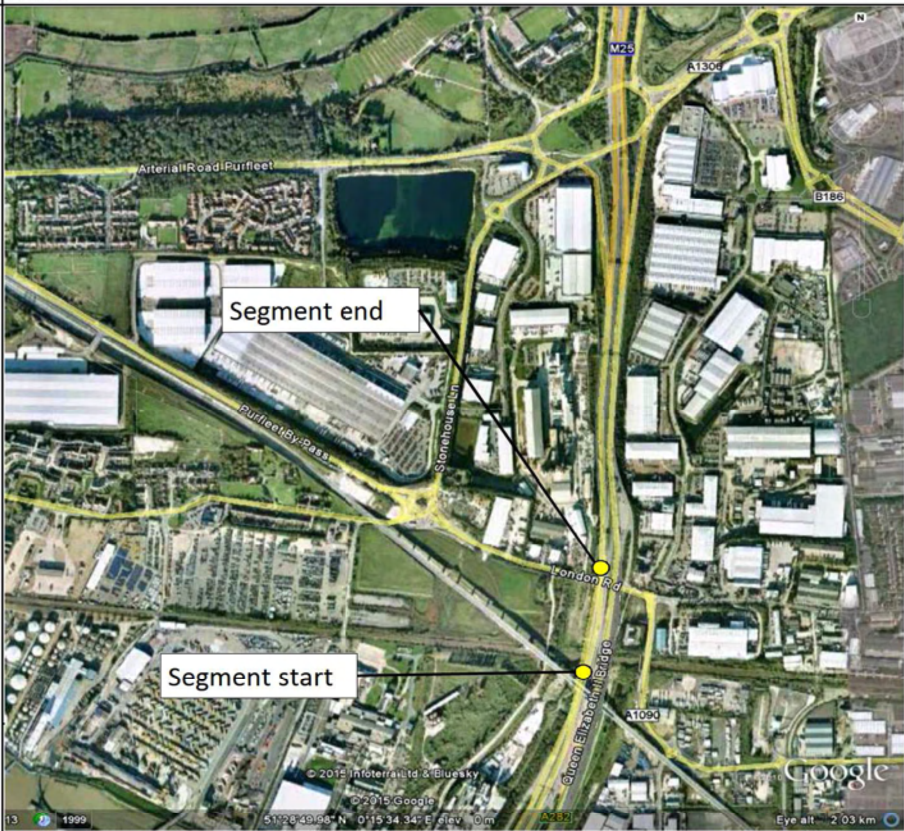
Output from the SAVeRS Tool: version beta002	Barrier	Lifetime cost	Cheapest lifetime cost highlighted
	N2 - Roadside - N2W2 Steel (GreatBrit	£728'353	
	N2 - Roadside - OBB (GreatBritain)	£731'594	
	N2 - Roadside - TCB (GreatBritain)	£728'206	
	~~N2 - Roadside - Wire rope (GreatBritain~~	~~£723'487~~	
	H1 - Roadside - DROBB (GreatBritain)	£752'575	
	H1 - Roadside - H1W4 Steel (GreatBrit	£748'002	
	H2 - Roadside - Concrete Step Barrier	£736'671	
	H2 - Roadside - H2W4 Steel (GreatBrit	£731'997	
	H4 - Roadside - Concrete (GreatBritain	£816'567	

Comment:	Wire rope is shown as the most cost effective solution but would not be suitable for this site as the working width is too great for the set back of the trees from the carriageway. N2 level of containment is required at this site and the selection tool confirms that N2 is the most cost effective solution. If no increase in working width could be obtained then only a concrete barrier would be feasible.

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accicents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparison purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. 14.6% over 20 years. From traffic modelling carried out in relation to a proposed highways scheme in the area

SaVERS	Pilot Site Data Form		Site No. 2
Road Number:	A282 (northbound)	Road Name:	n/a
Location			
Start OS Grid Reference:	TQ 57431 77486	End OS Grid Reference:	TQ 57474 77758
Speed Limit (mph):	60		
General Site Description:	Northbound carriageway of A282 which is part of the M25. This length is immendiately north of the exit portal of the Dartford tunnel. The carriageway is rising and is higher than the level of the adjacent ground on the east side (the southbound carriageway is at a higher level as it is on the approach to the Queen Elizabeth II bridge. The anticlockwise carriageway has just been installed with CSB, DROBB and SSOBB along the verge. There is TSB along the central reserve.		
Location Map:			



Page 2	**Pilot Site Data Form**				Site No. 2
Carriageway Characteristics					
Type of road: (single / dual carriageway)	Dual	No. of Lanes in carriageway:	2		
Segment length :	277	Curvature 1 (m. to 0dp):			
Average Gradient (% to 2dp):	2	Curvature 2 (m. to 0dp):			
Outside shoulder width (m to 2 dp):	0.80 (estimate) - 1m minimum used in analysis	Percentage of rumble strips (% to 0dp):	0		
Inside shoulder width (m to 2 dp):	0.5 minimum used in tool	Average Lane Width (m. to 2dp):	3.65 (estimate)		
Traffic Characteristics					
Traffic Flow (AADT) (see note 2):	38536				
HGV Proportion (% to 1 dp):	16.1				
Annual Traffic Growth:	1 % (see note 5)				
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):	unknown				
Predicted Crash Condition					
Reference country:	Great Britain				
Crash distribution (Cars):	Germany Dual Carr_Motorway				
Crash distribution (HGVs):	Motorway Roadside_2 lanes				
Containment Class:	H2				
Hazards Occuring within Segment Analysed					
		Comments			
Roadside type:	Bridge (High risk)	Lamp columns on both sides of carriageway Section on overbridge over local main road			
Type of Hazard:	n/a				

Recorded Accident History (see note 3)

Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)	

Existing VRS Provision (where applicable)

Location(s):	Both sides
Extents:	Whole segment
Barrier type:	

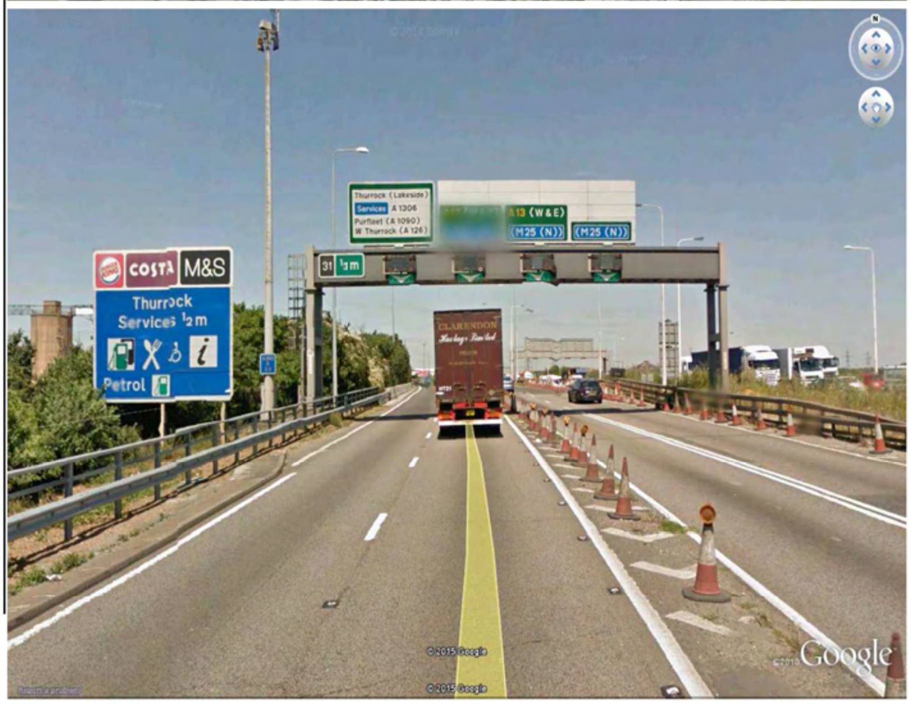
Cost benefit analysis

Start year:	2013		End year:	2032 (2062)
Interest rate (% to 2 dp) (see note 4):	3.5			
Output from the SAVeRS Tool: version beta002	**Barrier**	**Lifetime cost 20 years**	**Lifetime cost 50 years**	Cheapest lifetime cost highlighted
	H2 - Roadside - Concrete Step Barrier	£234'712	£559'184	
	H2 - Roadside - H2W4 Steel	£229'417	£564'359	
	H4 - Roadside - Concrete (GreatBritain)	£204'185	£357'337	
Comment:	The lower predicted injury cost for the H4 concrete barrier makes this barrier type the most cost effective overall despite having the highest construction cost.			

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the number
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accidents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparisson purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. Expected annual traffic growth calculated from growth factor for south east rural trunk roads between 2014 and 2024 derived from the National Trip End Model using TEMPRO.

SaVERS	Pilot Site Data Form			Site No. 3
Road Number:	A282 (northbound)	Road Name:	n/a	
Location				
Start OS Grid Reference:	TQ 57486 77831	End OS Grid Reference:	TQ 57483 77859	
Speed Limit (mph):	60			
General Site Description:	Northbound carriageway of A282 which is part of the M25. This length is north of the exit portal of the Dartford tunnel. The carriageway is rising and is higher than the level of the adjacent ground on the east side (the southbound carriageway is at a higher level as it is on the approach to the Queen Elizabeth II bridge. The anticlockwise carriageway has just been installed with CSB, DROBB and SSOBB along the verge. There is TSB along the central reserve.			
Location Map:				



Page 2	Pilot Site Data Form					Site No. 3
Carriageway Characteristics						
Type of road: (single / dual carriageway)	Dual		No. of Lanes in carriageway:	2		
Segment length :	60		Curvature 1 (m. to 0dp):			
Average Gradient (% to 2dp):	2		Curvature 2 (m. to 0dp):			
Outside shoulder width (m to 2 dp):	1.5m (estimate)		Percentage of rumble strips (% to 0dp):	0		
Inside shoulder width (m to 2 dp):	1.5m (estimate)		Average Lane Width (m. to 2dp):	3.65 (estimate)		
Traffic Characteristics						
Traffic Flow (AADT) (see note 2):	38536					
HGV Proportion (% to 1 dp):	16.1					
Annual Traffic Growth:	1 % (see note 5)					
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):		unknown				
Predicted Crash Condition						
Reference country:	Great Britain					
Crash distribution (Cars):	Germany Dual Carr_Highway					
Crash distribution (HGVs):	Motorway Roadside_2 lanes					
Containment Class:	H1					
Hazards Occuring within Segment Analysed						
			Comments			
Roadside type:	Verge (roadside)		Gantry foundations on both sides of carriageway			
Type of Hazard:	Rock					
Recorded Accident History (see note 3)						
Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)	
Existing VRS Provision (where applicable)						
Location(s):	Both sides					
Extents:	Whole segment					
Barrier type:						
Cost benefit analysis						
Start year:	2013		End year:	2032 (2072)		
Interest rate (% to 2 dp) (see note 4):	3.5					
Output from the SAVeRS Tool: version beta002	**Barrier**		**Lifetime cost 20 years**	**Lifetime cost 60 years**	Cheapest lifetime cost highlighted	
	H1 - Roadside - DROBB (GreatBritain)		£28'930	£78'331		
	H1 - Roadside - H1W4 Steel		£20'893	£76'983		
	H2 - Roadside - Concrete Step Barrier		£27'415	£70'410		
	H2 - Roadside - H2W4 Steel		£26'270	£71'335		
	H4 - Roadside - Concrete (GreatBritain)		£42'759	£87'802		
Comment:	The selection tool indicates that the H2 containment barriers are more cost effective that the H1 containment barriers that are a lower containment level. The H2 concrete barrier becomes a more cost effective option when costs over a longer timespan are considered.					

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the number
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accidents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparisson purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. Expected annual traffic growth calculated from growth factor for south east rural trunk roads between 2014 and 2024 derived from the National Trip End Model using TEMPRO.

SaVERS	**Pilot Site Data Form**		Site No. 4
Road Number:	A21	Road Name:	Pembury Road
Location			
Start OS Grid Reference:	TQ 60202 44588	End OS Grid Reference:	TQ 60486 44344
Speed Limit (mph):	60mph (97kph)		
General Site Description:	Single carriageway rural trunk road. Segment is a straight, flat section on low embankment with some trees and shrubs at the bottom of the embankment.		
Location Map:			

Page 2	Pilot Site Data Form			Site No. 4
Carriageway Characteristics				
Type of road: (single / dual carriageway)	Single (Ireland used as reference country)	No. of Lanes in carriageway:	2	
Segment length :	370	Curvature 1 (m. to 0dp):		
Average Gradient (% to 2dp):	0	Curvature 2 (m. to 0dp):		
		Spirals	n/a	
Outside shoulder width (m to 2 dp):	1 (estimate)	Percentage of rumble strips (% to 0dp):	0	
Inside shoulder width (m to 2 dp):	n/a	Average Lane Width (m. to 2dp):	3.65 (estimate)	
Traffic Characteristics				
Traffic Flow (AADT) (see note 2):	36328 (2012)			
HGV Proportion (% to 1 dp):	4.3			
Annual Traffic Growth:	1% (see note 5)			
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):	n/a			
Predicted Crash Condition				
Reference country:	Ireland			
Crash distribution (Cars):	Germany Single Carriageways			
Crash distribution (HGVs):	RSAPV3 Undivided_fric=0.45-0.6			
Containment Class:	N2			
Hazards Occuring within Segment Analysed				
		Comments		
Roadside type:	Verge (roadside)	Large shrubs / hedgerow on both sides of carriageway with occasional mature tree.		
Type of Hazard:	Tree			

Recorded Accident History (see note 3)					
Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)

Existing VRS Provision (where applicable)	
Location(s):	None
Extents:	
Barrier type:	

Cost benefit analysis			
Start year:	2012	End year:	2031
Interest rate (% to 2 dp) (see note 4):	3.5		

Output from the SAVeRS Tool: version beta002	**Barrier**	**Lifetime cost**	Cheapest lifetime cost highlighted
	N2 - Roadside - N2W2 Steel	£520'726	
	N2 - Roadside - N2W3 Steel	£513'943	
	N2 - Roadside - N2W4 Steel	£512'086	
	N2 - Roadside - N2W5 Steel	£508'210	
	N2 - Roadside - OBB (GreatBritain)	£523'585	
	N2 - Roadside - TCB (GreatBritain)	£520'361	
	N2 - Roadside - Wire rope	£515'163	
	H1 - Roadside - DROBB (GreatBritain)	£545'538	
	H1 - Roadside - H1W4 Steel	£540'175	
	H2 - Roadside - Concrete Step Barrier	£535'417	
	H2 - Roadside - H2W4 Steel	£528'889	
	H4 - Roadside - Concrete (GreatBritain)	£631'661	
Comment:	Verge width would probably require a lower working width class than the N2W5 steel which the selection tool shows is the most cost effective. Wire rope would also be excluded for the same reason.		

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the number of lanes for the carriageway analysed (i.e. single traffic direction only) is included.
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accidents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparisson purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. Expected annual traffic growth calculated from growth factor for south east rural trunk roads between 2014 and 2024 derived from the National Trip End Model using TEMPRO.

SaVERS	Pilot Site Data Form			Site No. 5
Road Number:	M4 (Heathrow spur)	Location:	Junction 4 to 4a	
Location				
Start OS Grid Reference:	TQ 07456 77832	End OS Grid Reference:	TQ 57477 77745	
Speed Limit (mph):	70mph (113mph)			
General Site Description:	Northbound carriageway of motorway spur from M4 to Heathrow Airport. Segment contains overbridge.			
Location Map:				

Page 2	**Pilot Site Data Form**			Site No. 5
Carriageway Characteristics				
Type of road: (single / dual carriageway)	Dual	No. of Lanes in carriageway:	3	
Segment length :	95	Curvature 1 (m. to 0dp):		
Average Gradient (% to 2dp):	0	Curvature 2 (m. to 0dp):		
Outside shoulder width (m to 2 dp):	3 (estimated)	Percentage of rumble strips (% to 0dp):	0	
Inside shoulder width (m to 2 dp):	0.5 (estimated)	Average Lane Width (m. to 2dp):	3.65 (estimated)	
Traffic Characteristics				
Traffic Flow (AADT) (see note 2):	27805 (2013)			
HGV Proportion (% to 1 dp):	2.84			
Annual Traffic Growth:	1 % (see note 5)			
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):	0			
Predicted Crash Condition				
Reference country:	Great Britain			
Crash distribution (Cars):	Germany Dual Carr_Motorway			
Crash distribution (HGVs):	Motorway Median_3 lanes			
Containment Class:	N2			
Hazards Occuring within Segment Analysed				
		Comments		
Roadside type:	Median	Lighting columns and sign posts in central reserve Concrete foundation with upstand <1m in embankment Overbridge with supports in embankment		
Type of Hazard:	n/a			

Recorded Accident History (see note 3)					
Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)

Existing VRS Provision (where applicable)	
Location(s):	Verge and central reserve
Extents:	Whole segment
Barrier type:	OBB

Cost benefit analysis				
Start year:	2013		End year:	2032
Interest rate (% to 2 dp) (see note 4):	3.5			
Output from the SAVeRS Tool: version beta002	**Barrier**	**Lifetime cost**	Cheapest lifetime cost highlighted	
	N2 - Median - N2W2 Steel (GreatBritain	£167'539		
	N2 - Median - N2W3 Steel (GreatBritain	£166'215		
	N2 - Median - N2W4 Steel (GreatBritain	£165'837		
	N2 - Median - OBB (GreatBritain)	£167'984		
	N2 - Median - TCB (GreatBritain)	£167'543		
	N2 - Median - Wire Rope (GreatBritain)	£165'543		
	H2 - Median - H2W4 Steel (GreatBritain	£71'852		
	H4 - Roadside - Concrete (GreatBritain)	£66'818		
Comment:	The selection tool indicates that high conta nment barrier types are much more cost effective than the N2 lower containment level barriers due to the reduction in injury costs for the H2 and H4 barriers although they have a higher initial construction cost.			

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the number
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accidents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparisson purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. Expected annual traffic growth calculated from growth factor for south east rural trunk roads between 2014 and 2024 derived from the National Trip End Model using TEMPRO.

SaVERS	Pilot Site Data Form		Site No. 6
Road Number:	M4	Road Name:	Junction 3 - 4
Location			
Start OS Grid Reference:	TQ 08057 78491	End OS Grid Reference:	TQ 09824 78304
Speed Limit (mph):	70mph (113mph)		
General Site Description:	Flat, straight section of three-lane motorway (eastbound carriageway) between junctions. The M4 motorway provides the primary access from the west to central London and, aside from the M25, is one of the most heavily used and congested motorways.		
Location Map:			

Page 2	Pilot Site Data Form	Site No. 6

Carriageway Characteristics

Type of road: (single / dual carriageway)	Dual	No. of Lanes in carriageway:	3
Segment length :	1770	Curvature 1 (m. to 0dp):	0
Average Gradient (% to 2dp):	0	Curvature 2 (m. to 0dp):	0
Outside shoulder width (m to 2 dp):	3.3 (estimate)	Percentage of rumble strips (% to 0dp):	0
Inside shoulder width (m to 2 dp):	0.7 (estimate)	Average Lane Width (m. to 2dp):	3.65 (estimate)

Traffic Characteristics

Traffic Flow (AADT) (see note 2):	45'913
HGV Proportion (% to 1 dp):	3.95
Annual Traffic Growth:	1 % (see note 5)
Proportion of AADT during hours where volume exceeds 1000 veh/hr/ln (% to 2dp):	unknown

Predicted Crash Condition

Reference country:	Great Britain
Crash distribution (Cars):	Germany Dual Carr_Motorway
Crash distribution (HGVs):	Motorway Median_3 lanes
Containment Class:	N2

Hazards Occuring within Segment Analysed

		Comments
Roadside type:	Median	Lighting columns and sign posts in central reserve
Type of Hazard:	n/a	

Recorded Accident History (see note 3)

Period (years covered by data):	Damage Only	Minor Injuries	Severe Injuries	Fatal	Total All Accidents (for information)	

Existing VRS Provision (where applicable)

Location(s):	Central reserve (on both sides)
Extents:	Whole segment
Barrier type:	OBB

Cost benefit analysis

Start year:	2013	End year:	2032 and 2062
Interest rate (% to 2 dp) (see note 4):	3.5		

Output from Selection Tool: version 40b	Barrier	Lifetime cost 20 years	Lifetime cost 50 years	Cheapest lifetime cost highlighted
	N2 - Median - Wire Rope	£3'640'226	£9'527'873	
	N2 - Median - N2W4 Steel	£3'640'991	£9'523'786	
	N2 - Median - N2W3 Steel	£3'648'012	£9'533'626	
	N2 - Median - N2W2 Steel	£3'672'876	£9'569'041	
	N2 - Median - TCB (GreatBritain)	£3'672'883	£9'574'677	
	N2 - Median - OBB (GreatBritain)	£3'677'398	£9'581'857	
	H2 - Roadside - Concrete Step Barrier	£1'512'677	£3'607'590	
	H4 - Roadside - Concrete	£1'332'417	£2'357'608	

Comment:	The selection tool indicates that high containment barrier types are much more cost effective than the N2 lower containment level barriers due to the reduction in injury costs for the H2 and H4 barriers although they have a higher initial construction cost.

Notes

1. For single carriageway roads lanes in both traffic directions are included. For dual carriageway roads the, only the
2. For single carriageway roads two-way AADT is used. For dual carriageway only the traffic flow for the carriageway analysed (i.e. single traffic direction only) is included.
3. The accident data includes all traffic accicents as it is not possible to identify Run-Off-Road incidents from that data available. Information on recorded accidents is included for comparisson purposes only.
4. Discount Rate from the Department for Transport's WebTAG guidance.
5. Expected annual traffic growth calculated from growth factor for south east rural trunk roads between 2014 and 2024 derived from the National Trip End Model using TEMPRO.

5 CRASH CUSHIONS AND TERMINALS

5.1 Crash cushions

Within the SAVeRS project dataset it was not possible to identify the VRS feature that was involved in the impact and therefore a specific assessment of different type of crash cushions involved in a SVROR crash was not possible but with the SVROR prediction model the number of expected passenger car and HGV crash cushion related crashes is estimated in the tool.

For this evaluation the user needs to input the number of crash cushions in the designed segment on the specific edge analysed. The area of interest of the crash cushion has been set to the *runout length* (L_R) (which means that any crash occurring in a segment L_R long prior to the crash cushion is considered to be potentially affecting the device). As discussed in section 2.7.3 the *runout length* calculated by means of the AASHTO 2011 procedure leads to very conservative results as compared to the L_R values determined in the NCHRP Project 17-43. This means that very low angles are included in the AASHTO 2011 calculation.

In the SAVeRS tool the following assumptions are made for the default area of interest:

- in a diverge area where the impact can occur with very low angles, the AASHTO 2011 L_R value is used;
- if the crash cushion is placed on the edge of the shoulder, where it is more unlikely that the impact may occur with very low angles, the L_R value derived from the NCRHP 17-43 (NCHRP, ongoing) as shown in section 2.7.3 is used;

This figure can be modified by the user.

If the crash cushion is placed in a motorway diverge area the number of passenger car SVROR crashes estimated based on the model described in section 3.3.2 is increased to account for the effect of the diverging manoeuvres.

This effect is accounted for by comparing the fatal+injury HSM base model for exit areas with the single vehicle fatal+injury HSM base model for segments with different number of lanes per direction.

The resulting increase factor is shown in Table 25. For 4 lane motorways the effect of the diverse area is negligible.

Table 25: Increase crash factor for crash cushions placed in diverge areas in motorways

Number of lanes per direction	Increase factor
2	1.15
3	1.07
4	1.00

The selection of the crash cushion performance class according to EN 1317-3 (the test conditions are summarised in Table 26) is usually based only on the local speed limit and on the physical geometry of the area where the crash cushions is to be installed but the number of potential crashes per crash cushion in the design period can be extremely useful in deciding the type of crash cushion to be installed:

- **Gating Crash Cushions**: systems characterized by a lower initial cost (compared with non-gating sacrificial crash cushions) but relatively high maintenance costs;
- **Sacrificial Crash Cushions**: non-gating crash cushions considered sacrificial (replaceable) are generally designed for a single impact (low initial cost);
- **Reusable Crash Cushions**: they have some parts that will be to be replaced after an impact to make the unit crashworthy again, however, major components of the non-gating system may survive an impact (more expensive than sacrificial);
- **Low Maintenance/Self Restoring Crash Cushions**: these systems are premium non-gating system designed for high traffic areas and locations where vehicular impacts can be expected frequently (high cost but they can sustain multiple impacts before repairs are needed).

All the HGV crashes against the crash cushion will need the replacement of the device and for this reason this figure is included in the tool even though the crash cushion will not affect HGV crashes severity.

Table 26: ENV 1317-3 test conditions for crash cushions

Test Level	Mass [kg]	Speed [km/h]	Impact angle (on the crash cushion end) [deg]	Impact angle (on the terminal side) [deg]
50	900-1300	50	0	15
80/1	900-1300	80	0	15-165
80	900-1300	80	0-15	15-165
100	900-1500	100	0-15	15-165
110	900-1500	100-110	0-15	15-165

The crash cushions section of the SAVeRS tool also allows to calculate the number of car crashes in the design period that could potentially impact the crash cushion at a speed above the nominal crash test speed (for 110 VRS class a speed of 110 km/h is considered) depending on the selected VRS class and on the selected speed distribution.

Considering the 5 car crash distributions included in the tool (Germany (GIDAS) motorways, Germany (GIDAS) divided highways, Germany (GIDAS) undivided rural roads, US (RSAP) divided and US (RSAP) undivided) the probabilities of impacting the crash cushions at a speed above the maximum crash speed have been defined, as shown in Table 29. If the user defines a different impact distribution for cars this speed distributions have to be defined accordingly by the user. An empty column for used defined distributions is available in the tool.

Table 27: probability of an impact speed above the crash cushion max test speed

Test Level	Speed [km/h]	Probability of impact speed above crash speed (%)
Germany (GIDAS) motorways		
50	50	93
80-80/1	80	84
100	100	65
110	**110**	53
Germany (GIDAS) divided highways		
50	50	90
80-80/1	80	54
100	100	21
110	110	13
Germany (GIDAS) undivided rural roads		
50	50	90
80-80/1	80	45
100	100	15
110	110	8
US (RSAP) divided roads		
50	50	95
80-80/1	80	69

100	100	37
110	110	18
US (RSAP) undivided roads		
50	50	87
80-80/1	80	42
100	100	14
110	110	7

In the literature very few studies have been found evaluating the severity of crash cushions related crashes but none of them compare the effectiveness of different performance classes based on EN1317. This area should be further investigated in the future.

5.2 Terminals

The design of barrier terminals has recently been evaluated in the ERANET SRO1 Project IRDES and a specific chapter is devoted to this issue in the CEDR Forgiving Roadsides Design Guide (CEDR, 2013). In the Guide a model for evaluating the effectiveness of replacing non crashworthy terminals with crashworthy terminals is also proposed.

Within the SAVeRS project dataset it was not possible to identify the VRS feature that was involved in the impact and therefore a specific assessment of different type of terminals was not possible but with the SVROR prediction model the number of expected passenger car terminal related crashes is estimated in the tool.

For this evaluation the user needs to input the number of crash cushions in the designed segment on the specific edge analysed. The area of interest of the crash cushion has been set to the *runout length* (L_R) (which means that any crash occurring in a segment L_R long prior to the crash cushion is considered to be potentially affecting the device). As discussed in section 2.7.3 the *runout length* calculated by means of the AASHTO 2011 procedure leads to very conservative results as compared to the L_R values determined in the NCHRP Project 17-43. This means that very low angles are included in the AASHTO 2011 calculation.

Considering that usually the terminal is placed on the edge of the shoulder, where it is more unlikely that the impact may occur with very low angles, the L_R value derived from the NCRHP 17-43 as shown in section 2.7.3 is used. If the terminal is used on a very peculiar situation where the area upfront the terminal is paved then it is recommended that the crash cushion area of interest calculated for a diverse area is used replacing the default figure.

Based on the detailed ROR crash data collected in SAVeRS (GIDAS (DE) and RSA (US) databases) it was also possible to evaluate the potential impact angles as shown in Figure 21. Very low impact angles (below 5%) are extremely rare (8.5%-12.5%) and this confirms the CEDR Forgiving Roadsides Guide Recommendation that, where sufficient lateral space is available, a flared or buried in backslope terminal should be considered as parallel terminals are designed and tested only for frontal crashes (0°).

In some countries (e.g. Italy) flared and buried in backslope crashworthy terminals are allowed based on design specifications even if these are not tested according to the relevant EN1317 standard (currently ENV 1317-4, in the future will become EN 1317-7).

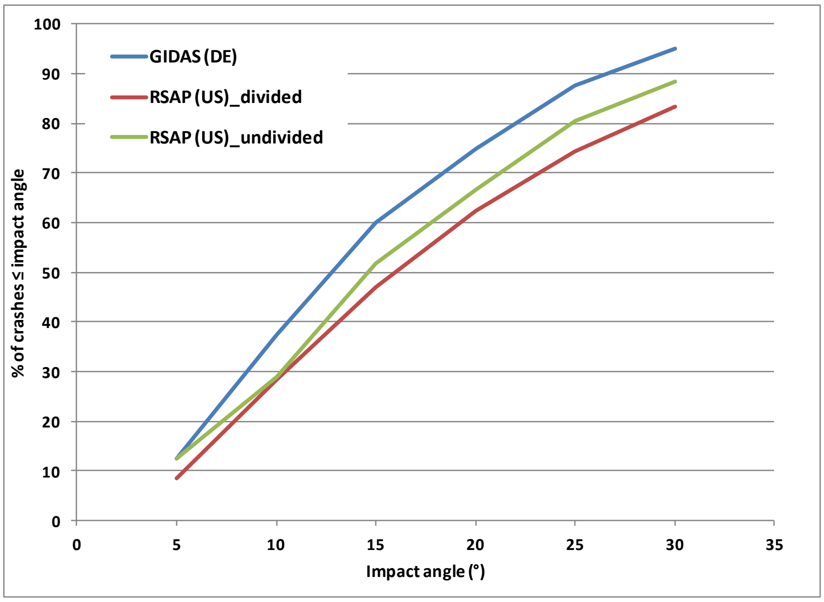


Figure 21: distribution of impact angles based on GIDAS and RSAP databases.

Where an energy absorbing terminal tested according to EN standards is adopted, the selection is usually based only on the local speed limit compared to the ENV1317-4 (CEN, 2002) standard test speed (Table 28).

Table 28: ENV 1317-4 test conditions for terminals

Test Level	Mass [kg]	Speed [km/h]	Impact angle (on the terminal end) [deg]	Impact angle (on the terminal side) [deg]
P1	900	80	0	-
P2	900-1300	80	0	15-165
P3	900-1300	100	0	15-165
P4	900-1500	100-110	0	15-165

If the terminal is placed in a two-way road a type U should be used (tested both upstream and downstream).

The terminals section of the SAVeRS tool also allows to calculate the number of car crashes in the design period that could potentially impact the terminal at a speed above the nominal crash test speed (for P4 a speed of 110 km/h is considered) depending on the selected VRS class and on the selected speed distribution.

Considering the 5 car crash distributions included in the tool (Germany (GIDAS) motorways, Germany (GIDAS) divided highways, Germany (GIDAS) undivided rural roads, US (RSAP) divided and US (RSAP) undivided) the probabilities of impacting the terminal at a speed above the maximum crash speed have been defined, as shown in Table 29.

Table 29: probability of an impact speed above the terminal max test speed

Test Level	Speed [km/h]	Probability of impact speed above crash speed (%)
Germany (GIDAS) motorways		
P1-P2	80	84
P3	100	65
P4	110	53
Germany (GIDAS) divided highways		
P1-P2	80	54
P3	100	21
P4	110	13
Germany (GIDAS) undivided rural roads		
P1-P2	80	45
P3	100	15

P4	110	8
US (RSAP) divided roads		
P1-P2	80	69
P3	100	37
P4	110	18
US (RSAP) undivided roads		
P1-P2	80	42
P3	100	14
P4	110	7

In the literature very few studies have been found evaluating the severity of terminal related crashes but none of them compare the effectiveness of different performance classes based on EN1317. This area should be further investigated in the future.

6 MOTORCYCLE PROTECTION SYSTEMS

Whilst crashes involving a motorcyclist impacting a safety barrier system are relatively rare, they often result in high severity crashes. It is due to this reason that a number of National procedures, and subsequently a European Technical Specification (TS1317-8:2010), for the testing Motorcyclist Protection Systems (MPS) was developed, involving a sliding dummy impacting the protection device. These testing procedures have then further led to the development and sale of a number of MPS devices on the European market.

The issue of motorcyclist impacts with safety barrier systems has become a hot topic within Europe over the past decade, to the point where a number of European countries now have National requirement for the use of such devices. In general such crashes occur on tight bends, and on straight sections of roads in the vicinity of junctions.

Examples from various standards range in complexity as follows:

- in the UK, the requirement is to identify (for example through accident records), sites with high risk to powered two-wheel vehicles, such as tight external bends. IN these cases consideration must be given to the form of VRS chosen to minimise the risk to this category of drivers. At such high risk sites, it is recommended to use an 'add on' MPS to post-and-rail type safety barriers to minimise the risk of injury to motorcyclists;

- the French national directive says that for new roads, MPS should be installed on the external side of highways and roads with separated carriageways when the radius of the bend is equal to or less than 400m. On the other roads, the MPS should be installed in the external side of bends with a radius equal to or less than 250m. The installation is also necessary in the external side of all bends for grade separated junctions;
- according to Portuguese regulations a MPS must be placed:
  - in curves with radius under a minimum value;
  - in curves with no superelevation or superelevation under a minimum value;
  - in small radius curves with a high downward gradient (>4%);
  - in consecutive circular curves in the same direction with decreasing radius;
  - in cloverleaf interchanges and other smaller radius ramps;
  - at entry points at intersections and interchanges;
  - in zones prone to skidding and icing.

  To improve powered two-wheelers safety the removal of the safety barrier and the adoption of a clear zone free of obstacles should be preferred whenever possible and economically cost effective.

- According to Spanish regulations, the installation of MPS on existing barriers is recommended at the outside shoulders in curves on dual carriageways with a radius lower than 400 m, and on deceleration lanes on exit ramps. MPS installation is also recommended for single carriageway roads with a shoulder width of under 1.5 m when the radius is lower than 250 m, and on any other highway that has a speed reduction at a curve higher than 30 km/h.

The following locations should be prioritised for assessing the risk posed to motorcyclists, using the methodology described below:

At Grade Separated Junctions:

- Ramps/Slip Roads:
    - barrier placed on the curve external edge (with the higher radius) of bends with a curve radius of 200 m or less.
- On the main road section of road at grade separated junctions, where traffic conflict zones such as merge, diverge and weaving areas are located.

On Link Roads:

- barrier placed on the curve external edge (with the higher radius) of bends with a curve radius of 200 m or less.

Enhanced prioritisation should also be given to grade separated junctions and link roads where one or more of the following characteristics also exists:

- routes regularly travelled by motorcyclists/where the percentage of motorcyclist traffic is high;
- locations where the barrier system is located close to the edge of the carriageway
- reverse and/or insufficient super-elevation;
- locations of frequently queuing traffic;
- locations of queue discharge;
- consecutive curves in the same direction, with decreasing radius;
- sharp horizontal curves located at the end of long straights, without a sufficient transition spiral;
- locations with poor sight distance;
- locations likely to experience icing and skidding;
- locations where other hazards to motorcyclists exist.

Assessment of possible safety improvements

From an examination of International best practice and an evaluation of crashes occurring on Highways Agency roads in England, the following approach is recommended for increasing the level of safety for motorcyclists in high risk locations as defined above:

- investigate the methods that would decrease the probability of a motorcyclist leaving the carriageway (e.g. improving road surface, improved signage or better visibility);
- where possible, remove any existing hazard;
- where possible, move any existing hazard further from the carriageway;
- where possible, make the hazard passively safe for an impact by a motorcyclist (as there is no published testing standard to ascertain the passive safety performance of roadside hazards through an impact by motorcyclist, engineering judgement should be used to make this assessment);
- with consideration of the safety for all road users, remove any unnecessary lengths of barrier;
- if the hazard cannot be removed, relocated or made passively safe for motorcyclists, then installation of an MPS, compliant with TS1317-8, should be considered;
- If the installation of an MPS cannot be justified (for example due to a cost benefit analysis), then a review of the proximity of any remaining hazards to the front face of the barrier should be carried out to ascertain whether the working width of the system could be increased by using barriers with increased post spacing. The reduction in the number of posts would decrease the probability of an impact by a motorcyclist, and thus reduce the risk of injury.

On Straight Sections of Dual Carriageway Roads:

Whilst a large number of the motorcyclist to barrier crashes occur on straight (larger than 1000 m horizontal curve radius) there would not be a positive cost-benefit ratio for the installation of MPS in sections of dual carriageway roads (excluding junctions), unless there is a history of motorcycle crashes.

7 CONCLUSIONS

Within the SAVeRS project a user friendly tool has been developed to make a quantitative assessment of different type of VRS (barriers, including bridge parapets, crash cushions and terminals). The tool allows to compare different barriers' containment classes and types based on the risk indicators and on the whole life costing.

The different risk indicators can also be used for analysing the existing network in order to define a priority list for replacing existing VRS.

The structure of the model implemented in the tool is such that different users can adapt the model to their network with different levels of adaptation based on their data availability.

In the literature very few studies have been found evaluating the severity of terminals and crash cushions related crashes but none of them compare the effectiveness of different performance classes based on EN1317 standards. This area should be further investigated in the future.

Similarly there is a lack of studies providing the data necessary to adapt the severity distribution functions to account for the use of different barriers classes and for the use of barriers with different severity index levels defined according to EN1317 standards.

As placing a barrier is one of the least favoured options for designing forgiving roadsides, criteria to identify where a barrier is needed are also given in the guide.

Finally a section of the guide has been devoted to motorcycle protection and criteria to identify potentially high risk locations are given together with the criteria to define possible interventions to reduce the motorcycle drivers' risk.

Future upgrades of the SAVeRS tool include the possibility of assessing also temporary barriers. As these are typically used in work zones this implementation requires the availability of specific crash models for work zones. Within the ASAP project (funded in the same CEDR Safety Call 2012 of the SAVeRS project) a specific study on motorway work zone crashes has been conducted and could serve as a basis for such implementation.

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ANNEX 1 - GLOSSARY

Term	Definition
A-pillar	The first pillar of the passenger compartment, usually surrounding the windscreen. A-pillars protect the vehicle occupants in roll-over crash, but could increase the size of blind spots in the driver's vision.
Bridge abutment	The end support of a bridge deck or tunnel, usually retaining an embankment.
Arrester bed	An area of land adjacent to the roadway filled with a particular material to decelerate and stop errant vehicles; generally located on long steep descending gradients.
Arterial	An arterial road, or arterial thoroughfare, is a high-capacity urban road. The primary function of an arterial road is to deliver traffic from collector roads to motorways, and between urban centres at the highest level of service possible. As such, many arteries are limited-access roads, or feature restrictions on private access.
Back slope	A slope associated with a ditch, located opposite the roadway edge, beyond the bottom of the ditch.
Boulder	A large, rounded mass of rock lying on the surface of the ground or embedded in the soil in the roadside, normally detached from its place of origin.
Break-away support	See "Passively safe support".
Carriageway	The part of the roadway constructed for use by vehicular traffic. The edge of the carriageway is delineated by either the "edge line" or, if no edge line is present, the edge of the paved area.
CCTV Masts	A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.

Central reserve	An area separating the carriageways of a dual carriageway road.
Clear zone	See "Safety zone".
Clearance	The unobstructed horizontal dimension between the front side of safety barrier (closest edge to road) and the traffic face of the protected object.
Contained vehicle	A vehicle which comes in contact with a road restraint system and does not pass beyond the limits of the safety system.
Containment level	The description of the standard of protection offered to impacting vehicles by a road restraint system. In other words, the Containment Performance Class Requirement that the object has been manufactured and tested to (EN 1317).
Crash cushion	A device that absorbs the energy of an impacting vehicle. It can be redirective or non-redirective.
Culvert	A structure to channel a water course. Can be made of concrete, steel or plastic.
Culvert end	The end of the channel or conduit, normally a concrete, steel or plastic structure.
Cut slope	The earth embankment created when a road is excavated through a hill, which slopes upwards from the level of the roadway.
Deformable safety barrier	A safety barrier that deforms during a vehicle impact and may suffer permanent deformation.
Design Speed	The speed which determines the layout of a new road in plan, being the speed for which the road is designed. It is the maximum safe speed that can be maintained over a specified section.
Distributed hazards	Also known as 'continuous obstacles', distributed hazards are hazards which extend along a length of the roadside, such as embankments, slopes, ditches, rock face cuttings, retaining walls, lighting, safety barriers not meeting current standard, forest and closely spaced trees.

Ditch	Ditches are drainage features that run parallel to the road. Excavated ditches are distinguished by a fore slope (between the road and the ditch bottom) and a back slope (beyond the ditch bottom and extending above the ditch bottom).
Divided roadway	See "Dual carriageway".
Double-sided safety barrier	A safety barrier designed to be impacted on both sides.
Drainage gully	A structure to collect water running off the roadway.
Drop-off	The vertical thickness of the asphalt edge.
Dual carriageway	Roadway where the traffic is physically divided with a central reserve and/or road restraint system. Number of travel lanes in each direction is not taken into account.
Dynamic deflection	Is the maximum lateral dynamic displacement of the front edge of a restraint system during a collision.
Edge line	Road marking indicating where the carriageway ends and the roadside or median begins. If a shoulder or emergency lane is present, these are located in the roadside beyond the edge line.
Embankment	A general term for all sloping roadsides, including cut (upward) slopes and fill (downward) slopes (see also "Cut slope" and "Fill slope").
Encroachment	A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.
End terminal	See "Terminal".
Energy absorbing structures	Any type of structure which, when impacted by a vehicle, absorbs energy to reduce the speed of the vehicle and the severity of the impact.
Fill slope	An earth embankment created when extra material is packed to create the road bed, typically sloping downwards from the roadway.

Flared barrier end	A barrier end that is angled away from the road to prevent errant vehicles to drive behind the barrier and to avoid direct impact with the extremity of the barrier.
Fore slope	The fore slope is a part of the ditch and refers to the slope closest to the roadway, before the ditch bottom.
Forgiving roadside	A forgiving roadside mitigates the consequence of the "run-off" type accidents and aims to reduce the number of fatalities and serious injuries from these events.
Frangible support	A sign, traffic signal or lighting support designed to break when struck by a vehicle.
Guardrail	A guardrail is another name for a metal post and rail safety barrier.
Hard strip	A strip, usually not more than 1 metre wide, immediately adjacent to and abutting the nearside of the outer travel lanes of a roadway. It is constructed using the same material as the carriageway itself, and its main purposes are to provide a surface for the edge lines, and to provide lateral support for the structure of the travel lanes.
Hard shoulder	An asphalt or concrete surface on the nearside of the carriageway. If a "hard strip" is present, the hard shoulder is immediately adjacent to it, but otherwise, the shoulder is immediately adjacent to the carriageway. Shoulder pavement surface and condition as well as friction properties are intended to be as good as that on the carriageway.

Highsider (PTW crash type)	A highsider or highside is a type of motorcycle accident characterized by sudden and violent rotation of the bike around its long axis. This generally happens when the rear wheel loses traction, skids, and then suddenly regains traction, creating a large torque which flips the rider head first off the road. The initial traction loss may be caused by a rear locked wheel due to excessive braking or by applying too much throttle when exiting a corner or by oversteering the bike in the turn or by any loss of traction to the rear wheel.
Highway	See "Motorway"
Horizontal alignment	The projection of a road - particularly its centre line - on a horizontal plane.
Impact angle	For a longitudinal safety barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle's longitudinal axis at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle's longitudinal axis at impact.
Impact attenuators	A roadside device which helps to reduce the severity of a vehicle impact with a fixed object by absorbing energy and by transferring energy to another medium. Impact attenuators include crash cushions and arrester beds.
Kerb (noun)	A border or row of joined stones elements intended to separate areas of different surfaces often on different level and to provide physical delineation or containment.
Lane line	See "Lane marking".
Lane marking	The road marking between the travel lanes.
Link road	a road used to link two cities or two more major hubs of road transport.
Leading terminal	See "Upstream terminal".
Length of need	The total length of a longitudinal safety barrier needed to shield an area of concern.

Limited severity zone	An area beyond the recovery zone that is free of obstacles in order to minimize severity in case of a vehicle run-off.
Lowsider (PTW crash type)	The lowsider or lowside is a type of motorcycle crash usually occurring in a turn and caused by a loss of grip between the tires and the road surface. It is most often caused by either locking a wheel due to excessive braking or application of excessive power out of or through the turn. It may also be caused by slippery or loose material (such as oil, water, dirt or gravel) on the road surface.
Median	See "Central reserve".
Median barrier	A longitudinal safety barrier that is used to prevent vehicles from going across a median and colliding with vehicles in the opposing traffic lanes.
Motorcyclist Protection System (MPS)	A vehicle restraint system designed to protect crashed PTW riders from severe injuries.
Motorways	A dual carriageway road intended solely for motorized vehicles, and which provides no access to any buildings or properties. On the motorways itself, only grade separated junctions are allowed at entrances and exits.
Nearside	A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to the vehicle's travelled way (not median).
Unpaved roadside	A roadside which contains very little or no paved surface immediately beyond the edge line.
Unpaved surface	A surface type that is not asphalt or concrete (e.g. grass, gravel, soil).
Offside	A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to opposing traffic or a median.

Parapet	A longitudinal safety barrier whose primary function is to prevent an errant vehicle or pedestrians from going over the side of the bridge structure.
Paved shoulder	See "Hard shoulder".
Pedestrian guardrail	A restraint system for pedestrians or other road users intended to restrain pedestrians or other road users from stepping onto or crossing a road or other area likely to be hazardous including headwalls and wingwalls remote from the road. Note: "other road users" includes cyclists, equestrians, road maintenance personnel, emergency services personnel and cattle.
Pedestrian parapet	A restraint system for pedestrians or other road users along a bridge or on top of a retaining wall or similar structure which is used to avoid falling and is not intended to act as a road vehicle restraint system. Note: "other road users" includes cyclists, equestrians, road maintenance personnel, emergency services personnel and cattle.
Pedestrian restraint system	A road restraint system installed to provide restraint for pedestrians.
Permanent safety barrier	A safety barrier installed permanently on the road.
Pier	An intermediate support for a bridge.
Point Hazard	A narrow item on the roadside that could be struck in a collision, including trees, bridge piers, lighting poles, utility poles, and sign posts.
Rebounded vehicle	A vehicle that has struck a road restraint system and then returns to the main carriageway.
Recovery zone	The recovery zone is a small strip immediately adjacent to the carriageway that allows drivers of errant vehicles to correct their behaviour and to continue their journey without consequences. No objects are allowed in the recovery zone. The surface should be sufficiently resistant to allow manoeuvring.

Retaining wall	A wall that is built to resist lateral pressure, particularly a wall built to support or prevent the advance of a mass of earth.
Rigid safety barrier	A safety barrier that has negligible deflection during a vehicle impact.
Road equipment	The general name for structures related to the operation of the road and located in the roadside.
Road furniture	See "Road equipment".
Road restraint system (RRS)	The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).
Roadside	The area beyond the edge line of the carriageway. The central reserve may also be considered roadside.
Roadside Barrier	A road vehicle restraint system installed alongside of roads.
Roadside hazards	Roadside hazards are fixed objects or structures endangering an errant vehicle leaving its normal path. They can be continuous or punctual, natural or artificial. The risks associated with these hazards include high decelerations to the vehicle occupants or vehicle rollovers.
Roadway	The paved area of the road including shoulders, for vehicular use.
Rock face cuttings	A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.
Rumble strip	A thermoplastic or milled transverse marking with a low vertical profile, designed to provide an audible and/or tactile warning to the road user. Rumble strips are normally located on hard shoulders and the nearside travel lanes of the carriageway. They are intended to reduce the consequences of, or to prevent run-off road events.
Rural roads	All roads located outside urban areas, not including motorways.
Safety barrier	A road vehicle restraint system installed alongside or on the central reserve of roads.

Safety zone	The safety zone is the zone adjacent to the carriageway for which measures should be taken to avoid severe consequences for drivers and passengers of vehicles that accidentally leave the road and enter into this zone. In general the zone consists of a small recovery zone and a larger strip which should be free of fixed and potentially aggressive objects, non-recoverable slopes and other installations that represent a hazard when impacted by an errant vehicle. The safety zone allows a controlled or uncontrolled slowdown and stop without severe injuries. The desired width depends on traffic volume, speed and road geometry.
Self-explaining road	Roads designed according to the design concept of self-explaining roads. The concept is based on the idea that roads with certain design elements or equipment can be easily interpreted and understood by road users. This delivers a safety benefit as road users have a clear understanding of the nature of the road they are travelling on, and will therefore expect certain road and traffic conditions and can adapt their driving behaviour accordingly.
Set-back	Lateral distance between the way and an object in the roadside for clearance.
Shoulder	The portion of the roadway contiguous with the travel lane, primarily for accommodation of stopped vehicles, emergency use, and lateral support of the carriageway.
Single carriageway	A carriageway with no physical separation between lanes.
Single-sided safety barrier	safety barrier designed to be impacted on one side only
Slope	See "Embankment".
Soft strip	A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).

Soft shoulder	A soft shoulder is defined as being a gravel surface immediately adjacent to the carriageway or hard strip (if present). In some countries it is used as an alternative for hard shoulders.
Temporary safety barrier	safety barrier which is readily removable and used at road works, emergencies or similar situations.
Terminal	The end treatment for a safety barrier. It can be energy absorbing structure or designed to protect the vehicle from going behind the barrier.
Termination	See "Terminal".
Transition	A vehicle restraint system that connects two safety barriers of different designs and/or performance levels.
Travel/Traffic lane	The part of the roadway that is travelled on by motor vehicles. A carriageway can include one or more travel lanes.
Treatment	A specific strategy to improve the safety of a roadside feature or hazard.
Underpass	A structure (including its approaches) which allows one road or footpath to pass under another road (or an obstacle).
Underrider (underride barriers)	A type of MPS, a closed surface on steel barriers to avoid the sliding of a rider under the barrier system.
Undivided roadway	See "Single carriageway".
Unpaved shoulder	See "Soft shoulder".
Upstream terminal	A terminal placed at the upstream end of a safety barrier.
Vehicle parapet	A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.
Vehicle Restraint System (VRS)	A system installed on the road to prevent an errant vehicle from colliding with objects located beside the road. This includes for example a safety barrier, a crash cushion, etc.

Verge	An unpaved level strip adjacent to the shoulder. The main purpose of the verge is drainage, and in some instances can be lightly vegetated. Additionally, road equipment such as safety barriers and traffic signs are typically located on the verge.
Vertical alignment	The geometric description of the roadway within the vertical plane.

ANNEX 2 - DEVELOPMENT OF A BASE SAFETY PERFORMANCE FUNCTION

The methodologies to model accident counts are well developed. Poisson and negative binomial (NB) regression are widely used method for modelling accident data. These models belong to the larger class of Generalized Linear Models (GLM) (Nelder and Wedderburn, 1972).

A GLM consists of three elements:

1. The response y is assumed to have a particular distribution in the exponential family.
2. A linear predictor $\eta = \boldsymbol{X}\beta$, where $\boldsymbol{X}$ denotes the vector of covariates and the coefficients β are to be estimated.
3. A link function g, which connects the mean of y (μ) to the linear predictor η

$$\boldsymbol{g}(\boldsymbol{\mu}) = \boldsymbol{\eta} \qquad \text{Eq. 1}$$

Usually an Iteratively Re-Weighted Least Squares (IWRLS) is employed to fit GLM models. This algorithm is equivalent to Fisher scoring, which leads to the maximum likelihood estimates. Poisson regression models are GLMs with the logarithm as canonical link function, and the Poisson distribution function as the assumed probability distribution of the response. A characteristic of the Poisson distribution is that the variance equals the mean (equidispersion)

$$\boldsymbol{Var}[\boldsymbol{Y}] = \boldsymbol{E}[\boldsymbol{Y}] = \boldsymbol{\mu} \qquad \text{Eq. 2}$$

Empirically, however, the data often exhibits over-dispersion, i.e. a variance larger than the mean. To overcome over-dispersion quasi-likelihood methods can be used as well as negative binomial models. The former assume that the variance is proportional to the mean, i.e.

$$\boldsymbol{Var}[\boldsymbol{Y}] = \boldsymbol{\phi}\boldsymbol{E}[\boldsymbol{Y}] = \boldsymbol{\phi}\boldsymbol{\mu} \qquad \text{Eq. 3}$$

where $\phi > 0$. The latter is another extension of the Poisson Model. The negative binomial model is basically a Poisson-gamma mixture model with a second ancillary parameter θ. The marginal distribution is a negative binomial distribution with mean and variance given by

$$\boldsymbol{Var}[\boldsymbol{Y}] = \boldsymbol{\mu} + \frac{\boldsymbol{\mu}^2}{\boldsymbol{\theta}}, \quad \boldsymbol{E}[\boldsymbol{Y}] = \boldsymbol{\mu} \qquad \text{Eq. 4}$$

According to Lord and Mannering, 2010, the negative binomial model is the most frequently used model in crash-frequency modelling and allow to account for overdispersion. This model was used in the SAVeRS project.

In the baseline scenario only a single predictor was used, the logarithm of AADT-values, with the only exception of the Swedish model for two-lane two-way rural roads that includes also speed limit.

Due to the aggregation to homogenous sections, the segment lengths are non-uniform therefore it is relevant to model accidents as a function segment length. Hence, the models have the following forms:

$$\mathbf{SVROR} = \mathbf{Sec\_Length} \cdot e^{\beta_0+\beta_1 \log(AADT)} \quad \text{Eq. 5}$$

(except Swedish two-lane two-ways rural roads)

$$\mathbf{SVROR} = \mathbf{Sec\_Length} \cdot e^{\beta_0+\beta_1 \log(AADT)+\beta_2 speed} \quad \text{Eq. 6}$$

(only Swedish two-lane two-ways rural roads)

where:

Sec_Length is the section length (in m)

AADT is the Average Annual Daily Traffic;

speed it the posted speed limit.

These models have been fitted with standard routines in the “R” or “SAS” environments but any other statistical package suitable for GLM evaluations can be used.

For fitting the model with a different network a set of section with “base” conditions have to be extracted from the overall crash database. Base conditions are different for motorways and for two-lane two-ways rural roads and are:

For motorways:

- road type: median divided dual carriageway;
- roadway type: segments (not including intersections, interchanges, driveways etc.);
- area type: rural;
- terrain: level (between -2 and 2% longitudinal gradient);

- alignment: straight roads;
- number of lanes: 2;
- hard shoulder: yes;
- lane width between 3.50 m and 3.75 m;
- outside shoulder width between 2.51 m and 3.00 m;
- inside shoulder width between 0.51 m and 0.75 m;
- no rumble strips.

For two-lane two-ways rural roads:

- road type: undivided single carriageway;
- roadway type: segments (not including intersections, interchanges, driveways etc.);
- area type: rural;
- terrain: level (between -3 and 3 % longitudinal gradient);
- alignment: straight roads;
- lane width between 1.50 m and 2.10 m;
- shoulder width between > 3.50 m.

For each of the sections included in the dataset the observed SVROR crashes have to be obtained for at least 3 years (a minimum of 5 years is recommended) and the Annual Average Daily Traffic has to be given for each year (per single direction for the motorways and bidirectional for the two-lane two-ways models).

A negative binomial model is then fitted with a statistical package to the baseline data to derive the parameters of the base crash prediction model adjusted to the local network.

This model will provide only the base crash conditions and the CMFs and calibration coefficients will still need to be applied to have the overall crash prediction. The procedure to develop calibration coefficients for local datasets is described in Annex 3 (for motorways) and Annex 4 (for two-lane two-ways rural roads).

ANNEX 3 - CALIBRATION OF THE MOTORWAY RUN-OFF-ROAD MODEL

The motorway full run off road model can be calibrated to local conditions to account for factors that are not accounted for in the model and to adapt the model to local conditions (climate, driving behaviour etc). The result of the calibration is a calibration coefficient "C" that can be used as an input in the SAVeRS Tool. The calibration coefficient can be a nation-wide value or a network-wide value or a value related to a specific portion of the network.
To calibrate the model the following steps are needed:

1. identify a set of homogenous sections in your network. A homogenous section has a constant traffic and number of lanes as well as single lane width class, outside shoulder class, inside shoulder class, longitudinal gradient class. For the definition of the classes refer to section 3.3.2.2. A minimum of 50 sections is recommended;
2. define the observation period (minimum 3 years but 5 years are recommended);
3. collect traffic data (single direction Annual Average Daily Traffic - AADT);
4. collect crash data (SVROR) for the observation period. For each section (*i*) the total number of SVROR crashes in the observation period has to be calculated ($N_{observed,i}$). The total number of crashes considering all the sections should be at least 100. If necessary increase the number of sections;
5. define the geometric parameters for each section (number of lanes, lane width class, outside shoulder class, inside shoulder class, longitudinal gradient class, % of the straight segments length with shoulder rumble strips, radius and length of each curve in the section);
6. select the base model parameters. These could be selected from the predefined SAVeRS parameters (refer to section 3.3.2.1) or defined based on a new base model fitting (refer to Annex 2);
7. for each section (*i*) and for each year calculate the number of base crashes as described in section 3.3.2.1 and sum the values together to obtain the base predicted crashes for each section ($N_{SPF,i}$);
8. calculate the CMF_i corresponding to each of the geometric features defined in step 5 for each of the analysed sections as described in section 3.3.2.2;
9. for each section calculate the predicted number of crashes as:

$$N_{pred,i} = N_{SPF,i} \times (CMF_{1,i} \times CMF_{2,i} \times \ldots \times CMF_{y,i}) \quad \text{Eq. 7}$$

10. calculate the calibration coefficient as:

$$C = \frac{\sum_{i=1}^{all\,sites} N_{obs,i}}{\sum_{i=1}^{all\,sites} N_{pred,i}} \quad \text{Eq. 8}$$

An excel spreadsheet for performing this calculation with local data can be downloaded at www.saversproject.com.

ANNEX 4 - CALIBRATION OF THE RURAL TWO-LANE TWO-WAYS RUN-OFF-ROAD MODEL

The rural two-lane two-ways full run off road model can be calibrated to local conditions to account for factors that are not accounted for in the model and to adapt the model to local conditions (climate, driving behaviour etc). The result of the calibration is a calibration coefficient “C” that can be used as an input in the SAVeRS Tool. The calibration coefficient can be a nation-wide value or a network-wide value or a value related to a specific portion of the network.

To calibrate the model the following steps are needed:

1. identify a set of homogenous sections in your network. A homogenous section has a constant traffic, speed limit (only if the model used accounts for speed limit as the Swedish model - refer to section 3.3.3.1) as well as single lane width class, shoulder class, longitudinal gradient class. For the definition of the classes refer to section 3.3.3.2. A minimum of 50 sections is recommended;
2. define the observation period (minimum 3 years but 5 years are recommended);
3. collect traffic data (total bidirectional Annual Average Daily Traffic - AADT);
4. collect crash data (SVROR) for the observation period. For each section (*i*) the total number of SVROR crashes in the observation period has to be calculated ($N_{observed,i}$). The total number of crashes considering all the sections should be at least 100. If necessary increase the number of sections;
5. define the geometric parameters for each section (lane width class, shoulder class, longitudinal gradient class, radius and length of each curve in the section, presence of spirals in approach to the curves);
6. select the base model function and parameters. These could be selected from the predefined SAVeRS base models (refer to section 3.3.3.1) or defined based on a new base model fitting (refer to Annex 2);
7. for each section (*i*) and for each year calculate the number of base crashes as described in section 3.3.3.1 and sum the values together to obtain the base predicted crashes for each section ($N_{SPF,i}$);
8. calculate the CMF_i corresponding to each of the geometric features defined in step 5 for each of the analysed sections as described in section 3.3.3.2;
9. for each section calculate the predicted number of crashes as:

$$\boldsymbol{N_{pred,i}} = \boldsymbol{N_{SPF,i}} \times \left(\boldsymbol{CMF_{1,i}} \times \boldsymbol{CMF_{2,i}} \times \ldots \times \boldsymbol{CMF_{y,i}}\right) \qquad \text{Eq. 9}$$

10. calculate the calibration coefficient as:

$$\boldsymbol{C} = \frac{\sum_{i=1}^{all\,sites} \boldsymbol{N_{obs,i}}}{\sum_{i=1}^{all\,sites} \boldsymbol{N_{pred,i}}} \qquad \text{Eq. 10}$$

An excel spreadsheet for performing this calculation with local data can be downloaded at www.saversproject.com.

ANNEX 5 - DEVELOPMENT OF AN HGV IMPACT ENERGY DISTRIBUTION

(model developed in *L. DOMENICHINI, F. LA TORRE, G. GIORDANO "Safety Analysis Of Multimodal Transportation Corridors", Proceedings of SIIV2004 II International Congress – New Technologies and Modeling Tools for Roads, Firenze, 27-29 October 2004* and adjusted for the SAVeRS project)

Accident conditions on a main road arterial can be different in terms of vehicle type and mass, vehicle speed, runoff angle and probability of occurrence.

For the evaluation of the impact conditions a "reference accident condition" has to be defined in terms of:

- the characteristics of the vehicle considered (geometry and mass);
- the lane from which the vehicle starts losing control;
- the travelling speed (in the moment when the vehicle starts losing control).

Given the fact that all these parameters are variable from one accident to another the definition of a reference condition needs to be tackled with a probabilistic approach. This means that the probability that a **given vehicle** is involved in a runoff accident from a **given lane** and with a **speed not lower than a given value** over a **given time period** has to be defined.

The procedure proposed in this study to tackle this issue can be described as follows:

a. define the probability that a given type of vehicle can be involved in a runoff accident;
b. define the probability that a vehicle of a given class loses control from a given lane;
c. define the probability that the speed of a vehicle of a given class travelling in a given lane is equal to or above a given value.

The first issue is therefore the definition of the "vehicle types". For the purpose of this study 5 different classes have been defined combining the usually available traffic and accident database classifications. For each class the geometric and mass characteristics have been defined considering the EN 1317-2 standard (CEN, 2010b) on crash tests over safety barriers and the Italian Road code as shown in Table 30.

Table 30: characterisation of the different vehicle classes

Vehicle Length (L)	5<L<=10 m		L>10		
Length sub-classes	5-7.5	7.5-10 8.5-10	10-12	12-15	>15
Type of vehicle	Light Truck (2 axles)		Heavy Trucks (3 axles)	Semitrailers and tractor-trailers	
Coding of vehicle type	**C2**	**C32**	**C42**	**C5**	**C6**
Mass (kg)	6000	13000	16000	26000	38000
centre of gravity height	1.5	1.5	1.5	1.9	1.9
vehicle width	2	2	2	2	2

For the definition of an accident probability for a given type of vehicle (part “a” of the procedure) an accident analysis has to be conducted on the site where the model is to be applied to identify the events that can be related to runoff problems (vehicles which actually runoff the road section or vehicles that hit the barriers on the right side of the carriageway). This analysis should cover a period of at least 4-5 years to collect a significant number of events.

For each vehicle type an accident rate can be defined by means of Eq. 11:

$$AR_C = \frac{\sum_t N_{t,C} \cdot 10^8}{365 \cdot \sum_t \sum_i \left(AADT_{t,i} \cdot L_i \right)} \qquad [accidents/100\ millions\ of\ vehciles\ for\ km]$$ Eq. 11

where:

N_{tC} is the number of accidents of the vehicle type “*C”* occurred over the year *t*

$AADT_{t,i}$ is the annual average daily traffic in the year *t* in the highway segment *i* (which is characterised by a constant traffic)

L_i is the length of highway segment *i* (in km).

The probability that a given type of vehicle will be involved in a runoff accident in one year (P_{AC}) can therefore be defined as:

$$P_{AC}(\%) = AR_C \cdot LT \cdot 100$$ Eq. 12

where:

LT is the total length travelled by all the vehicles over the analysed highway portion in 1 year (in 100 millions of km) defined as:

$$LT = \sum_i \left(AADT_i \cdot 365 \cdot L_i \right) \cdot 10^{-8}$$

To define the probability that a vehicle of a given type (*C*) will lose control from a given lane (part “b” of the procedure) it has been assumed that this is equal to the probability that the vehicle will be travelling in the same lane (P_{LC}). The values of P_{LC} for the different lanes and different vehicle types can be determined based on the actual traffic data, in case of an existing road section, as the ratio of the number of vehicles of a given class travelled in the lane over the total number of vehicles of the same class travelling in the monitored section as indicated in Eq. 13.

$$P_{CL} = \frac{number\ of\ vehicles\ of\ the\ class\ C\ travelling\ in\ lane\ L}{totale\ number\ of\ vehicles\ of\ the\ class\ C\ travelling\ in\ the\ section} \cdot 100$$ Eq. 13

The latter term that needs to be determined (part “c” of the procedure) is the probability that the vehicle speed is equal to or above a given value. Again the assumption that the distribution of the speed of the vehicles running off is equal to the distribution of all the travelling vehicles has been made and therefore the probability of having a vehicle running at a speed equal or above a given speed *V* can be calculated knowing the mean (V_m) and standard deviation (σ_V) of the distribution. Considering that the speed distribution is different for each vehicle class and travelling lane the probability that one of the vehicles of a given class (*C*) actually travelling in a given lane (*L*) runs at a speed equal or above a given speed (*V*) can be calculated by means of Eq. 14

$$P_{CV} = \left(1 - \frac{1}{\sqrt{2 \cdot \pi}} \cdot \int_{-\infty}^{x} e^{-\frac{1}{2} \cdot \xi^2} \, d\xi \right) \cdot 100 \qquad \text{Eq. 14}$$

where:

$$x = \frac{V - V_{m\_C\_L}}{\sigma_{V\_C\_L}}$$

The overall probability that a vehicle of a given class "*C*" will runoff from lane "*L*" at a speed equal or above "*V*" can then be defined as:

$$P_{ACVL} = P_{CA} \cdot P_{CL} \cdot P_{CV} \qquad \text{Eq. 15}$$

For design purpose the best indicator is the "return time" of a given event which can be defined as the time (in years) required to have a probability if occurrence equal to 1.

This means that the return time (*RT*) associated with the event of a vehicle of a given class "*C*" running off from lane "*L*" at a speed equal or above "*V*" can be defined as:

$$RT_{ACVL} = \frac{1}{P_{ACVL}} \qquad \text{Eq. 16}$$

This analysis is aimed at defining the runoff speed and angle at the roadway edge which serve as the basis for selection of the most appropriate VRS class.

Currently no statistical data are available to estimate these variables for Heavy Vehicles even though a project is currently running in the US for collecting specific truck data and a future refinement of the SAVeRS tool could account for those distributions.

For this reason a specific mathematical model has been set up based on the following assumptions:

- the driver losing control of the vehicle doesn't apply any breaking force;
- the vehicle reaches the road edge by means of a parabolic trajectory, as shown in Figure 22.

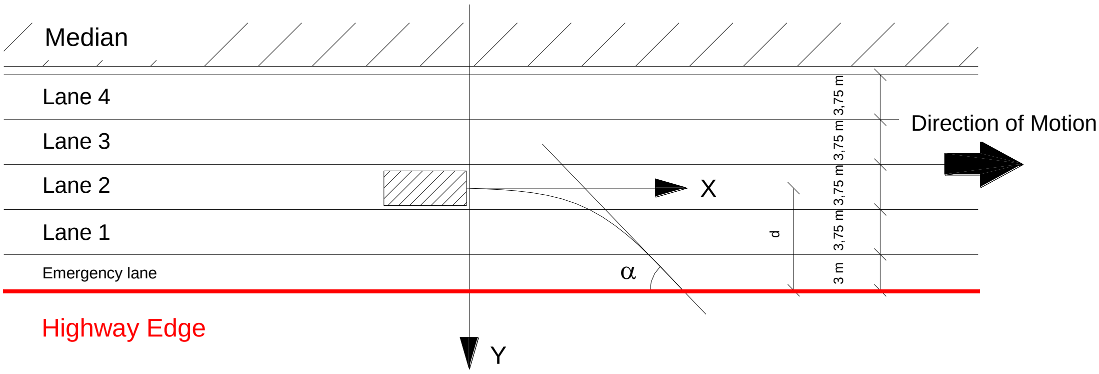

Figure 22: schematisation of the trajectory of the running off vehicle on the carriageway

The equation of the run off trajectory can therefore be defined as:

$$y = a \cdot x^2 \qquad \text{Eq. 17}$$

where $y'' = \frac{1}{R(x=0)} = 2a$ which means the trajectory can be defined as

$$y = \frac{1}{2 \cdot R(x=0)} \cdot x \qquad \text{Eq. 18}$$

and *R(x=0)* is the radius of curvature in the section where the vehicle starts to diverge from the road alignment.

The runoff angle (α), which is the angle between the trajectory and the road edge, can therefore be calculated as:

$$\alpha = \arctan\left(\sqrt{\frac{2 \cdot d}{R(x=0))}}\right) \qquad \text{Eq. 19}$$

where:

d is the distance between the point where the vehicle starts to diverge from its nominal trajectory (*x*=0) and the road edge.

If the run-off occurs in a bend the model is adjusted to account for the fact that the impact occurs at the intersection between the parabolic run off road trajectory and the road edge alignment as shown in Figure 23.

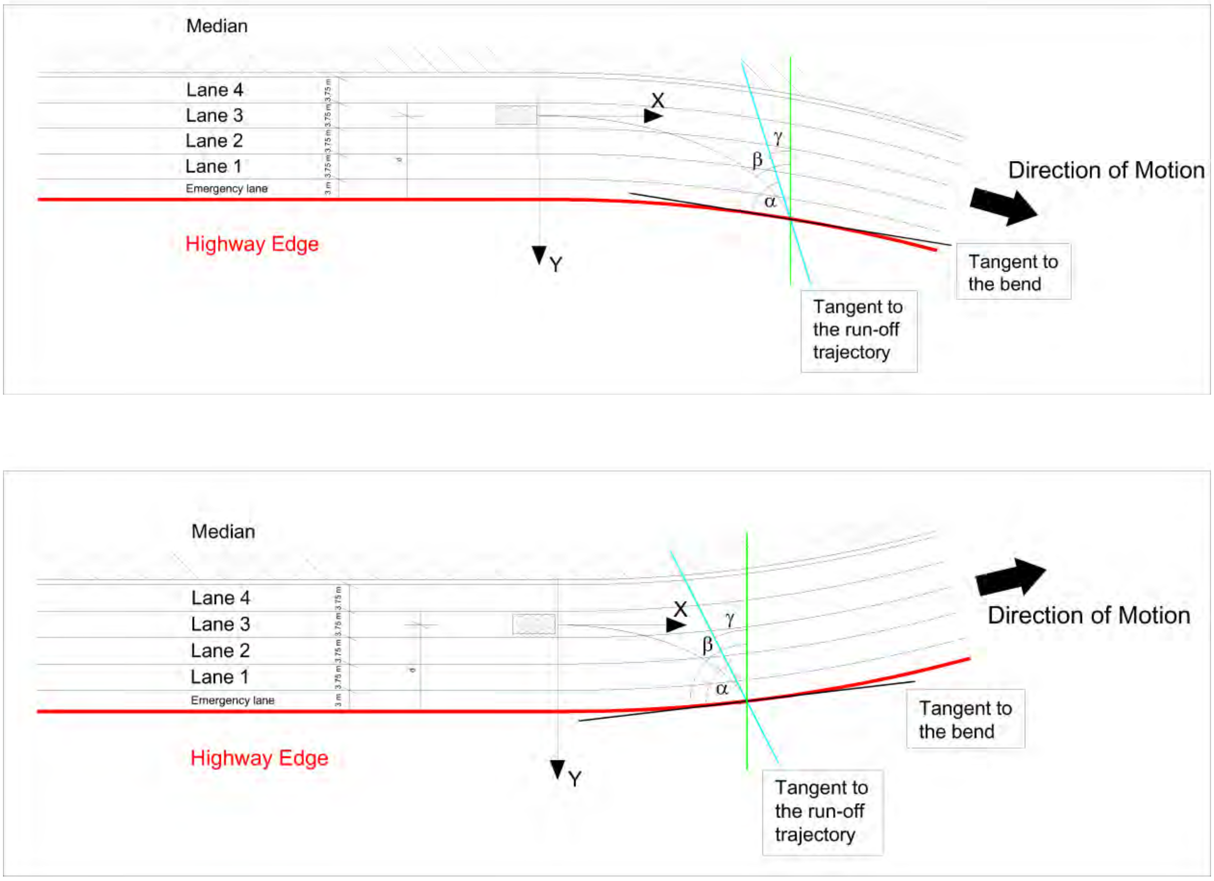

Figure 23: impact point and angle (γ) in bends

To completely define the runoff trajectory the curvature in the point where the trajectory diverges from the road alignment has to be defined. As is can be seen from Eq. 19 the most critical situation occurs when the *R(x=0)* value reaches its minimum (which leads to the maximum value of the runoff angle).

The limiting conditions for defining the *R(x=0)* value have been set considering that the maximum possible curvature (i.e. minimum radius) is limited by:
- the available friction over which the vehicle starts sliding (equilibrium of lateral forces);
- the roll-over of the vehicle (equilibrium of moments).

This can be therefore written as:

$$R(x=0) = \max \begin{Bmatrix} R_{\min\_slide} \\ R_{\min\_rollover} \end{Bmatrix} \qquad \text{Eq. 20}$$

where:

R_{min_slide} is the minimum radius over which the required side friction for the manoeuvre is higher than the available one;

$R_{min\_rollover}$ is the minimum radius over which the side force applied to the centre of gravity of the vehicle can cause a rollover.

The slide limiting radius can be calculated based on the side force equilibrium equation as:

$$R_{\min\_slide} = \frac{v^2}{g \cdot f_{t\_\max}} \quad \text{Eq. 21}$$

where:

v is the vehicle speed (in m/s);
g is the gravity acceleration (in m/s^2)
f_{t_max} is the maximum available side friction coefficient for the given motion conditions

The rollover limiting radius can be calculated based on the moment equilibrium equation as:

$$R_{\min\_rollover} = \frac{2 \cdot v^2 \cdot h_G}{g \cdot b_r} \quad \text{Eq. 22}$$

where:

h_G is the height of the centre of gravity of the considered vehicle
b_r is the width of the considered vehicle (distance between the wheels)

For the definition of the sliding limiting conditions the side friction values have been assumed according to Mak and Sicking, 1993 as:

- 0.6 for single unit trucks;
- 0.45 for tractor trailers.

These values have been adopted in the most recent studies on run of road crashes involving trucks (Ray and Carrigan, 2014, RSAP3, 2013).

Once the *R(x=0)*, and therefore the run-off trajectory, has been defined, the speed at the road edge can be estimated by considering the amount of energy which is dissipated between the time the driver loses control and when the vehicle reaches the roadway edge. The main assumptions are that the driver doesn't brake and that there are no impacts (which means that no major damages occur on the vehicle).

The different dissipation components (*dL*, in joules) which have been considered within a given space interval "*ds*, in meters" are:

- the energy dissipated by the contact forces between the tyre and the pavement (dL_f);
- the energy dissipated by the aerodynamic resistance (dL_a);
- the energy dissipated by the engine resistance (dL_m).

as indicated in the following equations.

$$dL_f = m \cdot \frac{v(s)^2}{R} \cdot \sin\left(\varphi\left(v(s)\right)\right) \cdot dS \quad \text{Eq. 23}$$

$$dL_a = \frac{1}{2} \cdot \rho \cdot C_x \cdot S \cdot v(s)^2 \cdot dS \quad \text{Eq. 24}$$

$$dL_m = k \cdot v(s) \cdot 3.6 \cdot m \cdot dS$$ Eq. 25

where:

- φ is the yaw angle which varies, during the runoff, due to the fact that both the speed and the radius of the curve reduce along the runoff trajectory. This is back-calculated from the friction Vs. yaw angle curve knowing the friction coefficient required for the side forces equilibrium in each location;
- m is the vehicle mass [kg];
- ρ is the air density in standard conditions [kg/m^3];
- C_x is the aerodynamic resistance coefficient;
- S is the surface of the section opposed to the vehicle motion [m^2];
- k is a factor which characterises the engine resistance that can be set in 0.007 for regular fuel passenger cars and 0.01 for diesel trucks.

The speed (v) at a given location (s_i) is defined as a function of the speed at the previous location ($s_{i-1}=s_i-ds$) by means of Eq. 26.

$$v(s_i) = \sqrt{\frac{2 \cdot \left(\left(\frac{1}{2} \cdot m \cdot v(s_{i-1})^2 \right) - dL_f - dL_a - dL_m \right)}{m}}$$ Eq. 26

The total energy dissipated between the point where the vehicle leaves the nominal trajectory and when it reaches the road edge (the length of which is defined as Sp) can therefore be estimated by means of Eq. 27.

$$L = \int_0^{Sp} \left(\left(m \cdot \frac{v(s)^2}{R} \cdot \sin(\varphi(v(s))) \right) + \left(\frac{1}{2} \cdot \rho \cdot C_x \cdot S \cdot v(s)^2 \right) + (k \cdot v(s) \cdot 3.6 \cdot m) \right) \cdot dS$$ Eq. 27

By means of this procedure the maximum impact conditions can be defined but this are typically much more severe than the real run off conditions and should be used only to define the upper impact conditions thresholds, of needed.

The current version of the US RSAP3.0 uses the passenger car distributions “cutting” the distributions to remove all the crashes that result in a crash angle above the stability conditions with a principle very similar to the one used in this procedure. The main difference is that in the SAVeRS procedure the actual speed distributions of the HGV and location in the carriageway (travelling lane) is considered based on the results of experimental monitoring of in service 2 and 3 lanes motorways.

In the SAVeRS tool the impact conditions calculated with the procedure shown above have been weighted for each vehicle type and departing lane, based on the run-off road impact angles distributions defined in the US RSAP3.0 programme, as described in 3.4. This allows to combine typical overall angle distributions with site specific speed, mass and departure lane data.

ANNEX 6 - SEVERITY DISTRIBUTION FUNCTIONS

The model implemented to define the base Severity Distribution Functions for contained crashes or for penetrated barriers in verges is the AASHTO Highway Safety Manual (HSM) freeway model which has recently been published as a supplement to the first edition of the HSM (AASHTO, 2014).

The structure of the SDF is as follows:

$$P_K = \frac{\exp\,(V_K)}{1.0 + \exp\,(V_K) + \exp\,(V_A) + \exp\,(V_B)}$$

$$P_A = \frac{\exp(V_A)}{1.0 + \exp(V_K) + \exp(V_A) + \exp(V_B)}$$

$$P_B = \frac{\exp\,(V_B)}{1.0 + \exp\,(V_K) + \exp\,(V_A) + \exp\,(V_B)}$$

$$P_C = 1pP_K - P_A - P_B$$

$$V_j = a_1 + (a_2 \cdot P_{hv}) + (a_3 \cdot P_r) + (a_4 \cdot P_c) + (a_5 \cdot W) + (a_6 \cdot P_b)$$

Where:

P_{hv} is the proportion of AADT during hours where volume exceeds 1,000 veh/h/ln;

P_r is the proportion of segment length with rumble strips present on the shoulder adjacent to the barrier analysed;

P_c is the proportion of the segment in a curve;

P_b represents the presence of a barrier (1 if a barrier is present 0 if a barrier is absent);

W is the lane width (in m).

and the a_1, a_2, a_3, a_4 and a_5 coefficients are given below.

	a_1	a_2	a_3	a_4	a_5	a_6
Fatal (K)	0.321	-0.924	0.387	0.208	-0.859	-0.388
Incapacitating injury (A)	-1.963	-0.853	0.391	0.243	0	-0.325
Non incapacitating injury (B)	0.2812	-0.872	0.135	0.131	-0.239	-0.250

For the SAVeRS base conditions:

P_{hv} = 0

P_r = 0 (no rumble strips)

P_c = 0 (straight segment)

W = 3.50 m - 3.75 m (average of 3.675 m)

the following results are obtained:

	% of fatal + injury crashes (with barrier)	% of fatal + injury crashes (without barrier)
Fatal (K)	2.6%	3.5%
Incapacitating injury (A)	6.4%	8.0%
Non incapacitating injury (B)	27.5%	31.7%
Possible Injury (C)	63.5%	56.8%
K/(K+A) ratio	*0.29*	*0.3*

In the SAVeRS tool the configuration “with a barrier” is considered as representative of a condition where the vehicle is potentially contained (IKE ≤ VRSCL) with a “reference” H1 barrier (different VRS class will be considered by means of the scaling factor defined in section 3.5) while the condition “without a barrier” is considered to be representative of a barrier penetration without a specific hazard. If the barrier shields a high risk hazard a correct factor is considered as discussed in section 3.5.