Guide for the Assessment of Treatment Effectiveness

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IRDES

Guide for the Assessment of Treatment Effectiveness

Deliverable Nr 2

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Executive summary

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded research programme “ENR SRO1 – Safety at the Heart of Road Design”. Each year around 35,000 persons are fatally injured in Europe due to road accidents. The fatality rate in single vehicle run-of-road accident is around 45%. One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”.

The aim of this deliverable is to presents the results of Work Package 2, which include four studies on different approaches to analyse the effectiveness of identified treatments which are variation of shoulder width; removal of barrier terminals; implementation of grooved rumble strips and treatments in curves. The report focuses on the methodologies rather than on the result of the studies.

To assess the effectiveness of shoulder width extension a tool designed to analyse vehicle speeds and trajectories was evaluated. The tool, named OT (Observatory of Trajectories), enables to measure vehicle movements. Due to delays in the modifications of the road, only measurement before the modifications could be conducted and analysed. Some issues regarding the amount of data collected were found and modifications to the method are needed.

In the study assessing the safety effects of removing unprotected barriers terminals on secondary rural roads the development of a Crash Modification Factor was derived. The method is based on cross sectional analysis of part of the Arezzo Prince road network in Italy. The procedure proposed could be applied to the evaluation of different roadside features.

To assess the effectiveness of the implementation of grooved rumble strips on dual carriageways comparisons between treated and non-treated roads were evaluated by statistical methods. Accident data including all severities in single vehicle accidents from several years with and without treatment was used in the analysis. The results showed that the estimated treatment effect is a 27.2% reduction of the accident intensity rate for single vehicle accidents.

The assessment of the effectiveness of treatments in curves was evaluated by using Vehicle-Infrastructure-Interaction Simulations (VIIS) based on measured road infrastructure parameters. Case studies of two accident spots in curves were selected and simulated with different safety treatments and parameter values (sensitivity analyses).

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Abbreviations

Abbreviation	**Definition**
AADT	Annual average daily traffic
AASHTO	American Association of State and Highway Transportation Officials
ADT	Average Daily Traffic
AIS	Abbreviated Injury Scale
ASI	Acceleration Severity Index
CEDR	Conference of European Directors of Roads or Conférence Européenne des Directeurs des Routes
EES	Energy Equivalent Speed
ERA-NET	European Research Area Network
HIC	Head Injury Criterion
HSM	Highway Safety Manual
IRDES	Improving Roadside Design to Forgive Human Errors
MAIS	Maximum Abbreviated Injury Scale
NCHRP	National Cooperative Highway Research Programme
OT	Observatory of Trajectories
PTW	Powered Two-Wheeler
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run-off-road
RVS	Richtlinien und Vorschriften für das Straßenwesen
SAVe	System of Analysis of Vehicles
SVA	Single vehicle accident
TG	Technical Group
TRB	Transportation Research Board

1 Introduction

IRDES (Improving Roadside Design to Forgive Human Errors) is a research project of the cross-border funded research programme “ENR SRO1 – Safety at the Heart of Road Design”, which is a trans-national joint research programme that was initiated by “ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” (ENR), a Coordination Action in the 6th Framework Programme of the EC. The funding partners of this research programme are the National Road Administrations (NRA) of Austria, Belgium, Finland, Hungary, Germany, Ireland, Netherlands, Norway, Slovenia, Sweden and United Kingdom.

Each year around 35,000 persons are fatally injured in Europe due to road accidents. The RISER project has shown that even though 10 percent of all accidents are single vehicle accidents (typically run-off-road (ROR) accidents) the rate of these events increases to 45 percent considering only fatal accidents (see [1]). One of the key issues of this high ROR fatality rate is to be found in the design of the roadsides that are often “unforgiving”. CEDR has identified the design of forgiving roads as one of the top priorities within the Strategic Work Plan. For this reason, a specific Team dealing with Forgiving Roadsides has been established within the Technical Group (TG) on Road Safety of CEDR.

1.1 Aim of the IRDES project

The aim of the IRDES project is to:

- Deliver a report which summarise the state-of-the-art treatments to make roadsides forgiving, as well as to harmonise currently applied standards and guidelines.
- Conduct and present the results from a survey, circulated among European Road Administrations, concerning the safety interventions used to improve roadside design and their estimated effectiveness.
- Deliver a report for assessing (in a quantitative manner) the effectiveness of applying a given roadside treatment (identified in the project).
- Deliver a practical and uniform guideline that allows the road designer to improve the forgivingness of the roadside.
- Arrange and report on two workshops including stakeholders to discuss the outcome of the project.

1.2 Aim of this deliverable (D2)

The aim of this deliverable is to presents the results of Work Package 2, which include four studies on different approaches to analyse the effectiveness of identified treatments. The treatments identified by the project are:

- Variation of shoulder width
- Removal of barrier terminals
- Rumble strip (grooved rumble strip in the shoulder, outside the edge line i.e. no painted lines)
- Treatments in curves (using vehicle-infrastructure-interaction simulation)

2 IRDES nomenclature

2.1 Definition of road side

According to the RISER project [1], a roadside is defined as the area beyond the edge line of the carriageway. There are different views in literature on which road elements are part of the roadside or not. In this report, the median is considered as roadside, since it defines the area between a divided roadway. Therefore, all elements located on the median are considered as roadside elements as well. Figure 1 depicts a roadway cross section (cut and embankment section) including some roadside elements. In this specific figure, the roadside can be seen as the area beyond the driving lanes (or carriageway). The shoulders are thus part of the roadside, since the lane markings define the boundaries.

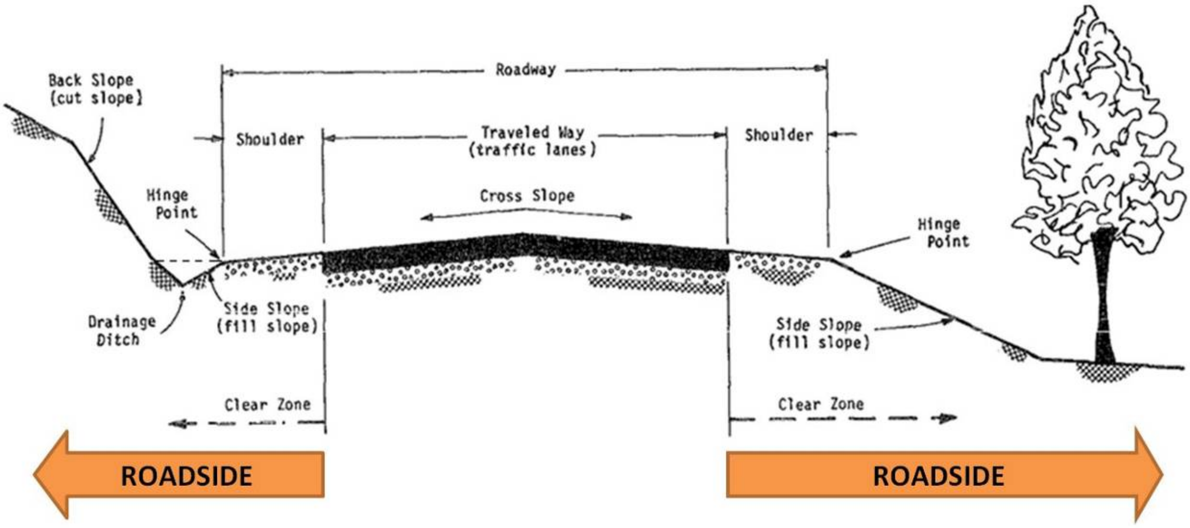


Figure 1. Roadway cross section with examples for roadsides with clear zones [2].

2.2 Forgiving vs. self-explaining roads

Forgiving and self-explaining roads are two different concepts of road design, which aim at reducing the number of accidents on the whole road network. The project IRDES and therefore this report only deals with forgiving roadsides. However, the term "self-explaining" needs to be defined in order to differentiate it from the term "forgiving".

According to [3], self-explaining roads are based on the idea that appropriate speed or driving behaviour can be induced by the road layout itself. They therefore reduce the need for speed limits or warning signs. It is generally known that multiple road signs in complex traffic situations can lead to an information overload and an increasing risk of driving errors. Herrstedt [4] writes that a safe infrastructure depends on a road-user-adapted design of different road elements such as markings, signs, geometry, equipment, lighting, road surface, management of traffic and speed, traffic laws etc. The idea behind self-explaining roads is to design the road according to an optimal combination of these road elements.

In short, self-explaining roads aim at preventing driving errors, while forgiving roads minimize their consequences. The first priority of forgiving roadsides is to reduce the consequences of an accident caused by contributing factors in the human, vehicle or road domain. It must be focused on treatments to bring errant vehicles back onto the lane to reduce injury or fatal run-off-accidents. If the vehicle still collides with a road element, the second priority is to reduce the severity of the crash.

3 Effectiveness of shoulder width extension

3.1 Introduction

In the framework of the IRDES project, a tool designed to analyse vehicle speeds and trajectories was evaluated. This tool, named OT (Observatory of Trajectories), enables to measure vehicle movements.

In order to test the tool, the technical research centre CETE NC identified an interesting road where shoulders are planned to be improved, in terms of broader width. The modifications to be assessed (before/after) consist in managing the road area by reducing the lane width and widen the paved shoulders at the same time. The results of the experiment should not only allow assessing the efficiency of the OT tool, but it should also provide information on the effects of the new design on driving behaviours.

3.2 Methodology

3.2.1 Measurement data unit

Vehicle type

The OT tool enables to segregate different road users. Even if it cannot measure powered two-wheelers, it can identify distinguish between cars and trucks. Thus, this tool is able to define some driving characteristics according to the road users.

Lateral position (from central road marking)

The lateral positioning of the vehicle is given in metres. The result represents the difference between the lateral centre of the measured vehicle and the centre of the carriageway. It has to be noticed that the lateral positioning of vehicles is analysed on a distance from 20 to 25 metres. It is possible to determine an average positioning over these 20-25 metres.

Speed

As for lateral positioning, speed is measured on a distance from 20 to 25 metres. It is given in metres per second [m/s].

Accurate datation

The data collection system allows combining several types of sensors, depending on the site to be studied. In order to « merge » all the data provided by the different sensors, it is necessary to set the same time basis.

In the present study, the two sensors that are used are a scanning laser range finder and radar. The time difference between these two sensors is estimated by a few milliseconds, which is acceptable for further data processing.

Binary information about the interaction with meeting vehicles

Among the first objectives defined in the protocol, there is the assessment of the influence of meeting vehicles on the opposite lane.

Through speed and lateral positioning measurements, the OT can differentiate between situations when vehicles are approached by another vehicle in the opposite lane or not.

3.2.2 Aggregate data

Average speed and lateral position on the measurement field of view for every type of vehicle by each hour of each day

The OT store speed and lateral positioning of each vehicle on a distance of about 25 metres on several positions of the trajectory. The average speed and average lateral positioning of each vehicle on the trajectory is calculated, as well as the maximum speed of each vehicle on the trajectory. The observation is carried out on a straight line and therefore the average speed and maximum speed do not differ much.

Identification of "free" vehicles (time space greater than 5 s between two vehicles)

In the present study, only free light vehicles are measured. A vehicle is « free » when its trajectory is not troubled with preceding vehicles. A vehicle is free when it can reach the desired speed because the nearest vehicle is too far to constrain it. The first interest of this discrimination is to enable behaviour analysis in relation with road infrastructure and external conditions independent from traffic values. The criterion used is the Inter Vehicle Time (TIV). The threshold selected to qualify free vehicles is 5 seconds.

Identification of vehicles crossing the central road marking

Previously explained, the OT enables to calculate average lateral position from central road marking, and if the vehicle cross the median line. These results are analysed in order to assess the impact of the trajectories when approaching vehicles are in the opposite lane.

Identification of vehicles which speed is 20km/h above posted speed limit

In addition to the parameters described above, we calculate the percentage of vehicles which are over legal speed and also the percentage of vehicles which are 20 km/h over posted speed.

3.2.3 Description of the OT measurement systems

The OT is composed of two tools: a multi-sensor acquisition tool and data processing software to follow moving objects.

Acquisition tool

For this study the acquisition tool included a scanning laser range finder and radar. A data acquisition centre automatically recorded 30s of data every 1.5 minute.

Software

The software called SAVe (System of Analysis of Vehicles) provides several algorithms to follow moving objects in video cameras and range finders.

In special zones which can be defined in the road scenery measurements, the software calculates for every image the most probable position of each moving object.

3.2.4 A roadside improvement analysis

Description of the design

The selected design consists in managing the road space by both reducing the lane width and providing wider paved shoulders (see Figure 2 and Figure 3).

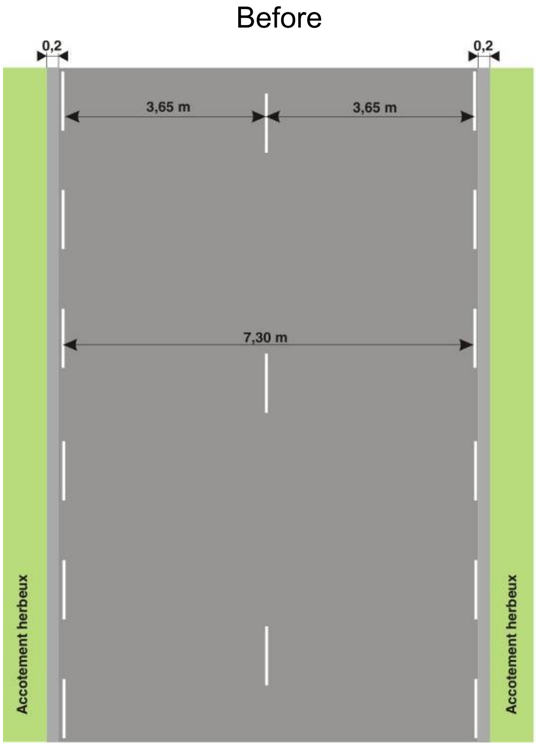


Figure 2. Before situation;
- 7,30 m-wide carriageway
- 0,20 m-wide hard strip

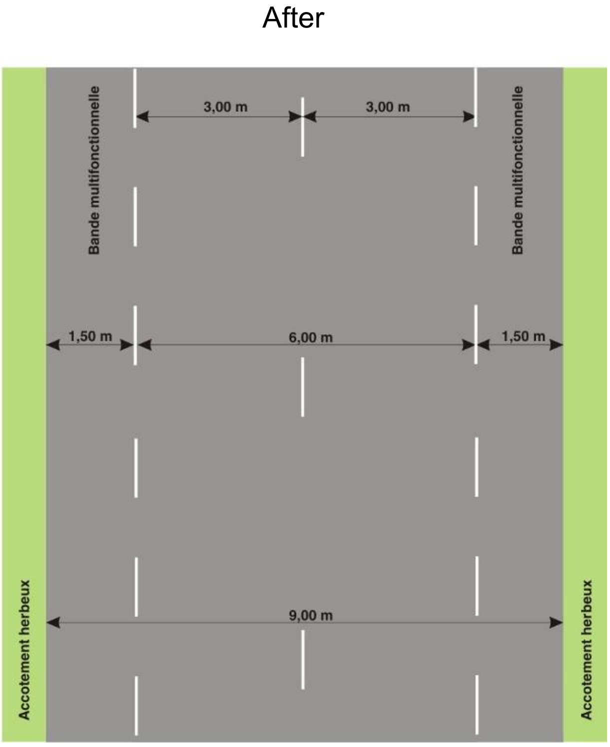


Figure 3. After situation;
- Lane width is reduced from 3,60 to 3m
- Usable roadway enlarged on both sides
- Provision of 1,50m-wide paved shoulders

In order to know the effects that could be expected from this new design, a literature review has been carried to find the impacts on accident rate, speeds and lateral positioning [5]...[12].

The literature review shows that reorganising spaces with the provision of wider paved shoulders is a complex phenomenon and does not permit to conclude on the effectiveness of a reduced lane width and wider paved shoulders. Most of the studies are limited to the effect of a reduced lane width, or a wider shoulder, but not both.

Nevertheless, it is possible to assume some elements about this design:

- **Slight decrease in the accident rate** after the implementation of the design
- **No significant effects on speeds**
- **Observed effect on lateral positioning**, moving more towards the centre of the lane during daylight.

Description of the study site

The design takes place in the South-East of Caen on the Departmental Road RD16, between Saint-Pierre-sur-Dives and Crève coeur-sur-Auge, on a 9 km road segment. The construction period was February to June 2011.

The tool was installed on the straight line and on the shoulder of the lane opposite the vehicles observed (see Figure 4).

Figure 4. Installation of the OT tool

3.3 Results of the roadside design changes

3.3.1 Results before works

Measurements before the road works were carried out in May 2010, for one week

Among the analysed vehicles (3415 on the straight line), it has been necessary to remove several measures, in particular these where there were doubts on the measurement quality.

In addition, vehicles which were not free (following another vehicle) have been removed from the analysis because their speed and lateral positioning could have influenced by the preceding vehicles.

Some recordings in the before situation were made for 30 seconds every 1.5 minute, it has been necessary to remove the first vehicle of each sequence of 30 seconds, in order to be sure it was not a vehicle troubled by others.

The exploitable sample consists of 260 vehicles of which 231 light vehicles (cars) and 29 heavy goods vehicles (trucks).

Results about speed:

Results about speed on the straight line are shown in Figure 5. The posted speed limit is 90 km/h on the studied road segment.

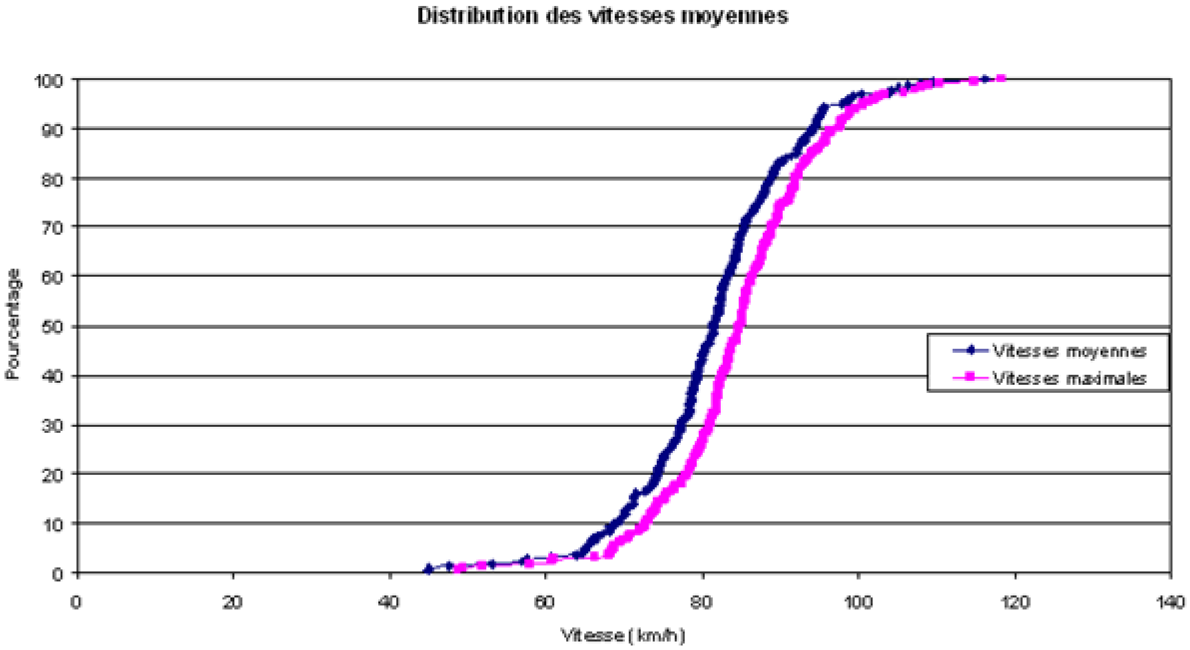


Figure 5. Measured average speed distribution. In blue line, the mean speed distribution and in pink line, the maximum speed distribution

The document shows that the V15 (with regard to average speeds) is of 92 km/h, whereas the V15 (with regard to maximum speeds) is of 94 km/h.

In this stage, it is difficult to interpret the data before the after situation has been analysed.

In the frame of speed analysis, the situation where another vehicle was approaching in the opposite lane could not be analysed because of too few situations were recorded (nine). This point should be improved in the after situation.

Further analysis of the speed function separated in day-time and night-time periods could not be performed due to low number of vehicles during night. The problem with low number of vehicles during night is neither due to sensor field of view nor visibility but due to low traffic volume. Again, the optimisation of the tool in the after period should enable to get this data.

Results about lateral positioning:

Readings of the lateral positioning of vehicles is shown in the Figure 6.The vehicle positioning is given in metres. It represents the difference between the lateral centre of the measured car and the centre of the median road marking. Each point, shown in the graph, is the representation of the average deviation of vehicles on the whole trajectories on 20-25 metres.

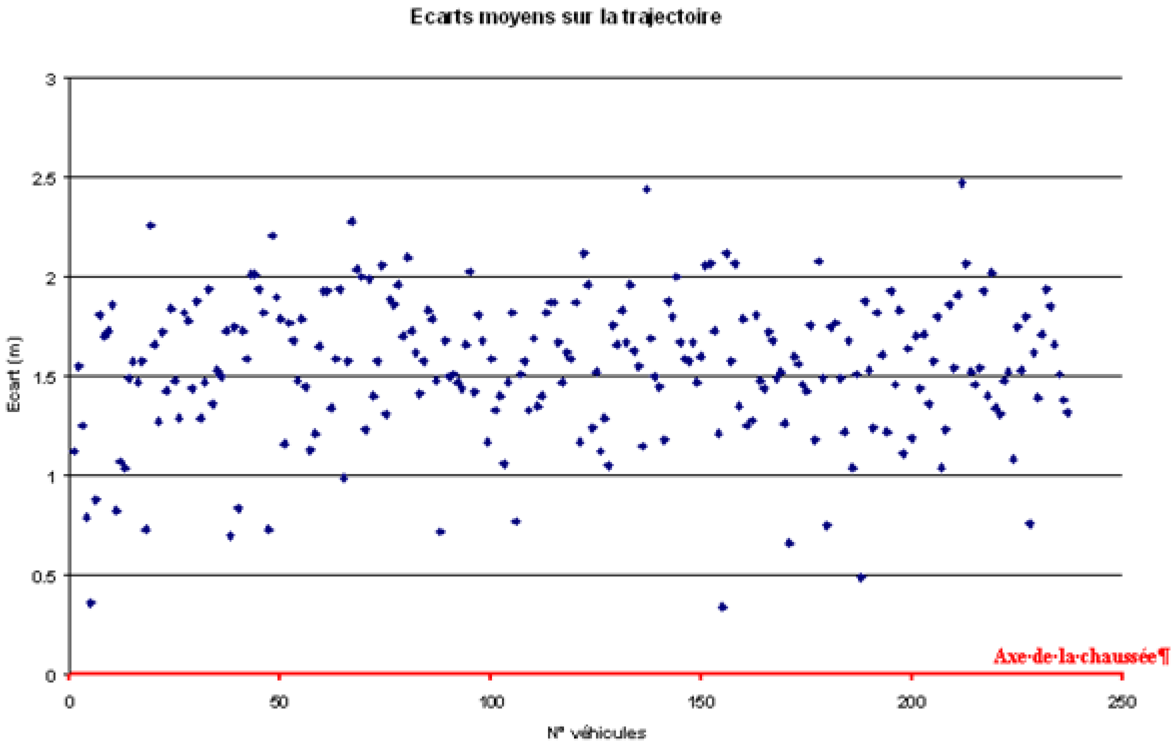


Figure 6. Lateral positioning from axial road markings

In general, the lateral centre of the vehicle is in a range of 1 to 2 metres from the central road marking, in particular in the range 1.5 to 2 metres.

Given that the average width of a vehicle (distance between external parts of tyres) is 1.80 metres (example of Renault Mégane), most of the vehicles travel at a distance between 0.5 to 1 metre from the edge of the central road marking.

The analyses show that there are 15 measures out of 260 (5.7%) where the vehicle crossed the median line, due to an (normal) overtaking manoeuvre on a straight road section.

Similar to the speed analysis, it was not possible to segregate lateral positioning by day and by night, because of the low number of vehicles registered by night.

3.3.2 Results after works

Due to delays in the modifications of the road the after analysis has not been performed.

Conclusion of the evaluation

Before the publication of the after situation results, it is however possible to draw some conclusion about this experiment in the before situation:

- the number of measured vehicles is insufficient. Due to the low number of measurements of free vehicles, it was not possible to analyse all parameters as required (e.g. the situation where another vehicle was approaching in the opposite lane). The system can calculate the width and the length of each vehicle so the lateral position is the distance between the left part of the vehicle and the median marking.
- the percentage of removed data are higher for trucks than for cars.

- the use of the OT tool enabled to get reliable data as far as speed and lateral positioning are concerned.

To improve the second analysis, the four experience feedbacks are:

- Increase the recording time to have more free vehicles tracked (2 minutes instead of 30 seconds).
- Measurement of the central marking in the rangefinder referential to improve accurate calibration.
- Use of 2 rangefinders at 2 different heights. One for the car measurement and the other for the heavy goods vehicle because their wheels are bigger.
- Need two weeks of recordings to be sure to have enough information.

4 Safety effects of removing unprotected barriers terminals on secondary rural roads

4.1 Introduction

Road barriers terminations, usually called “terminals”, are commonly recognized as an important roadside safety hazard but currently there is no quantitative manner to estimate the safety effects of removing them.

In the NCHRP Report 4090 “In-service performance of safety barriers” several studies concerning barriers terminals have been analysed but it resulted that they are essentially devoted are understanding how the specific terminal is working and not at quantifying the effect of modifying the terminal configuration [13].

In the recently published “Highway Safety Manual” the Roadside Hazard Rating doesn’t account for the terminals configuration [14].

One of the reasons is that crashes against terminals are rare event and a typical “before/after” analysis cannot be performed in these cases.

The aim of this part of the project was the development of a Crash Modification Factor for the effect of having unprotected Terminals on secondary rural roads based on the cross sectional analysis of part of the Arezzo Prince road network in Italy. It should be noted that the procedure proposed could be applied also to the evaluation of different roadside features.

4.2 Methodology

4.2.1 The procedure implemented

To evaluate the effect of a given road feature two different approaches are typically used:

- The development of a Safety Performance Functions (SPF) which allows directly to compare two alternative road configurations which differ only in terms of the given configuration. The limitation of this approach is that it should be applied only to networks with characteristics comparable with those of the network used for developing the SPF applied. In addition a Safety Performance Function can combine the effect of different variables which are not independent leading to wrong assumptions on the effect of the given variable;
- To overcome this problem a new approach has been developed by Harwood et al. [15] and has been adopted in the recently published Highway Safety Manual [14]. This approach includes a “base” model (that is a SPF base on a limited number of variables, typically length and traffic, that allows for the estimation of the expected number of crashes in “standard” or “base” conditions) and one or more multiplying factors called “Crash Modification Factors” (CMFs) that account for the effect of differences between the analysed section and the “base” conditions. The basic form of the safety prediction model, in this case, is:

$$E[N] = E[N]_b \times CMF_1 \times CMF_2 \times \cdots\cdots\cdots \times CMF_n$$

With:

$E[N]$ = expected crash frequency, crashes/yr;
$E[N]_b$ = expected base crash frequency, crashes/yr; and

CMF_i = crash modification factor for the generic feature i (i = 1, 2, ..., n).

Each CMF represents the ratio N_w/N_{w_o} where, N_w represents the number of crashes expected in segment *with* one or more specified geometric design elements or traffic control devices, and $N_{w/o}$ represents the expected number of crashes that would be experienced *without* the specified feature. A CMF can be a constant or a function that represents the change in safety following a specific change in the design or operation of a segment.

The direct evaluation of a CMF for a given features requires either:

- To implement a specific intervention in a given section aimed at modifying the analysed treatment;
- To compare two sections that have all the same attributes with the only exception of the analysed feature.

In most databases, as in the one analysed in the IRDES project, the only way to have sections with identical attributes is to make them extremely small but this leads to have often sections with no accidents, as shown earlier. If longer sections are considered there are usually relatively few pairs of sections, if any, that have all identical attributes with the exception that the analysed one. And this is true also for the number of unprotected terminals, which is the aim of this investigation.

To overcome the aforementioned limitation a procedure has been proposed by Bonneson and Pratt [16] that uses a multivariate regression model to estimate the expected crash frequency for one segment of each pair, as may be influenced by its attributes. This estimate is then refined using the empirical Bayes (EB) technique developed by Hauer [17] to include information about the reported crash frequency for the segment. The segment for which the expected crash frequency is estimated is referred to as the “before” segment.

The second segment of each pair is considered to be the “after” segment. Its reported crash frequency is compared with the Empirical-Bayes (EB) estimate for the “before” segment during CMF calibration. The CMF is therefore given by:

$$CMF_i = \frac{E[N]_2}{E[N]_1}$$

Where 1 and 2 are the segments that have all the attributes equal with the only exception of the one for which the CMF is estimated. This type of procedure solves the problem of comparing sections with “zero” crashes but still needs to have sections with the same attributes.

In the IRDES project this procedure has been slightly adjusted to account for the fact that two sections of the pair are not “identical” in terms of attributes but also in terms of length and therefore there might be a difference even in other features and not only in the analysed one and these difference could lead to a wrong estimation of the CMF. In this case the CMF equation becomes:

$$CMF_i = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p\_1}(\text{var}\, i = base)}{N_{p\_2}(\text{var}\, i = base)}$$

Where $N_{p\_1}(\text{var } i = \text{base})$ and $N_{p\_2}(\text{var } i = \text{base})$ are the number of crashes predicted for the two sections by using the safety performance function with the specific feature to be analysed set to the base value instead than to the specific value registered in the section. In the specific case of the estimation of the effect of unprotected terminals this would mean no unprotected terminals in both sections.

This modification also accounts for the difference in length between the two sections in the pair as this will affect in the same manner both the $E[N]_i$ and the $N_{p\text{-}i}$ values:

$$CMF_i = \frac{\dfrac{E[N]_2}{L_2}}{\dfrac{E[N]_1}{L_1}} \times \frac{\dfrac{N_{p\_1}(\mathrm{var}\, i = base)}{L_1}}{\dfrac{N_{p\_2}(\mathrm{var}\, i = base)}{L_2}} = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p\_1}(\mathrm{var}\, i = base)}{N_{p\_2}(\mathrm{var}\, i = base)}$$

To allow for the development of the CMF prediction model a number of activities have to be conducted that can be summarized as follows:

- Step 1: Identification of the sections to be analysed;
- Step 2: Survey of the roadside features;
- Step 3: Segmentation and Identification of homogeneous section;
- Step 4: Accident Data Collection;
- Step 5: Accident analysis (development of the safety performance function and estimation of the unprotected terminals CMF).

Each step will be described in details in the following sections.

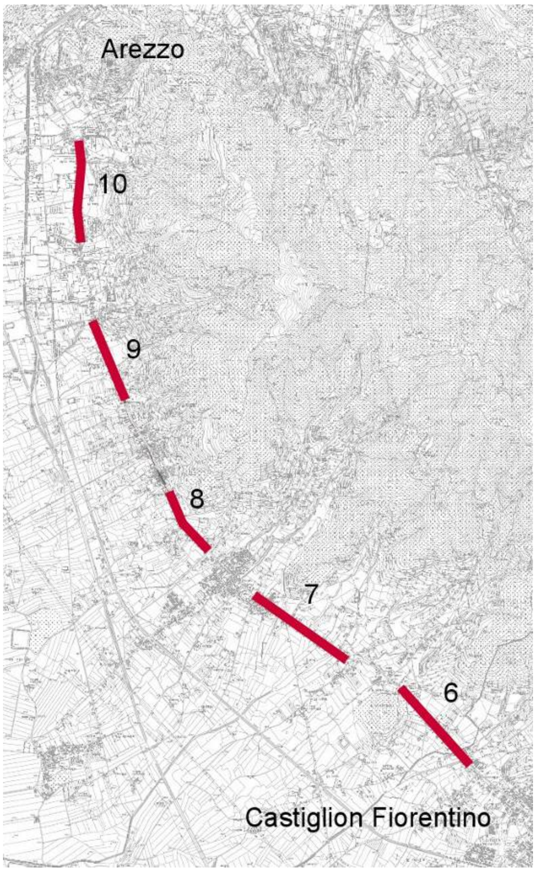
4.2.2 Identification of the sections to be analysed

The road network used for the analysis is a typical rural provincial network with a single carriageway with 2 lanes bidirectional managed by the Arezzo Province. The overall length of the network considered for the analysis is 90 km 50% of which are within urban areas or mountain roads and have been therefore excluded from the analysis. Within the timeframe of the IRDES project only part of this length could be covered by the fully roadside survey for a total length of 24 km divided in 7 consecutive stretches as shown in Table 1 and in Figure 7.

Out of the 24 km surveyed 3 km had to be excluded from the accident analysis as during the observation period (2001-2008) major infrastructural interventions have been conducted in the analysed sections. The final dataset is therefore referred to 21 km of secondary single carriageway rural roads.

Table 1. Provincial road stretches analysed

Stretch number	*From*	*To*	*Municipalities interested*	*Stretch length (km)*
T1	Catiglion Fiorentino	Vitiano	Castiglion Fiorentino Arezzo	1.0
T2	Ghetto	Rigutino	Arezzo	0.8
T3	Rigutino	Policiano	Arezzo	0.6
T4	Policiano	Il Matto	Arezzo	1.8
T5	Il Matto	Olmo	Arezzo	1.4
T6	Case Nuove di Ceciliano	Subbiano	Arezzo Capolona Subbiano	10.3
T7	Subbiano	Rassina	Subbiano Castel Focognano	8.2
			TOTAL	24.1



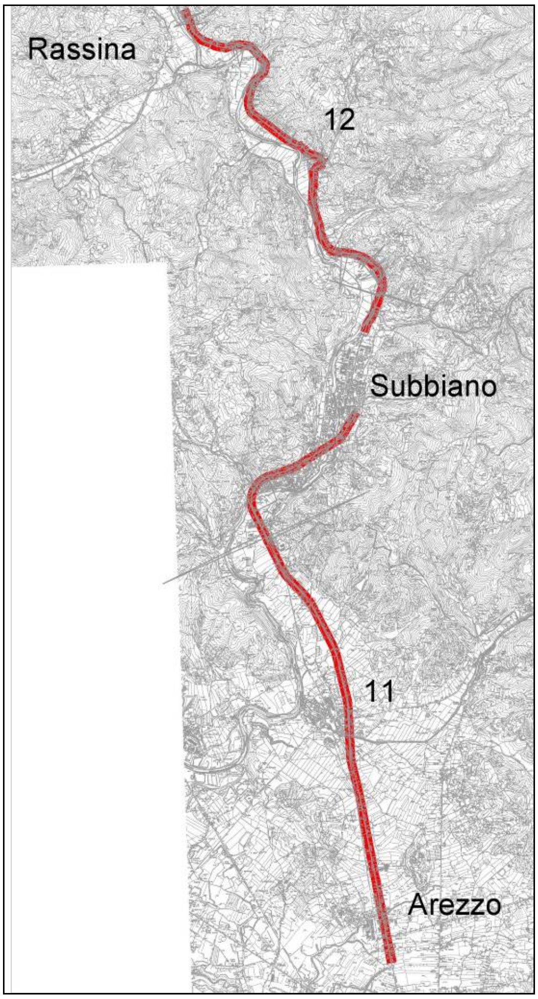


Figure 7. Provincial road stretches analysed South of Arezzo (left) and North of Arezzo (right)

4.2.3 Survey of the roadside features

As far as the official road inventory of the Arezzo Province doesn't contain information regarding the roadside configuration, the first step of the analysis has been to establish a procedure for the classification of the roadside features and the actual survey on part of the provincial road network.

The roadside feature that have been identified as potentially relevant for the safety assessment are listed in Table 2 while in Annex A the full survey check list has been included.

Table 2. Roadside features surveyed on site

Roadside element	*Required measure*
Shoulders	Width/Type
Banks	Width
Safety barriers	Type /Length
Safety barrier terminals	Type
Ditch	Width
Driveways	Type
Obstacles	Type – distance from horizontal marking
Lay-bys	Type - Width – Length

The survey of the different roadside features has been extended to any object within a range of 7 metres from the horizontal marking.

The linear features (shoulders, banks and ditches) are measured at constant intervals and at every section where they change in a visible manner (Figure 8). The safety barriers and the terminals are classified according to the coding given in the survey check list shown in Annex A. The terminals are recorded only if they are exposed to the traffic of the analysed road segment (Figure 9, left) which means that if the barriers bends in the driveway and the terminal is on the driveway this will not be included (Figure 9, right).

As far as in the analysed network there are no flared terminals or absorbing terminals tested according to ENV 1317-4 [18] this are not included in the check list coding. If these type of terminals are present a new coding have to be added for each type.

Lay-bys are areas parallel to the carriageway limited in longitudinal extension where the vehicle can stop without disturbing the traffic on the roadway and can be either paved or unpaved (Figure 10).

In addition to the specific roadside features the locations of the gas stations (Figure 11) and of the driveways have been identified as these are relevant variables for accident analysis. In Italian rural roads Gas Stations have a direct access from the main roadway and drivers pull in and out increasing the conflict points as in an intersection and the accidents tend to increase.

Figure 8. Survey of linear features

Figure 9. Type "a" barrier terminal (left) and barrier curved in the driveway that is not considered as un "unprotected" terminal (right).

Figure 10. Different type of lay-bys (unpaved, left – paved, right).

Figure 11. Gas station.

4.2.4 Segmentation and Identification of homogeneous section

One of the key issues in any accident analysis it the road segmentation aimed at identifying sections which can be considered “homogenous” with respect to the different variables analysed.

In defining when a section can be considered as “homogenous” the following parameters have been considered:

1) Horizontal layout (linear or transition/bend);
2) Roadside configuration: *embankment, cut, at grade, bridge or tunnel*;
3) Shoulder width;
4) Lane width;
5) Bank width;
6) Ditch width.

with a minimum length of 100 m.

The variation in the longitudinal grade has not been considered as a variable for road segmentation as this information was not available and couldn’t be collected directly on site.

An additional element required to identify homogeneous section is the location of intersections. Before and after the intersection are considered as two different locations. Minor intersections with very limited traffic on the secondary road are considered as driveways and do not change the homogenous section.

As far as several variables are continuous the following classifications have been adopted to identify where a variable can be considered as “constant” within a section.

Shoulder width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm

Embankment width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm

Ditch width

a. 0 cm – 60 cm
b. 61 cm – 120 cm
c. 121 cm – 180 cm
d. 181 cm – 240 cm
e. 241 cm – 300 cm

The direct application of the procedure lead to 235 sections within the 24.1 km, 173 of which turned had a length below the minimum of 100 m. This length is already shorter than the minimum assumed by the Highway Safety Manual [14] for the same type of application (0.1 mile = 160 m) and further reduction in length was not considered as acceptable. In addition a considerable amount of sections (145 of 235) resulted in “zero” accidents over the analysis period and this would lead to statistical problems in developing the accident prediction model.

Different segmentation procedures have then been considered:

A. Considering as triggering variables only the ones considered by the HSM which are the shoulder width, the lane width, the horizontal layout and the overall roadside configuration defined by means of the Roadside Hazard Rating (RHR) considered by the HSM as the only parameter characterising the roadside ;

B. Considering sections approximately 1 km centred on the kilometre post. The actual section length varies between 0.5 and 1.4 km due to the fact that the sections had to be trimmed in entering an urban area and at any intersection.

Figure 12 shows the two different segmentation procedures applied at the same road stretch.

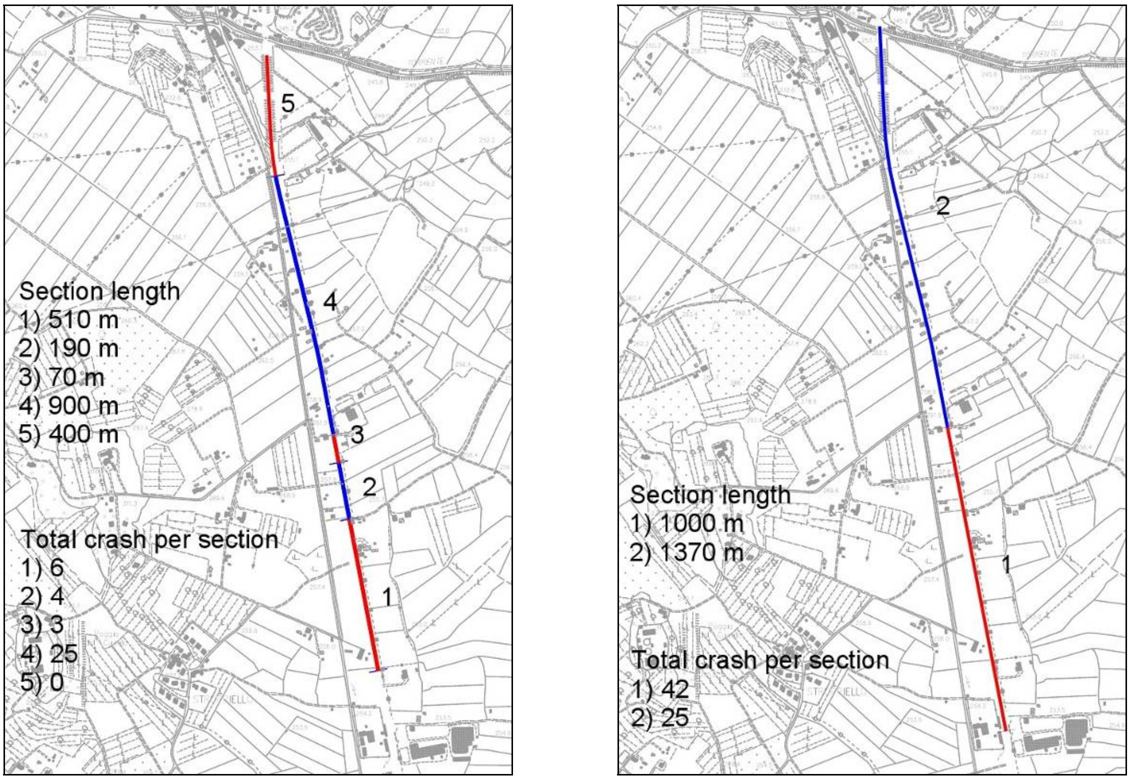


Figure 12. Segmentation by procedure A (left) and B (right).

The application of the procedure “A” lead to the analysed road network resulted in 50 sections with only 14 having a length of less than 100 m and with an average length of 280 m. In this case 28% of the sections still have “zero” accidents in the period of observation (2001-2008). In addition the localization of the accident was often given at the kilometre post and not at the metre (see § 4.2.5) which lead to excluding from the analysis 32% of the accident data.

The second procedure resulted in 23 sections, all longer than 100 m, with an average length of 790 m and with no section characterized by “zero” accidents.

In each section all the observed variables have be coded according to the following criteria:

OD = Object Density (number of obstacles/km)
AD = Average Obstacle Distance (m)
DD = Driveways Density (number of driveways/km)
UT = number of Unprotected barrier Terminals/km
LAY = number of Laybays/km
SW = Weighted Average of the Shoulder Width (m)
BG = Weighted Average of the Bank or Gutter width (m)
LW = Weighted Average of the Lane Width (m)
CURV = Average Curvature (m^{-1})
GS = binary variable (0-1) indicating if there is a gas station in the section

The traffic volume of the different road stretches, in terms of Annual Average Daily Traffic averaged over the period of observation, has also been obtained by the road administration and each section is therefore characterized also with this parameter.

For the parameters that are not constant in the “type B” segmentation procedure a weighted average has been applied considering the length as the weight for each “subsection” where the parameters remain constant.

4.2.5 Accident Data Collection

Accident data have been provided directly from the Arezzo Province and list all the events occurred on the S.R. 71 in the years 2001-2008. Two databases are available: the internal Province database and the database of the Integrated Regional Road Safety System (SIRSS).

In analyzing the data the following problems occurred:

1) A relevant part of the data in the SIRSS database doesn’t have the location of the accident on the road;
2) When the location is given this is given rounded to the nearest kilometre post, in accordance with the standard adopted by the Italian National Statistic Institute (ISTAT). This means that these set of data cannot be used to allocate the data in the type “a” segmentation (short but more homogeneous sections). The Province database, on the other hand, as a much more accurate accident location rounded at the metre. It should be noted, anyhow, that even in this case, a concentration of accidents seems to occur at the rounded kilometre distance which likely means that often the accident report doesn’t actually locate the accident but provides the nearest kilometre milepost.

Given the problems with the accident location listed above it was decided to conduct the accident analysis:

- With the type “b” segmentation;
- Combining the two accident databases to locate as many events as possible.

Given the fact that roadside safety features affect more the severity of the event than the occurrence it was decided to limit the analysis to injury and fatal accident (excluding the property damage only events which are also extremely underreported).

Consistently with the model proposed by the Highway Safety Manual for the Roadside Design CMF(see [14], chapter 10, eq. 10-20) the analysis has been developed for the total roadway segment crashes. In future developments of the research when more data will be available the development of models referred only to run-off-road crashes will be investigated.

Table 3. Fatal and injury accident records related to the period 2001-2008 for the type “b” sections

SEC	*CRASH*	*L (km)*	*AADT*
2_6_1	14	1.100	15193
2_7_1	14	0.740	15193
2_8_1	9	0.620	15193
2_9_1	24	1.300	15193
2_10_1	23	0.840	15193
2_11_1	21	0.500	14654
2_11_2	40	1.000	14654
2_11_3	24	1.370	14654
2_11_4	9	1.130	14654
2_11_5	3	0.640	14654
2_11_6	11	0.940	14654
2_11_7	3	0.430	14654
2_11_8	2	0.220	14654
2_11_9	3	0.500	14654
2_11_10	9	0.510	14654
2_12_1	8	0.500	8825
2_12_2	11	1.000	8825
2_12_3	5	1.000	8825
2_12_4	13	1.150	8825
2_12_5	10	0.800	8354
2_12_6	3	0.500	8354
2_12_7	6	0.800	8354
2_12_8	7	0.600	8354
TOTAL	272	18.190	-

4.2.6 Accident analysis

Development of a safety performance function for secondary rural roads

The safety performance function (SPF) used for accident model predictions usually is defined by:

$$Y = EXPO \times e^{(a_1 + a_2 \times v_2 \times \ldots \times a_n v_n)}$$

Where:

Y	is the dependent variable: Number of fatal+injury crashes occurred in the section in the 8 years of observation;
EXPO	is the total exposition given by 365 x 8 x L x AADT
L	is the section length in km
AADT	is the Annual Average Daily Traffic
$v_2 \ldots v_n$	are the independent variables considered for the study which are OD, AD, DD, UT, LAY, SW, BG, LW, CURV, GS as described in § 4.2.4.
$a_2 \ldots a_n$	are the model coefficients.

Amongst the different variables two groups have been identified, the *key variables* and the *supplemental variables*:

- The *key variables* are the Length (L) and the Traffic (AADT) as well as the input variable for which the CMF has to be developed (in the specific case the number of unprotected terminals, UT). These variables are kept in the model regardless of whether they are found to be statistically significant;
- The *supplemental variables* are the addition variables derived from the detailed survey that will be included in the model if they result to be statistically significant.

For the identification of the optimal relation between crashes (Y) and the traffic volume (AADT) both the linear and non linear solutions have been investigated. The linear solution has been adopted (consistently with the HSM model for rural two lane roads[1]) as the exponent of the non linear solution turned out to be very close to 1.

To identify the variables statistically significant for the model and to calibrate the SPF to the actual data the Generalized Linear Model (GLZ) tools of the “Statistica” software has been applied with a Poisson distribution of the dependent variable. This tool enables to model user defined functions and to evaluate the statistical significance of the different variables implemented in the model.

Given the rather limited number of datapoints available as compared to the number of variables investigated the following procedure has been applied to verify if the model tends to overfit the data lacking of prediction capabilities.

The evaluation of the statistically significant variables has been performed considering all the 23 datapoints. Out of the full dataset a subset of approximately 80% (19 data) has been extracted randomly to form the calibration dataset. These data are then used for the calibration of the multivariate regression model the variables of which have been defined in the previous stage. The remaining 4 data are used to test the prediction capabilities on the model (validation dataset).

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[1] See [14], chapter 10, eq. 10-6

For the identification of the statistically significant variables the model as in eq. 1 has been calibrated by means of the Non Linear Estimation tool considering all the variables. For each calibration parameter the *p-value* is given by Statistica allowing for the identification of the statistically significant variables. The *p-value* is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true. In the development of the model the null hypothesis is rejected, and the result is said to be statistically significant, when the p-value is less than 0.05. The higher the *p-value* the less significant is the parameter.

With an iterative process the less significant variable *supplementary variable* is excluded from the analysis to the point where all the calibration parameters in the model, excluding those referred to the *key variables* result to be statistically significant. As it can for the summary results shown in Table 4 all the *supplementary variables* parameters (in the grey cells) result in a very low *p-value* (always below 0.03 and mostly below 0.01). The variable UT is left in the model independently of its significance as it is considered a *key variable*.

Table 4. Statistical significance of the selected variables

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*	
	P
Intercept	0.000229
OD	0.000000
AD	0.003956
UT	0.316004
SW	0.027129
LW	0.000262
GS	0.008344

Once the variables are identified the model is then calibrated based on the *calibration dataset* (containing 19 data points) and the results are shown in Table 5 while in Table 6 the goodness of fit statistics are shown. The Pearson χ^2 statistic for the model is 10.38 and the degree of freedom are 12 (=number of cases-number of variables=19-7). The $\chi^2_{0.05,12}$ is equal to 21 and therefore the actual χ^2 is significantly less meaning that the hypothesis that the model fits the data cannot be rejected. The goodness of fit statistics also show that both the Deviance/degrees of freedom and the Pearson χ^2/degrees of freedom result slightly less than 1 (0.7) meaning that there is no over-dispersion in the data distribution.

The Statistica Observed vs. Predicted plot of the calibration effort is presented in Figure 13 showing that the model fits extremely well the data over all the range of application. The residuals plot presented in Figure 14 shows that the residuals are evenly distributed with respect to the “zero” and among the whole range of predicted values.

Table 5. Calibration of the multivariate model for the SPF

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*

	Estimate (a1 .... a7)
Intercept	8.89908
OD	-0.03037
AD	0.61177
UT	0.02381
SW	-1.02801
LW	-2.87574
GS	0.46892

Table 6. Goodness of fit of the SPF

*CRASH=EXPO*exp(a1+a2*OD+a3*AD+a4*UT+a5*SW+a16*LW+a7*GS)*

	Df	*Stat.*	*Stat/Degree of freedom*
Deviance	12	8.27186	0.689322
Scaled Deviance	12	8.27186	0.689322
Pearson Chi²	12	8.42864	0.702386
Scaled P. Chi²	12	8.42864	0.702386
Loglikelihood		-4.51799	

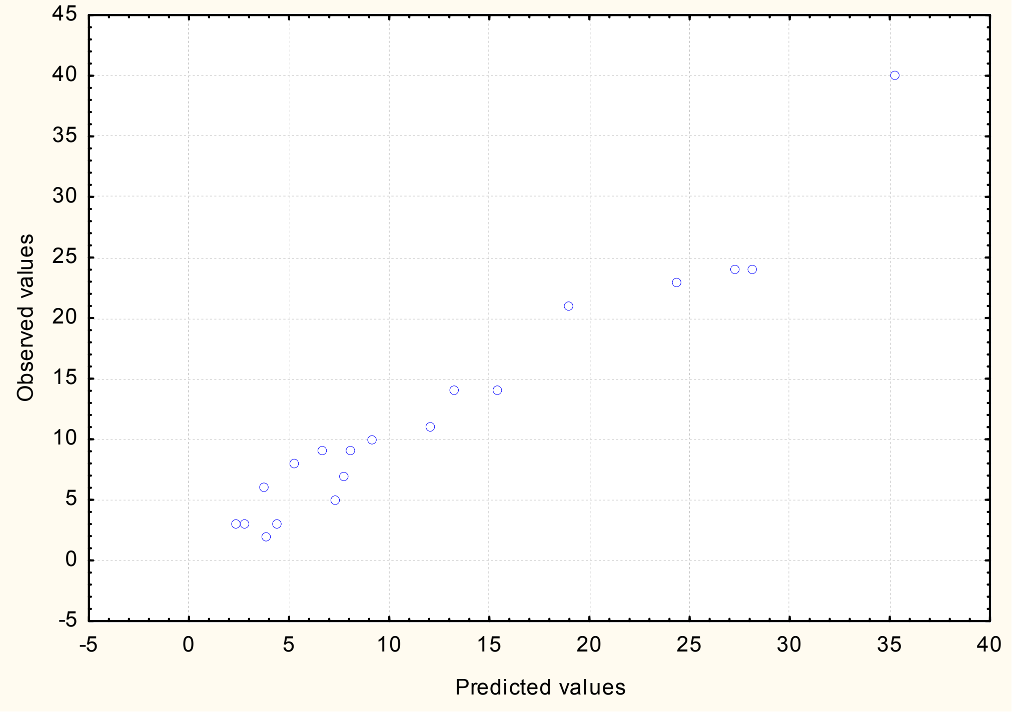

Figure 13. Observed vs. predicted plot or the calibration effort

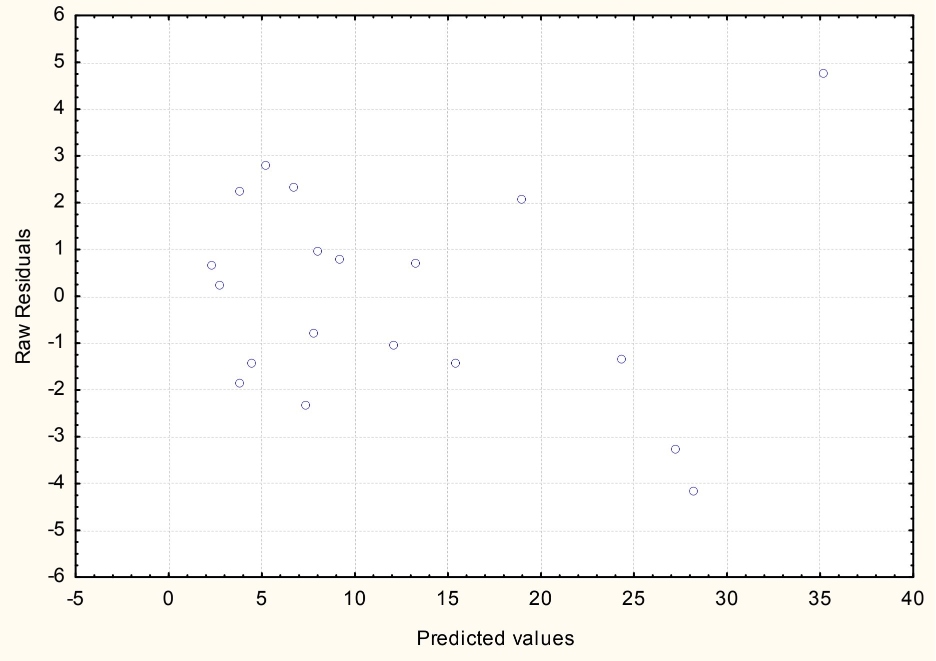

Figure 14. Residual vs. predicted plot or the calibration effort

The model parameters show a “counterintuitive” effect for the variables OD (obstacle density) and AD (average distance of obstacles). In the first case the number of predicted crashes reduces with increasing the OD while in the second case an increase in AD will lead to an increase in the number of predicted crashes.

This is due to the fact that the different variables OD and AD, even though statistically significant in the model, are not independent from the other variables and especially the shoulder width (SW) and the lane width (LW). As an example in Figure 15 clearly shows that the sections with a lower number of obstacles are also the sections with wider lane widths (which correctly would result in lower SPF predicted crashes). If the section with a specific combination of OD and LW is analysed the prediction is quite accurate but the SPF should not be used to derive a CMF for OD alone.

A very important variable in model resulted to be the presence of a gas station (GS) which is usually not considered in single carriageway rural roads. This is likely due to the fact that in Italian rural roads gas stations have a direct access on the roadway with extremely short diverge/merge lanes and left turns are allowed for vehicles pulling out of the gas station.

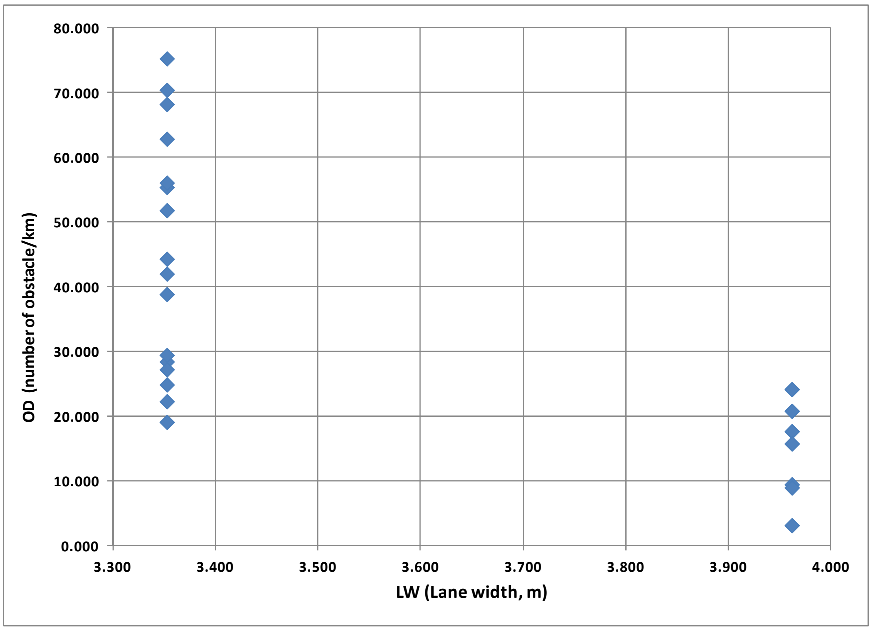

Figure 15. Number of obstacles per km vs. lane width

To test the prediction capabilities of the SPF proposed the 4 sections not used for the calibration has been analyzed with the model and the predicted values compared with the observed ones, as sown in Figure 16 where the annual crashes are plotted instead than the total crashes in 8 years. As it can be seen there is no bias in the model when used to analyze the validation data set and therefore the model can be used also to predict accidents for other roads than the one analysed. Given the small set of data used for the analysis the application leads to reliable estimations only for roads having parameters comparable with those used for the calibration of the model (see Table 7).

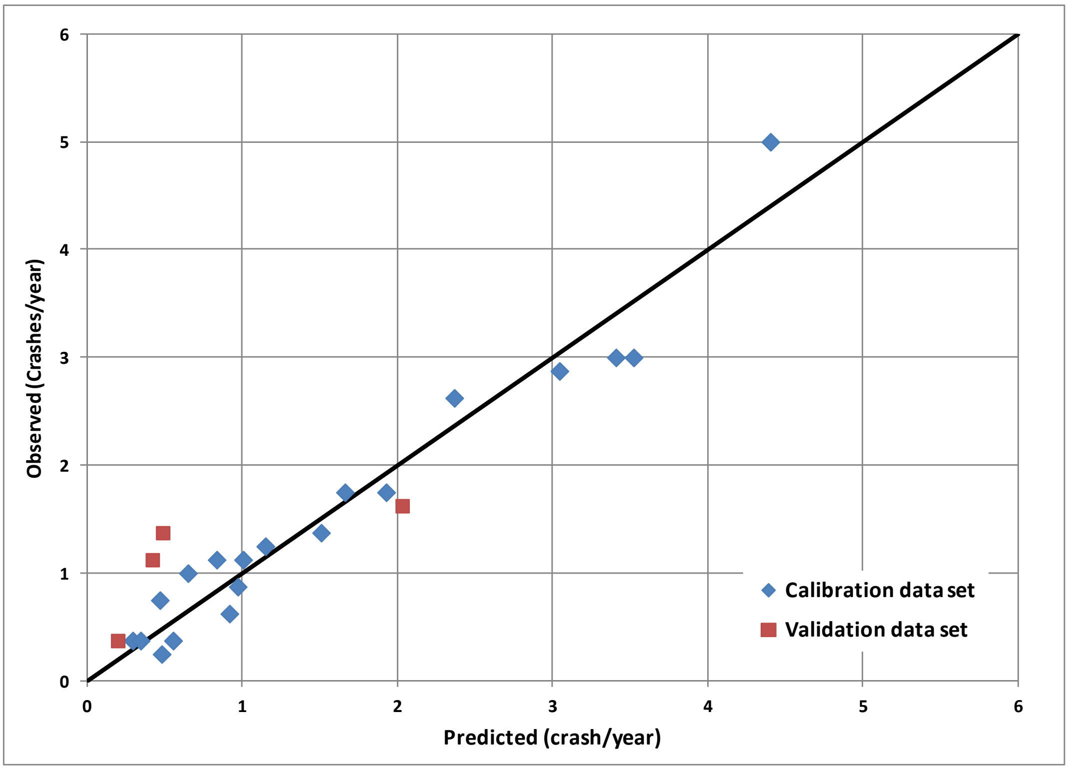

Figure 16. Observed vs. predicted annual crashes for the calibration and validation dataset

4.2.7 Estimation of the unprotected terminals CMF

As indicated in § 4.2 the CMF for the effect of having unprotected terminals in a section will be calculated by means of the following equation:

$$CMF_i = \frac{E[N]_2}{E[N]_1} \times \frac{N_{p\_1}(\text{var}\, i = base)}{N_{p\_2}(\text{var}\, i = base)}$$

Where:

> $E[N]_1$ and $E[N]_2$ are the expected crash frequencies (in crashes/yr) for the two sections of a “pair”;
>
> $N_{p\_1}(\text{var } i = \text{base})$ and $N_{p\_2}(\text{var } i = \text{base})$ are the number of crashes predicted by means of the SPF for the same two sections with *var i* = UT set to 0.

The first issue is the identification of the “pairs” which have been extracted from the database based on the following criteria:

- The AADT has to be the same in the two sections;
- The lane width has to be the same in the two sections;
- The two sections in the pair have a different number of unprotected terminals per km (UT);
- The value of $N_{p\_1}(UT = 0)/L_j$ rounded to the integer should be similar in the two sections. The only pair where the two values differ for more than 1 crash/km is pair

"2" where the two sections have 33 and 35 crashes per km predicted by the model with UT=0;

- The two sections should be adjacent (if possible) to limit the possible environmental differences not quantified by the SPF.

Out of the 23 sections 6 pairs have been identified as shown in Table 7.

Table 7. Identification of the PAIRS for the unprotected terminals (UT) CMF definition

SEC	CRASH	OD	AD	UT	SW	LW	L	AADT	GS	N_{p_j}(UT=0)/Li	PAIR
2_6_1	**14**	**70.515**	**3.053**	**7.273**	**0.300**	**3.353**	**1.100**	**15193**	**0**	**12**	**1**
2_7_1	**14**	**68.313**	**2.513**	**13.514**	**0.403**	**3.353**	**0.740**	**15193**	**1**	**13**	**1**
2_8_1	9	75.360	2.893	9.677	0.373	3.353	0.620	15193	0	9	
2_9_1	24	51.916	2.682	10.000	0.300	3.353	1.300	15193	0	17	
2_10_1	23	55.492	3.006	4.762	0.407	3.353	0.840	15193	1	26	
2_11_1	**21**	**28.545**	**2.702**	**6.0000**	**0.300**	**3.353**	**0.500**	**14654**	**0**	**33**	**2**
2_11_2	**40**	**42.125**	**2.796**	**0.0000**	**0.342**	**3.353**	**1.000**	**14654**	**1**	**35**	**2**
2_11_3	24	56.190	2.746	2.1898	0.471	3.353	1.370	14654	1	20	
2_11_4	**9**	**17.780**	**2.977**	**3.5398**	**1.494**	**3.962**	**1.130**	**14654**	**0**	**3**	**3**
2_11_5	**3**	**15.885**	**3.308**	**3.1250**	**1.533**	**3.962**	**0.640**	**14654**	**0**	**3**	**3**
2_11_6	11	9.574	3.656	0.0000	1.737	3.962	0.940	14654	0	4	
2_11_7	3	20.930	3.056	0.0000	1.161	3.962	0.430	14654	0	4	
2_11_8	2	9.091	2.700	27.2727	0.414	3.962	0.220	14654	0	9	
2_11_9	**3**	**24.286**	**2.905**	**8.0000**	**0.762**	**3.962**	**0.500**	**14654**	**0**	**5**	**4**
2_11_10	**9**	**3.268**	**2.300**	**41.1765**	**0.770**	**3.962**	**0.510**	**14654**	**0**	**6**	**4**
2_12_1	8	38.966	1.912	9.998	0.378	3.353	0.500	8825	0	8	
2_12_2	**11**	**27.333**	**1.646**	**21.995**	**0.697**	**3.353**	**1.000**	**8825**	**0**	**7**	**5**
2_12_3	**5**	**44.420**	**1.769**	**8.998**	**0.448**	**3.353**	**1.000**	**8825**	**0**	**6**	**5**
2_12_4	13	29.565	2.583	13.041	0.828	3.353	1.150	8825	0	10	
2_12_5	**10**	**22.404**	**1.398**	**14.997**	**0.527**	**3.353**	**0.800**	**8354**	**0**	**8**	**6**
2_12_6	**3**	**19.222**	**1.367**	**4.000**	**0.600**	**3.353**	**0.500**	**8354**	**0**	**8**	**6**
2_12_7	6	62.962	1.582	18.746	0.396	3.353	0.800	8354	0	3	
2_12_8	7	25.000	1.692	14.997	0.509	3.353	0.600	8354	0	9	

The estimated number of counts for each of the two segments of a pair is determined by means of the Empirical-Bayes method as:

$$E[N]_j = w_j \times N_{p\_j} + (1-w_j)\times N_{o\_j}$$

Where

N_{p_j} is the number of crashes predicted by means of the SPF for the segment j for the entire analysis period (in the specific case 2001-2008);

N_{o_j} is the number of crashes in the segment j in the analysis period (in the specific case 2001-2008);

w_j is the Empirical-Bayes weight for segment j given by:

$$w_j = \frac{1}{1 + k \times N_{p-j}}$$

Where k is the overdispersion parameter of the SPF function which can be either a constant value or, according to Hauer [19], preferably a function of the section length. This latter formulation has been adopted also in the Highway Safety Manual that, for the specific base SPF proposed for rural single carriageway two lane roads, defines the over-dispersion as:

$$k_j = \frac{0.236}{L_j(miles)} = \frac{0.3776}{L_j(km)}$$

In the specific case of the analysis based on the Arezzo Province the SPF didn't exhibit any overdispersion leading to a value of w_j = 1 and $E[N]_j = N_{p\_j}$. The $CMF_{2/1}$ value calculated for each pair is listed in Table 8, with section "2" being the section with the lowest number of unprotected terminals per km (UT) that represents the "after" condition.

The values of $CMF_{2/1}$ obtained are the crash modification factors that relates a section with UT_2 number of unprotected terminals to a section with UT_1 number of unprotected terminals and not with the base condition with UT=0.

The general form of the CMF for unprotected terminals should be in the form of:

$$CMF = e^{\beta \times UT}$$

so that the number of crashes in a given section could be estimated as:

$$N = N_b \times CMF$$

being N_b the number if crashes estimated in the base conditions with UT=0.

For each value of $CMF_{1/2}$ the corresponding value of CMF_2 (relating the section 2 of the pair to an ideal base condition with UT=0) has therefore to be calculated as:

$$\beta = \frac{\ln(CMF_{2/1})}{UT_2 - UT_1}$$

$$CMF_2 = e^{\frac{\ln(CMF_{2/1})}{UT_2 - UT_1} \times UT_2}$$

The correlation between CMF and UT as been obtained assuming:

- CMF=1 for UT=0;
- An exponential relation between CMF and UT.

The results of this final analysis are shown in Figure 17 and the equation relating the CMF with the reduction in the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

In the specific application developed for the Arezzo Province network the SPF didn't show any overdispersion and therefore the "β" of the CMF is the coefficient of UT in the SPF function. This is a very peculiar result and therefore the general formulation of the procedure has been described in this section in order to allow the user to develop the same CMF for different dataset which might more likely result in an over-dispersed SPF.

Table 8. CMF values for each of the 6 analysed pairs

SEC	CRASH (N_{o_j})	UT	L	PAIR	$N_{p\_j}(UT=0)$	N_{p_j}	$CMF_{2/1}$
2_6_1	14	7.273	1.100	1	13.0	15.4	0.862
2_7_1	14	13.514	0.740		9.6	13.3	
2_11_1	21	6.0000	0.500	2	16.4	18.9	0.867
2_11_2	40	0.0000	1.000		35.2	35.2	
2_11_4	9	3.5398	1.130	3	3.1	3.4	0.990
2_11_5	3	3.1250	0.640		2.2	2.4	
2_11_9	3	8.0000	0.500	5	2.3	2.8	0.454
2_11_10	9	41.1765	0.510		3	8.0	
2_12_2	11	21.995	1.000	6	7.1	12.1	0.734
2_12_3	5	8.998	1.000		5.9	7.3	
2_12_5	10	14.997	0.800	7	6.4	9.2	0.770
2_12_6	3	4.000	0.500		4	4.4	

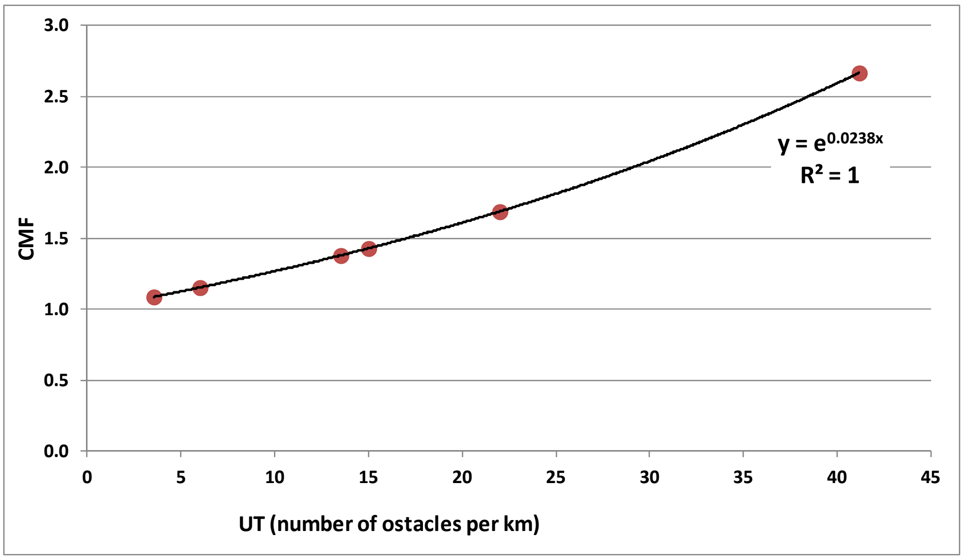

Figure 17. CMF Vs. number of unprotected terminals per km (UT)

4.3 Conclusions

The statistical analysis conducted on a typical secondary rural network in Italy shows a significant reduction of the number fatal and injury crashes when the number of unprotected terminals is reduced and a Crash Modification Factor was derived as a function of the reduction in the number of unprotected terminals.

The equation relating the CMF with the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

The Safety Performance Function developed on the basis of the collected data resulted to be extremely accurate but the effect of other roadside related variables, such as the number of obstacle and the distance from the carriageway was confounded by the cross correlation with more relevant parameters, namely the lane width and the shoulder width.

The effect of changing the type of terminal from un unprotected to a flared or energy absorption one could not be established as this type of terminals are not yet installed in the analysed network.

A very important variable in the model resulted to be the presence of gas station which a variable usually not considered in Safety Performance Functions for single carriageways rural roads.

5 Effectiveness of Grooved Rumble Strips

5.1 Introduction

During the summer of 2007 (June - October) grooved rumble strips was implemented on a 200 km stretch of a dual carriageway in western Sweden. The intended effect of these rumble strips is to keep drivers from accidently leaving the lane due to fatigue or inattention and thus reduce the number of single vehicle accidents. Phillips and Sagberg [20] state that as much as 64 % of those drivers that falls asleep on roads with rumble strips implemented are awaken by them.

5.1.1 Aim

This study aims to evaluate the accident reducing effect of the implementation of grooved rumble strips on dual carriageways with a posted speed limit of 110-120 km/h in Sweden.

5.2 Methodology

To evaluate the effect of the grooved rumble strips, accident data for the treated road sections and non treated similar road stretches was obtain from STRADA (Swedish Traffic Accident Data Acquisition). It contains general accident information on all police reported injury accidents. Information from all single vehicle accident between 1st January 2004 to 31st December 2010 was extracted for the road sections of interest. The treatment was implemented during 14th June to 12th October 2007 and this period is therefore excluded in the analysis. The treated road stretch was divided into two sections to be able to exclude a section where it passes through a large city with changes of the road characteristics. Similarly is the not treated road divided into several sections to exclude road sections that differ substantially in their characteristics. The treated road sections are henceforth denominated as T1 and T2 and the not treated as N1, N2 and N3.

In Table 9 the length of the sections and amount of traffic can be seen for the investigated road sections. The total traffic amount (million vehicle km/year) is very similar for the treated and non treated road sections but the non treated roads have a lower traffic density in average. The variation in traffic density is quite large with 2-3 times as much traffic for the most trafficked road (N3) compared to the road section with the least traffic (N2). The Annual Average Daily Traffic (ADT) has not been taken into account in the analysis.

Table 9. Length and traffic for the investigated road sections

Road section	*Start and Endpoint*	*Distance [km]*	*Million vehicle [km/year]*	*Treated*
T1	Kungälv-Gläborg	67.0	506.2	Yes
T2	Karup-Kållered	133.3	1160.0	Yes
N1	Lagan-Jönköping	72.4	368.1	No
N2	Helsingborg-Lagan	101.7	434.4	No
N3	Kronetorp-Hallandsås	71.7	841.4	No

The total investigated road length is approximately 450 km which contain some variations in the road layout. In general, the road sections have a typical layout illustrated in Figure 1 consisting of a dual carriageway with two lanes in each direction, wide paved shoulders and painted edge markings that have some rumbling effect.

Figure 18. Typical layout of the investigated roads

The treatment consists of milled rumble strips on the outer paved shoulder approximately 0.5 m from the painted edge marking. The milling was performed in a pattern called Pennsylvanian rumble strips which can be seen in Figure 2.

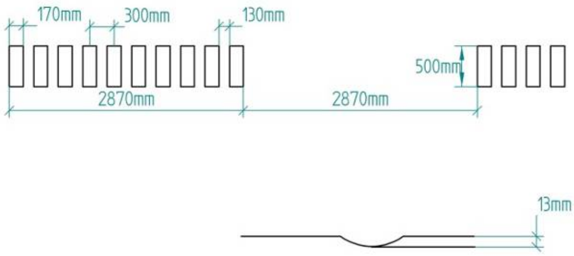

Figure 19. Dimensions of Pennsylvanian rumble strips

5.3 Statistical analysis and result

The statistical analysis is basically a before and after comparison but by using a non treated road as comparison a time correction factor can be added. This factor (later called period effect, c) should capture the changes in accident rate that are not of interest and thus make it possible to state that the improvements are due to the rumble strips.

The period up until 14 June 2007 is considered as the pre-treatment period, denoted B (before), and the period after 12 October 2007 as the post-treatment period, denoted A (after). The accidents is summarised for each roadway in periods B and A in Table 10.

Table 10. Number of accidents per road in the before (B) and after (A) period

Road section	*B*	*A*
N1	66	49
N2	74	85
N3	124	132
Ntot	264	266
T1	64	60
T2	190	125
Ttot	254	185

A Fisher's exact test testing the independence of period and treatment results in a p-value p=0.014 (Odds Ration 0.72). That is, there is a significant effect of the treatment on the number of accidents in the post-treatment period. Other confounding factors such as time and changing policies were not accounted for because the time window is very narrow and is therefore not consider having a significant impact.

A more detailed analysis of each roadway and the treatment effect was also performed. Treating each pre- and post-treatment accident count for each roadway as a Poisson variable and performing a likelihood ratio test on the treatment effect parameter. Denoting the accident intensity of each roadway in the pre-treatment period B by I1, I2, I3, I4 and I5 (for the 5 roadways above) where I4 and I5 correspond to T1 and T2. By adding an overall period effect, c, which impacts the accident rate equally for all roadways the accident rate in the post treatment period can be reduced toI1*c, I2*c, I3*c for roadways 1-3.

The parameter c should capture possible improvements to the roadways, vehicle standards etc. that might exist independently from the treatment. The effect of the treatment which is added in the expression for the treated road ways is denoted by E. The accident rate on treated road segments post-treatment can then be expressed as I4*c*E and I5*c*E. The 7 parameters are estimated (5 roadway accident intensity rates, the period effect c, and the treatment effect E) via maximum likelihood. The results are summarised in Table 11.

Table 11. Result of the maximum likelihood test

Parameter	*Estimate*	*Std error*
I1	57.3	5.9
I2	79.2	7.2
I3	127.5	9.7
I4	71.5	7.1
I5	181.7	12.6
c	1.008	0.088
E	**0.728**	**0.095**

The standard errors were obtained from the observed fisher information. The 95% confidence interval for the treatment effects is [0.543, 0.914]. That is, the estimated treatment effect is a 27.2% reduction of the accident intensity rate, but the upper confidence interval boundary indicates this effect could be as low as 8.6%.

The treatment effect E=1 are restricted and re-compute the maximum likelihood estimates of the other parameters. The two likelihood results are compared via a standard likelihood ratio test. The obtained p-value is 0.0124, which declare that the treatment effect significant.

Specific cases:

The data contains some general information about each accident which made it possible to investigate in which conditions the treatment seems to have or lack effect. The conditions found suitable for this analysis was light condition, road surface condition and weather. For each condition of interest the data was subdivided into categories of interest and investigated for which conditions the treatment had significant effect or not. Further analysis on the effect of these conditions was not included.

For light condition the data was categorized into darkness, daylight and dusk/dawn. The results are summarised in Table 12 below and concludes that the treatment has a significant effect for dark driving conditions.

Table 12. Accident categorized by light condition.

Light condition	*B*	*A*	*p-val*
DARK			
N	79	95	
T	69	42	0.007
DAY			
N	156	144	
T	158	122	0.317
DUSK/DAWN			
N	23	25	
T	25	17	0.297

For road surface condition the data was categorized into dry, wet and snow/ice. The results are summarised in Table 13 below and concludes that the treatment has a significant effect for dry driving conditions.

Table 13. Accident categorized by road surface condition.

Surface condition	*B*	*A*	*p-val*
DRY			
N	123	114	
T	120	68	0.014
WET			
N	71	78	
T	77	63	0.24
SNOW/ICE			
N	64	71	
T	54	50	0.51

For road weather the data was categorized into clear, rain and snow. The results are summarised in Table 14 below and concludes that the treatment has a significant effect for rain.

Table 14. Accident categorized on weather condition.

Weather condition	*B*	*A*	*p-val*
CLEAR			
N	176	172	
T	151	123	0.29
RAIN			
N	36	46	
T	54	34	0.03
SNOW			
N	38	36	
T	30	19	0.35

5.4 Discussion and Conclusion

The statistical analysis shows a significant reduction of the number of single vehicle accident on the roads where Pennsylvanian rumble strips has been implemented. The dataset is unfortunately not large enough to estimate the magnitude of the effect with high certainty but the indication of 27% is promising. To get a more detailed result more data is needed or the possibility to distinguish the run of road accidents from other single vehicle accidents as the treatment is targeting this type of accidents. Unfortunately, the data is not detailed enough to know if fatigue was a factor in the accident or not.

As this study does not take the severity of the accident into account it is impossible to know if the effect is evenly distributed between sever and less sever accidents. To investigate this would be an interesting next step reassuring that the severity of the remaining accidents is not increased.

In the dataset it is not possible to distinguish between run of road to the right or to the left. The effect might differ if this parameter was known.

In the study the comparison road sections were selected to be as similar to the treated roads as possible but as there are no identical roads there are some differences that have not been possible to take in to account such as weather, traffic density and traffic composition.

The significant effect of the treatment for rain is not contradicting the lack of significance for wet roadways. The rain condition is a subset of the wet roadway condition (i.e. the roadway can be wet when it is not raining). It can be hypothesize that the significance of the rain condition is the reduced visibility rather than the road condition.

6 Simulation and assessment of forgiving roadside treatments in curves

6.1 Introduction

Most common single vehicle accidents are related to a leaving of the road, which is literally described as run-off-road accident. Based on national crash statistics and reconstruction simulations, single vehicle accidents are often a consequence of wrong driver behaviour, like an inadequate speed choice. This leads to the appraisal that the consequences of these accidents can be reduced by either changing the driver behaviour or minimizing the effects of wrong behaviour. The focus of this work is related to the mitigation of accident consequences by looking at measures to forgive human errors.

6.2 Methodology

6.2.1 Tools

Simulating the effectiveness of different forgiving roadsides is realized by using infrastructure data measured by RoadSTAR, the software tool MARVin and the simulation tool VIIS (Vehicle-Infrastructure Interaction Simulation) as well as the accident reconstruction software PC Crash (see Annex B with the full research report).

- The RoadSTAR is a mobile laboratory of AIT, which measures all safety relevant road surface and geometry parameters, e.g. skid resistance, texture, alignment parameters etc.
- MARVin is a software tool developed by AIT to detect correlations between road infrastructure and road accidents. It combines the gathered data of the RoadSTAR with the road accident data in Austria.
- VIIS is a project of AIT where the interaction between vehicles and road infrastructure is simulated. The aim is to get detailed information about the effects of various road parameters on the vehicle behaviour. Real accident data and corresponding roadside parameters are linked via MARVin and can be integrated in the simulation model. This allows simulating real accident high risk sites with all necessary information.
- PC Crash is a 3D collision and trajectory simulation software. It enables the user to analyse accidents and incidents regarding motor vehicles.

6.2.2 High risk accident sites

In Austria, a high risk site is defined as a road section, where the responsible road administration has to take measures as soon as they are identified. It is further defined as a location with a maximal range of 250 metres or an intersection, where either five accidents of similar type (including accidents without personal injuries) within one year or at least three similar personal injury accidents within three years happened.

Two accident high risk sites have been investigated within the IRDES project.

Accident high risk site A

The first investigated accident high risk site is interesting in terms of an existing safety barrier. In four out of six ROR accidents, the corresponding circumstance “Crash into a road restraint system” was mentioned. The accident high risk site ranges over 170 m and can be seen in Figure 20. Additionally, the accidents locations are marked as points, whereas one point can refer to more than one accident.

Figure 20: Accident high risk site A

The accidents are distributed over the curve, starting with number one at km 20.75 and ending with number four at km 20.6. At the second point, three accidents are recorded, so that this seems to be the most hazardous position. An important differentiation is the driving direction. Four of the six accidents happened in the downstream direction, while only two happened upstream. At point 2, the distribution is two in downstream and one upstream direction.

The road condition was reported as dry once, while four times the road was wet and one time icy. In two of the six accidents, darkness was recorded by the police.

Accident high risk site B

The second investigated location is accident high risk site B, which is most interesting in terms of accident severity. At this location three ROR accidents occurred within the investigated time period, whereas all three ended fatally. This relates to an average severity rate of 130 based on the Austrian directive RVS 02.02.21. The weighted severity was the highest observed value for all ROR accident high risk sites with 390. In one case, one severely injured person was recorded.

All three accidents happened at the same recorded position (checked also with the police records) and in the same driving direction (downstream). The corresponding accident type is “leaving left side in a right bend”. In one case the accident type ”collision with an obstacle” was indicated. It can be assumed that the fatal accidents were caused by a collision with a tree, but it was not specified in the police report.

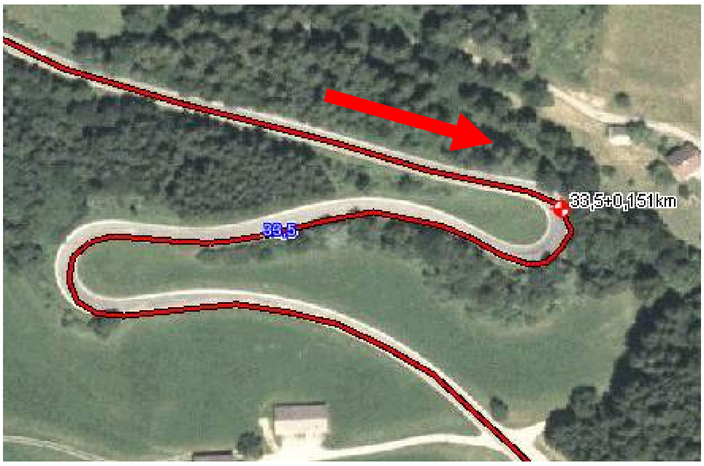

Figure 21: Accident high risk site B

6.2.3 Simulation setup and results

The simulation setup and results can be found in Annex B. The result was assessed by using the following scenarios:

- No forgiving roadside / grass stripe
- Soft shoulder
- Hard shoulder with varying widths or friction coefficients
- Tree accident
- Safety barrier

6.3 Assessment of Effectiveness in terms of safety

By using different scenarios, the effects of roadside measures on injury severity. For this purpose, several different methods are used, which rely on vehicle dynamics data, gathered out of PC Crash during the simulation scenarios. On the one hand, this vehicle information is directly derived from the measured collision parameters (e.g. for tree collisions), while on the other hand, the overall accelerations and velocities are used.

6.3.1 Accident Severity Measurement Methods

The described accident severity measurement methods mainly refer to methods, which are used during crash tests to determine the requirements of a traffic barrier, as described in the EN 1317 [P 2] (see Annex B for further details).

- Delta-V
- Energy Equivalent Speed (EES)
- Acceleration Severity Index (ASI)
- Head Injury Criterion (HIC)
- Abbreviated Injury Scale (AIS)

6.3.2 Assessment for accident high risk site A

For all assessments of the injury severity, the estimated Maximum AIS (MAIS) level is stated. The scenarios and their results are stated in the following table.

Table 15: Simulation results for accident high risk site A

Scenario	Roadside friction coefficient	Run-off	dV	EES	ASI	HIC	MAIS
No forgiving roadside (1)	0.1 (grass)	Yes	-	-	0.08	6	6
Soft shoulder (2)	0.3 (gravel)	No	-	-	0.08	7	2
Hard shoulder (3,4,5)	0.45 (pavement)	No	-	-	0.08	8	0
Tree (6)	0.1 (grass)	No	23.56	31.73	0.64	1985	6
Safety barrier (7)	-	No	1.61	3.69	0.1	10	1

It must be highlighted, that the first three MAIS-values are 'only' assumed due to there is no correlation between the HIC and the MAIS for lateral collisions.

In scenario one, only minor accelerations could be observed, but the vehicle exceeded the roadside. The ASI value of 0.08 as well as the HIC value of 6 is negligible. However, entering the roadside leads to severe or fatal consequences, according to a higher rollover probability, depending on the slope. Therefore the MAIS of 6 can be stated.

In scenario 2, the vehicle is forced to turn by 180 degree. The acceleration forces do not show significant indications for a hazardous situation with an ASI of 0.08 and an HIC of 7. However, due to vehicle rotation, a higher acceleration can be observed leading to an increased injury probability. Hence a MAIS value of 2 is assumed.

The implementation of a hard shoulder showed an optimal measure. The vehicle resumes its original driving manoeuvre. Figure 22 illustrates the longitudinal (red), lateral (blue) and vertical (green) accelerations during this scenario (about 1.5 sec)

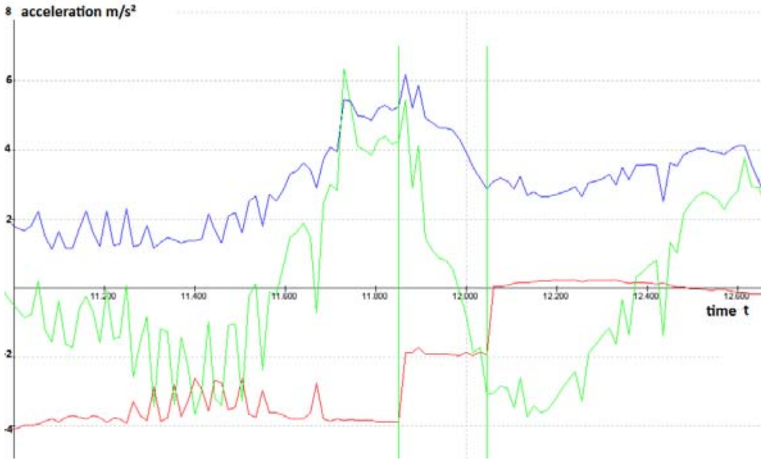

Figure 22: Acceleration forces for scenario 3 (hard shoulder) of accident high risk site A

The separate accelerations do not exceed a value of 6 m/s², so that the maximum average acceleration for this scenario was 9.22 m/s² (at t=11.73). Typically the acceleration during the curve is between 4 and 8 m/s². Therefore, it only slightly increased in this case and can be seen as harmless. The ASI is still 0.08, the HIC is 8 and therefore no injuries are expected. Hence the MAIS is 0.

In scenario six the consequences of hitting a tree are simulated and the results showed a difference to the prior ones. It is the first scenario, where besides the ASI and HIC also the EES and delta-v could be measured efficiently. The delta-v can be considered dangerous with a value of 23.56. The EES of 31.73 km/h indicates a high probability for severe or fatal consequences.

The ASI value is 0.64, which would be still a suitable value for safety barriers, according to the EN-1317. On the other hand, the HIC value is 1985, where fatal consequences have to be assumed. This shows that the ASI value is not a suitable measure for lateral collisions, since it is mainly considered to evaluate frontal impacts. Because of the high HIC value, MAIS of 6 can be stated.

In the last scenario of accident high risk site A, a safety barrier is implemented. The vehicle is directed in a smooth way back onto its original trajectory. The delta-v of 1.61 and EES of 3.69 support this observation. Also the ASI with 0.1 and the HIC with 10 do not show significant deviations, leading to a MAIS of 1.

Summary of the results for accident high risk site A:

- As expected, the simulation of a tree accident showed high accelerations and deformations at the vehicle. It is recommended to remove, relocate or shield trees on the roadside.
- The implementation of a soft shoulder showed an improvement, but it is not suitable for higher speeds, since the vehicle slides along the road in a dangerous way (especially for other road users).
- The hard shoulder resulted in no injuries and only slight acceleration forces.
- The safety barrier was a suitable solution, but it caused a collision, leading to vehicle deformations and slightly increased accelerations.
- Another option, in general, would be a proper signage or a lower speed limit.

6.3.3 Assessment for accident high risk site B

For accident high risk site B the scenarios show major differences compared to accident high risk site A. The summary of the scenarios can be seen in Table 16.

Table 16: Scenarios accident high risk site B

Scenario	**Roadside friction coefficient**	**Run-off**	**dV**	**EES**	**ASI**	**HIC**	**MAIS**
No forgiving roadside (1)	0.1 (grass)	Yes	-	-	0.1	17	6
Soft Shoulder (2)	0.3 (gravel)	Yes	-	-	0.1	17	6
Hard Shoulder (3)	0.45 (pavement)	Yes	-	-	0.1	17	6
Hard Shoulder (4)	0.6 (pavement)	No	-	-	0.1	17	1
Tree (5)	0.1 (grass)	No	16.75	13.3	0.31	309	6
Safety Barrier (6)	-	No	6.6	17.4	0.16	58	3

For this specific run-off-road accident case, the first four scenarios have identical values for ASI and HIC and the implementation of soft and hard shoulder does not affect the vehicle behaviour. However, the vehicle still runs off the road, whereas a MAIS of 6 is stated.

When applying a hard shoulder with a higher friction value than the traffic lane, positive safety effects can be observed. However, in reality this case not likely nor practical. For this scenario, the ASI and HIC values are still the same, but the vehicle is now able to stop before leaving the road. The corresponding MAIS is 1, since minor injuries are still likely.

As expected, the collision with the tree (scenario 5) shows an increased injury severity. The

HIC does not seem to be dangerous with a value of 309, since a HIC of 1000 is assumed to be the limit for slight injuries. But a closer look at the accident shows that the vehicle laterally crashes into the tree, while the driver is seated on the impact side. The probability of the driver's head to penetrate the side window is high, since this is reached with a HIC of 200. Combining this with the limited flexibility of the head in the transversal direction, a fatal accident is likely. The impact speed is low with 24 km/h, but a delta-v of nearly 17 km/h can be considered dangerous. Moreover, the EES of 13 is high, which leads to an MAIS level of 6.

In scenario 6, a safety barrier is implemented. Similar to accident high risk site A, the vehicle laterally crashes into the safety barrier. Four collision points could be observed, before the vehicle was able to resume its original driving manoeuvre. This caused an overall speed reduction of 17 km/h over a time period of 30 ms. The highest measured impact resulted in a delta-v of 6.6 km/h. The overall deformation for all four impacts leads to an EES of 17.3 km/h. The ASI of 0.16 and the HIC of 56 are relatively low. Considering the high EES and the four impact points, an MAIS of 3 can be assumed.

Summary of the observations of accident high risk site B:

- The tree showed a higher risk potential so that the removing or relocation is recommended.
- The soft shoulder showed no positive effect on safety.
- The hard shoulder was only useful with a greater friction coefficient than the traffic lane (which is not likely nor practical).
- The safety barrier was effective against the tree accident, but it showed strong deformations and accelerations.
- Another option (as for high risk site A), would be a proper signing and/or lower driving speeds

6.4 Conclusion and discussion

The assessment of forgiving roadside treatments in curves is carried out by simulating ROR accidents. A simulation-based framework was developed to replicate high-risk accident sites in a virtual environment and simulate vehicles running off the road. The road and roadside models are created from laser measurement data and are imported into the 3D collision and trajectory simulation tool PC-Crash. In a kinetic simulation procedure, the vehicle model runs off the road with a specific driving speed. Several roadside treatments are implemented to evaluate their effectiveness on safety. Important indicators for the evaluation are the head injury criterion (HIC) and the abbreviated injury scale (AIS), which describe the injuries to occupants involved in collisions.

The simulation and assessment framework was applied to two curvy road sections in Austria, which were identified as high-risk accident sites. The implementation of a soft shoulder can be seen as useless in those specific case studies. A soft shoulder in conjunction with a barrier (large working width) would probably be of benefit. It shows an improvement for the drawn-out curve with a reduced probability to exceed the roadside, but on the other hand the risk to slide is increased. This causes a reduction of injury severity, but on the other hand an increased hazard for other road users. It can be said that this measure is not appropriate for the speed of 90 km/h and should mainly be used on sections with lower speed. Also in sharp curves the implementation of soft shoulders is not suitable, as the analysis of the second accident high risk site has shown. The vehicle passes the shoulder without any reaction. Therefore this measure was the least effective one for the two test cases.

The second measure, the implementation of a hard shoulder, prevented the vehicle to leave the road in the drawn-out curve. The shoulder acts as an extended traffic lane. This enables the vehicle to stay on its original trajectory, without strong steering or braking sequences.

Therefore the consequences of the ROR were minimized. For the sharp curve, an extended traffic lane was not suitable. Only the implementation of a shoulder with better friction value than the traffic lane would increase roadside safety. However, this measure is not practical, since high friction variations between road and shoulder surface should be avoided.

An effective measure for both spots was the implementation of a safety barrier. In both cases, the safety barrier redirected the vehicle back onto its original trajectory, without any indications of sliding or overturning. However the impact on the barriers caused increased accelerations and deformations at the vehicle. Therefore this measure should be only used in cases, where other measure are not possible, or do not show any positive effect.

The tree accident scenario at both spots shows high decelerations and deformations at the vehicle. Therefore the risk of severe injuries within these accidents is high. Removing the trees in the near surrounding of the traffic lane is strongly recommended. If this is not possible, shielding with safety barriers is a suitable measure, since the severity of the impact is much lower.

The investigated sharp curve (accident high risk site B) is a good example for a location, where only safety barriers seem to be an effective measure. The other measures or the implementation of a safety zone are not practical. Due to the surrounding forest on the roadside, the space for measures is limited, and the removing of all trees is no alternative. The same is true, when investigating the real surrounding of the drawn-out accident high risk site A. Due to the trees and the steep ditch, space for a hard shoulder is not available, although it would be an effective measure according to the simulations.

In general, the methodology used for assessing roadside treatments in curves allows an effective evaluation of roadside safety. Accurate replications of high-risk road sites are crucial for applying this methodology. Therefore, a measurement device for capturing road alignment, surface parameters and roadside elements is necessary. For the final decision on roadside treatments, it may also be necessary to perform an additional inspection at the spot. Other factors such as environmental impacts or cost-benefit ratio have to be included in this decision.

7 Conclusion and recommendations

7.1 Variations of shoulder width

Part of the study was to evaluate driver behaviours before and after treatment with a tool, called Observatory of Trajectories (OT), composed by rangefinder and cameras. However, due to delays in the modifications of the road only measurement before the modifications could be conducted and analysed. The analysis of the measurements of the before situation concluded that:

- Measured speed and lateral position show reliable results.
- Number of measured vehicles is insufficient to analyse other parameters as required (e.g. the situation where another vehicle was approaching in the opposite lane).
- The percentage of removed data is higher for trucks than for cars.
- The recording time needs to be increased to have more free vehicles tracked (2 minutes instead of 30 seconds).
- Measurements of the central marking in the rangefinder referential are needed to improve accurate calibration.
- It is a need to use two rangefinders at different heights for the car and heavy goods vehicle measurement respectively.
- The recording period should be increased to at least two weeks to ensure a larger data sample.

7.2 Removing unprotected barrier terminals

The statistical analysis conducted on a typical secondary rural network in Italy shows a significant reduction of the number fatal and injury crashes when the number of unprotected terminals is reduced. A Crash Modification Factor (CMF) was derived as a function of the reduction in the number of unprotected terminals.

The equation relating the CMF with the number of unprotected terminals per km is given by:

$$CMF = e^{0.02381 \times UT}$$

The Safety Performance Function developed on the basis of the collected data resulted to be accurate. However, the effect of other roadside related variables, such as the number of obstacle and the distance from the carriageway was confounded by the cross correlation with more relevant parameters, namely the lane width and the shoulder width.

An important variable in the model resulted to be the presence of gas stations which a variable usually not considered in Safety Performance Functions for single carriageways rural roads.

A test with a validation dataset has shown that there the model can be used also to predict accidents for other roads than the one analysed. Given the small set of data used for the analysis the application leads to realiable estimations only for roads having parameters comparable with those used for the calibration of the model.

7.3 Grooved rumble strips

To assess the effectiveness of the implementation of grooved rumble strips on dual carriageways comparisons between treated and non-treated roads were evaluated by statistical methods. Accident data from several years with and without treatment are needed to perform the analysis.

The statistical analysis shows a significant reduction of the number of single vehicle accident on the roads where Pennsylvanian rumble strips has been implemented. It was not evaluated if the effect is evenly distributed between severe and less severe accidents.

The significant effect of the treatment for rainy weather conditions is not contradicting the lack of significance for wet roadways. The rain weather condition is a subset of the wet roadway condition (i.e. the roadway can be wet when it is not raining). It can be hypothesize that the significance of the rainy weather condition is the reduced visibility rather than the road condition.

7.4 Treatments in curves

The method of using Vehicle Infrastructure Interaction Simulation (VIIS) was tested in two case studies.

In both cases the implementation of a soft shoulder did not show any positive results. The extended roadside reduced the probability to exceed the roadside, but increased the risk of skidding. The injury risk was reduced but the due to the uncontrolled vehicle it increased the risk for other road users. The case studies showed that soft shoulder is not appropriate for the speeds of 90 km/h and in sharp curves.

Implementation of a hard shoulder, showed an ideal vehicle manoeuvre for the extended curves but not for sharp curves. For the case with the same friction value, the shoulder acts as an extended traffic lane. This enables the vehicle to stay on its original trajectory, without strong steering or braking sequences. Therefore the consequences of the ROR were minimized in an optimal way. For the sharp curve the positive effect was only found when the shoulder had a better friction value than the traffic lane.

For both spots the implementation of a safety barrier showed positive effect. In both cases the safety barrier redirected the vehicle back onto its original trajectory, without any indications of sliding or overturning. However, the impact on the barriers caused increased accelerations and deformations at the vehicle.

Removing the trees in the near surrounding of the traffic lane or shielding with safety barriers is recommended. The deceleration of the vehicle is lower in impacts with safety barriers decrease the risk of injuries.

The methodology shows that VIIS (Vehicle-Infrastructure Interaction Simulation) can be used as assessment tool for estimating the effectiveness of forgiving roadside measures in a practical way. The critical point is the availability of data to create a 3D road model, since laser measurement data are not commonly used in road data bases. The interface to simulation software is not the key problem for designing that simulation tools. This methodology can be easily transferred to different software solutions.

Glossary

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.

Back slope (see ditch)
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
A sign, traffic signal or luminaire support designed to yield or break when struck by a vehicle.

Abutment
The end support of a bridge deck or tunnel, usually retaining an embankment.

Vehicle parapet (on bridges)
A longitudinal safety barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. It can be constructed from either steel or concrete.

CCTV Masts
A mast on which a closed circuit television camera is mounted for the purpose of traffic surveillance.

Carriageway
The definition of the ‘carriageway’ differs slightly amongst countries. 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.

Central reserve
An area separating the carriageways of a dual carriageway road.

Clearance
The unobstructed horizontal dimension between the front side of safety barrier(closest edge to road) and the traffic face of the.

Clear/Safety zone
The area, starting at the edge of the carriageway, that is clear of hazards. This area may consist of none or any combination of the following: a ‘hard strip’, a ‘shoulder’, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes, speeds and on the roadside geometry.

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 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 road vehicle energy absorption device (road restraint system) installed in front of a rigid object to contain and redirect an impacting vehicle ("redirective crash cushion") or to contain and capture it ("non-redirective crash cushion").

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.

Design speed
The speed which determines the layout of a new road in plan, being the speed for which the road is designed, taking into account anticipated vehicle speed on the road.

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, 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
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. See also ‘dual carriageway’.

Drainage gully
A structure to collect water running off the roadway.

Drop-off
The vertical thickness of the asphalt protruding above the ground level at the edge of the paved surface.

Dual carriageway
A divided roadway with two or more travel lanes in each direction, where traffic is physically divided with a central reserve and/or road restraint system. See also ‘divided roadway’.

Edge line
Road markings that can be positioned either on the carriageway surface itself at the edge of the carriageway, or on the ‘hard strip’ (if present) next to the carriageway.

Embankment
A general term for all sloping roadsides, including cut (upward) slopes and fill (downward) slopes (see ‘cut slope’ and ‘fill slope’).

Encroachment
A term used to describe the situation when the vehicle leaves the carriageway and enters the roadside area.

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.

Frangible
A structure readily or easily broken upon impact (see also ‘break-away support’).

Fore slope (see ditch)
The fore slope is a part of the ditch, and refers to the slope beside 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.

Guardrail
A guardrail is another name for a metal post and rail safety barrier.

Hard/Paved 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.

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.

Highway
A highway is a road for long-distance traffic. Therefore, it could refer to either a motorway or a rural road.

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 (passive safety) device which helps to reduce the severity of a vehicle impact with a fixed object. Impact attenuators decelerate a vehicle both by absorbing energy and by transferring energy to another medium. Impact attenuators include crash cushions and arrester beds.

Kerb (Curb)
A unit intended to separate areas of different surfacings and to provide physical delineation or containment.

Lane line
On carriageways with more than one travel lane, the road marking between the travel lanes is called the 'lane line'.

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.

Length of need
The total length of a longitudinal safety barrier needed to shield an area of concern.

Median
See 'central reserve'.

Motorways
A dual carriageway road intended solely for motorized vehicles, and 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).

Non-paved surface
A surface type that is not asphalt, surface dressing or concrete (e.g. grass, gravel, soil, etc).

Offside
A term used when discussing right and left hand traffic infrastructure. The side of the roadway closest to opposing traffic or a median.

Overpass
A structure including its approaches which allows one road to pass above another road (or an obstacle).

Paved shoulder
See ‘hard shoulder’.

Pedestrian restraint system
A system installed to provide guidance for pedestrians, and classified as a group of restraint systems under ‘road restraint systems’.

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.

Recovery zone
A zone beside the travel lanes that allows avoidance and recovery manoeuvres for errant vehicles.

Rebounded vehicle
A vehicle that has struck a road restraint system and then returns to the main carriageway.

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.

Road restraint system (RRS)
The general name for all vehicle and pedestrian restraint systems used on the road (EN 1317).

Road equipment
The general name for structures related to the operation of the road and located in the roadside.

Road furniture
See ‘road equipment’.

Roadside
The area beyond the roadway.

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 roadway includes the carriageway and, if present, the hard strips and shoulders.

Rock face cuttings
A rock face cutting is created for roads constructed through hard, rocky outcrops or hills.

Rumble strip (Shoulder rumble strips)
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
See ’clear zone’.

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. (Ripcord-Iserest, Report D3, 2008).

Set-back
Lateral distance between the way and an object in the roadside for clearance).

Shoulder
The part of the roadway between the carriageway (or the hard strip, if present) and the verge. Shoulders can be paved (see ‘hard shoulder’) or unpaved (see ‘soft shoulder’).
Note: the shoulder may be used for emergency stops in some countries; in these countries it comprises the hard shoulder for emergency use in the case of a road with separate carriageways.

Single carriageway
See ‘undivided roadway’.

Slope
A general term used for embankments. It can also be used as a measure of the relative steepness of the terrain expressed as a ratio or percentage. Slopes may be categorized as negative (fore slopes) or positive (back slopes) and as parallel or cross slopes in relation to the direction of traffic.

Soft/Unpaved 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.

Soft strip
A narrow strip of gravel surface located in the roadside, beyond the roadway (normally beyond a hard strip/shoulder).

Termination (barrier)
The end treatment for a safety barrier, also known as a terminal. It can be energy absorbing structure or designed to protect the vehicle from going behind the barrier.

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/carriageway that is travelled on by vehicles.

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
A motorcyclist protection system installed on a road restraint system, with the purpose to reduce the severity of a PTW rider impact against the road restraint system.

Undivided roadway
A roadway with no physical separation, also known as single carriageway.

Unpaved shoulder
See ‘soft shoulder’.

Vehicle restraint system
A device used to prevent a vehicle from striking objects outside of its travelled lane. This includes for example safety barriers, crash cushions, etc. These are classified as a group of restraint systems under ‘road restraint systems’.

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.

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Annex A

Survey of the Roadside Features – Checklist

IRDES

Improving Roadside Design to Forgive Human Errors

Check List of Roadside Features

Table 1 – Roadside element

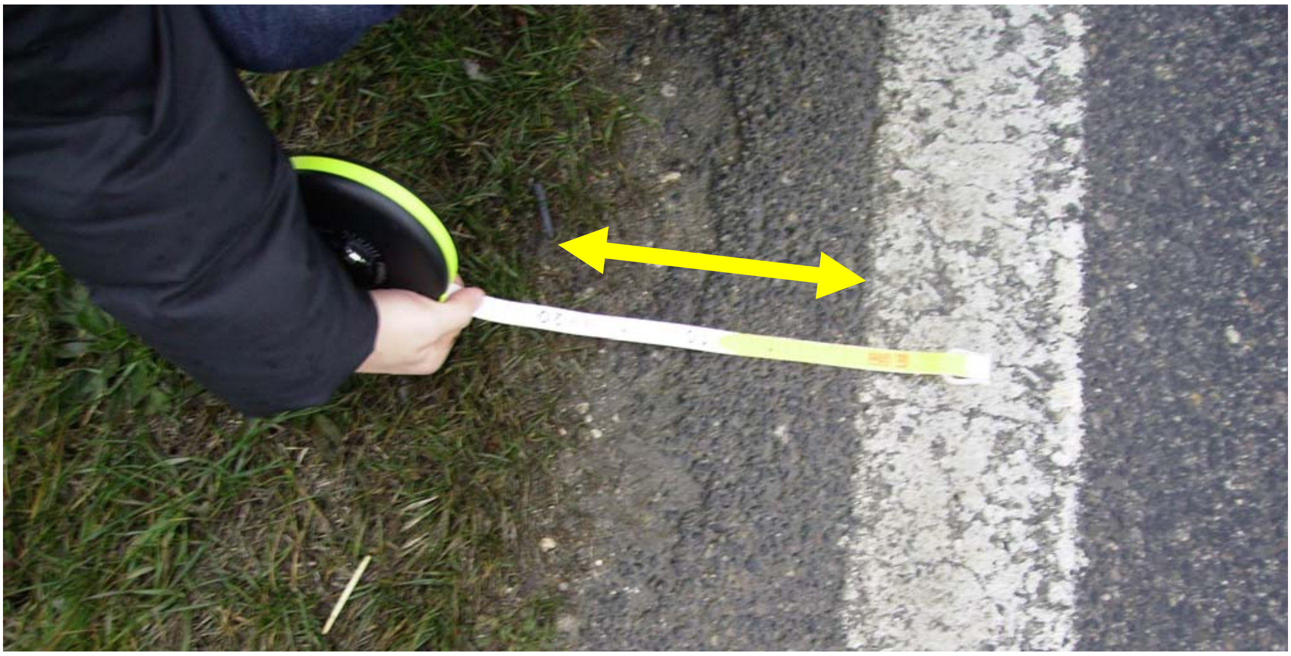
ROADSIDE ELEMENT	REQUIRED MEASURE
Shoulder	Width/Type
Bank	Width
Safety barrier	Type /Length
Safety barrier termination	Type
Ditch	Width
Driveways	Type
Obstacles	Type – distance from horizontal marking
Lay-by	Type - Width - Length

Road	
Start section: km	
End section km	
Side (1)	

Roadside configuration (2)	**Geometrical element (3)**	**Roadside element (4)**	**Measure (5)**

(1) Right (R) or Left (L)
(2) Embankment, Cutting or Bridge
(3) Bend (B) or Linear (L)
(4) Roadside element (see Table 1)
(5) Measure

Shoulder



Bank

Safety barrier

Type A – Double wave

Type B – Double wave with handrail

Type C – Triple wave

Type D – Triple wave with handrail

Safety barrier terminations

Type A

Type B

Ditch

Type A

Type B

Driveways

Type A – With open drainage

Type B – With close drainage

Obstacles

Type A – Vertical sign on single marker post

Type B - Building

Type C – Vertical sign on two marker post

Type D - Artefacts

Type E – Lighting column

Type F – Garbage bin

Type G – Overpass

Type H – Isolated Rocks

Lay-by

Type A – Not paved

Type B - Paved

Annex B

Vehicle-Infrastructure-Interaction-Simulation (VIIS) regarding roadside measures in curves (case studies)

Vehicle-Infrastructure-Interaction Simulation (VIIS) regarding roadside measures in curves

Case studies

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Abstract

To increase safety on European roads the concept of Forgiving Roadsides is one of the main priorities in the area of road infrastructure measures. It mainly aims to mitigate the consequences of single vehicle accidents, which are responsible for nearly half of all EU road accident fatalities. To analyse the necessity and effectiveness of this concept, run-off-road accidents are investigated in terms of frequency and severity for the Austrian road network. Additional the influence of roadside objects as trees and safety barriers on the accident severity is determined. By identifying hazardous accident locations in Austria, further typical run-off-road accidents are simulated at real existing accident high-risk sites, using the Vehicle- Infrastructure-Interaction-Simulation (VIIS).

In the simulations different roadside measures as shoulders and safety barriers are included, so that impacts on level of safety are obtained. An indicator for the effectiveness of the proposed measures is the head injury criterion, which states the injury risk for vehicle occupants.

Keywords: Forgiving roadside, Run-off-road accidents, Vehicle infrastructure interaction simulation, Head injury criterion

Table of Contents

1 Activity Description

1.1 Introduction

In the year 2001 the European Union (EU) announced the “White Paper on Transport Policy”, which had the aim to reduce the current number of about 54,000 road accident fatalities by 50 % till 2010. To reach this goal several measures have been developed, addressing the vehicle, the infrastructure and the driver himself. Unfortunately in the year 2007 still around 43,000 fatalities due to road accidents could be observed on European roads [P 1], which is only a reduction of 22 %. This indicates that the aimed number of around 27,000 fatalities in the year 2010 will not be reached and further improvements have to be developed.

Analysing European road accident fatalities in more detail showed that most of them are, with about 45 %, due to single vehicle accidents, although this accident type only accounts for 10 % of all road accidents. This assumes that countermeasures for this accident type have a huge impact on road safety.

Most commonly single vehicle accidents are related to a leaving of the road, which is literally described as run-off-road accident. The problem is that single vehicle accidents are in lots of cases a consequence of wrong driver behaviour, like an inadequate speed choice. This leads to the appraisal that the consequences of these accidents can be reduced by either changing the driver behaviour or minimizing the effects of wrong behaviour. Since the first part is an extremely difficult topic, the focus in this work is related to the mitigation of accident consequences by looking at measures to forgive human errors.

From vehicle perspective many systems as the Anti-lock Braking Systems (ABS) and Electronic Stability Program (ESP) can be found, but on infrastructure side the measures are spare. Investigating the possibilities in this sector, the term forgiving roadside was identified as a high potential short-time measure of the European road directors, which aims to mitigate the consequences of ROR accidents. It assumes that an appropriate roadside design can support the driver to regain control of the vehicle in these situations and avoid even more hazardous scenarios as crashing into a trees or ditches.

Therefore in this activity as a task within WP2 of the IRDES project, the necessity and effectiveness of roadside intervention will be analysed for some specific spots in Austria.

1.2 Aim and Methodology

The aim of that work can be described in the following hypotheses:

- Roadside intervention in terms of forgiving roadside reduces the crashworthiness, leading to less harmful injuries and less accident costs
- There is a necessity to implement the concept of forgiving roadsides
- Simulation tools (VIIS – Vehicle Infrastructure Interaction Simulation) are useful for assessing the effectiveness of forgiving roadsides

To prove the hypotheses several goals have to be fulfilled, within this activity:.

- High-risk site analysis over the last 5 years with focus on run-off-road accidents (as basic sites for the simulation activities)
- Investigation of the accident data base in terms of correctness and availability of roadside data (MARVin analyses and RoadSTAR data)
- Simulating the vehicle behaviour on real existing road sections
- Implement several roadside measures (road restraint systems, soft and hard shoulders) in the simulation scenarios
- Assessment of effectiveness of roadside intervention
- Assessment of cost-effectiveness of roadside intervention

In that specific activity within WP2, the vehicle behaviour on prior identified accident high-risk sites will be simulated. Out of this vehicle behaviour the injury risk of the occupants will be derived. In the simulation various roadside measures will be implemented, so that a forgiving roadside is simulated. Out of the resulting vehicle behaviour, the effectiveness of the measures will be derived.

2 Background

The basics for the task to simulate the effectiveness of different forgiving roadsides are the infrastructure data measured by RoadSTAR, the software tool MARVin and the simulation tool VIIS.

2.1 RoadSTAR

The RoadSTAR is a mobile laboratory, which measures all safety relevant road surface and geometry parameters on its own e.g. skid resistance. The RoadSTAR is a truck capable of measuring these parameters under normal traffic conditions at speeds between 40 and 120 km/h. To guarantee optimal and comparable measurement conditions, the road is watered, so that every measurement is related to a wet road. It is equipped with modern technology starting with differential global positioning system (DGPS), to allocate measurements to its real position. Following parameters are measured with independent sensors.

1. Skid resistance

For the measurement of the skid resistance the frictional force is measured. This is done by relating the force between the measuring tyre and the road surface to the wheel load. The output parameter is designated as friction coefficient µ. Important is, that the friction is measured for a wet road, so the values are around 0,4 less than for a dry road. This parameter will be one of most important parameters for the simulation, so that is necessary to know some reference values before (Table 1).

Table 1: Typical friction values for a wet road

Surface	Wet-friction
Optimal road condition	>0,8
Good road condition	0,6 - 0,8
Acceptable road condition	0,4-0,6
Gravel	0,3
Grass	0,1
Snow, Ice	<0,1

The friction of a road is influenced by several factors. For example a dirty road has less friction than a clean one. This is avoided by the watering of the road. Also the pavement wear, caused by the daily traffic, especially of heavy-good vehicles, causes a loss of friction. Typically after some time, longitudinal ruts can be observed on the usual trajectory of the vehicles.

2. Texture

The texture is a representation of the surface, determined by the form, size and distribution of aggregates. It is measured with a laser, whereas a distinction according to the wave length is made between microtexture (up to 0.5 mm), macrotexture (0.5 – 5 mm) and megatexture (50-500 mm). For the RoadSTAR the term texture is related to macrotexture.

3. Longitudinal evenness

The longitudinal evenness is a important factor for driving comfort and road safety. Inappropriate longitudinal evenness can lead to more wheel load, higher pavement wear and hence a shorter infrastructure lifetime. The longitudinal evenness is measured with four laser sensors.

4. Transverse evenness

   As the longitudinal evenness also transverse evenness is important in terms of road safety and driving comfort. Typical parameters for the transverse evenness are the rut depth, profile depth and the water film thickness in the wheel track. It is measured with 23 laser sensors in the front of the vehicle.

5. Road geometry parameters

The inertial measurement unit (IMU) consist of three acceleration sensors, three gyroscopes and a GPS unit. It enables information about the course angle, leading to road geometry parameters, as curve radius.

6. Crack detection (Video camera)

Additional to the laser systems, also a video system takes an image of the road surface. This gives the opportunity to analyse the road surface in more detail.

7. Roadside objects (Video camera)

The integrated video system allows the recording of the whole road averment, including road signs and even kilometre signs. But because of the limited storage capacity for data, the video system is only activated on demand, so that the video files are only rarely available.

8. Position

The position of the vehicle is measured via a DGPS unit on the roof of the vehicle.

All measurement units can be seen at following figure (Figure 1).

Figure 1: RoadSTAR measurement units [AIT Picture]

2.2 MARVin – Model for assessing risks of road infrastructure

Marvin is a software tool developed by the AIT to detect correlations between road infrastructure and road accidents. It combines the gathered data of the RoadSTAR with the road accident data delivered by Statistik Austria, which enables a new dimension in road accident analysis. With this information it is now possible to detect weaknesses in the road network and relate them directly to the existing road infrastructure. It is an appropriate tool for traffic planner, since the safety conditions of existing roads and roads in planning can be easily evaluated. Therefore Road safety audits (RSA) and Road safety Inspections (RSI) are two types of applications, where the software can be used efficiently.

The main objectives of the software can be described as following:

- Evaluation of risk potential of existing and planned road sections
- Evaluation of safety measures
- Detection of correlations between road surface parameters and accident risk
- Identification of potentially dangerous road sections
- Effects on planning decisions of new roads and maintenance management of existing roads

Especially the identification of potentially dangerous road sections has a high priority in future developments of the software. The patented method used is called “Similarity search”. It provides the road safety analyst with a tool to find similar road sections. The comparison is not limited only to road geometry, but can also include skid resistance or evenness. It can be used to identify road sections, which are similar to existing high-risk sites, so that future accidents can be avoided in advance. An additional feature is that existing roads can be found according to an artificially created sample.

2.3 VIIS – Vehicle Infrastructure Interaction Simulation

VISS, as the name already states, is a project of AIT where the interaction between vehicles and road infrastructure is simulated. The aim is to get detailed information about the effects of various different road parameters on the vehicle behaviour. The clue of this project is that real accident data and corresponding roadside parameter are linked via MARVin and can be integrated in the simulation model. This generates the opportunity to simulate real accident high-risk sites with all necessary information. This has a tremendous benefit for road maintenance and road safety, since the identification of accident causes and weaknesses in the road infrastructure can be more easily obtained.

The first step of the project was to identify suitable accident simulation software, which is cable of:

- Integration of a 3D road model

- Integration of different friction patches according to measurement data from the RoadSTAR

For this purpose two different software where tested:

- PC- Crash by DSD (Dr. Steffan Datentechnik) [W 1]
- Dymola by Modelon

Additional software is MADYMO (Mathematical Dynamic Models) by TASS (TNO Automotive Safety Solutions), which is specialised in human body models for reconstruction of vehicle occupant and pedestrian injuries [W 3]. It can be implemented in the accident simulation software as independent tool, but is not used by AIT. Another example is Analyzier Pro by DWG (Dr. Werner Gratzer) [W 2]

After an evaluation phase, PC Crash was determined as the most suitable choice for AIT intentions to integrate real infrastructure measurement data.

2.3.1 PC Crash

PC Crash by Dr. Steffan Datentechnik is collision and trajectory simulation software. It enables the user to analyse all kinds of accidents and incidents regarding motor vehicles. It has a huge database containing all kinds of vehicle types and brands. With the software it is possible the re-enact a real traffic accident and get more details about the accident history. It is possible to create a road model, as well as several vehicle trajectories and collision scenarios can be evaluated. The software automatically creates diagrams and tables with all vehicle relevant information, as velocity and acceleration data.

2.3.2 Import of RoadSTAR data

One of the main requirements for PC Crash was the implementation of a road model out of the measured road data from the RoadSTAR. For this purpose a dxf-file is created, containing following information (Table 2). The dxf (Drawing Interchange Format) is a format, which is used to exchange technical drawings, created for example in AutoCAD.

Table 2: 3D- Road Model Parameter

Parameter	Description	Resolution
Course angle	Derived from the IMU	1m
Slope	Derived from the height profile	1m
Transverse evenness	Derived from the 23 lasers	1m
Cross fall	Derived from the transverse evenness	1m

The dxf-file is automatically created by a python script. Python is a free to use programming language, which contains functionalities for database and dxf-file interaction.

3 High-risk sites

As a first step towards the later simulation of ROR accidents, it is necessary to identify suitable hazardous locations in Austria. It is a practical and feasible approach to look for road sections, where – under normal conditions – the accident records would require immediate countermeasures against ROR accidents. Therefore an tool of MARVin, the virtual high-risk site analysis (VBSA) is used. By definition, accident high-risk sites are road sections, where the responsible road administration has to take measures as soon as they are identified. The main criterion for an accident high-risk site is:

- At minimum three similar accidents with personal damage in three years

Because of the limitation to ROR accidents, only the accidents, which can be categorized as single vehicle accident or accidents caused by opposing traffic, are considered.

The analysis was performed for a time period of five years (2005-2009), leading to total 207 accident high-risk sites in Austria.

For the simulation two accident high-risk sites, were found to be of special interest because of following characteristics:

- One location with existing safety barriers, to verify the necessity of this measure at this location
- One location with three fatal accidents in three years (which was highest observed severity)

3.1 High-risk site A

The first investigated accident high-risk site is interesting in terms of an existing safety barrier. In four out of six ROR accidents, the corresponding circumstance 15 was mentioned. The accident high-risk site ranges over 170 meter and can be seen in Figure 2. Additional the accidents locations are marked as points, whereas one point can refer to more than one accident.

Figure 2: Accident high-risk site A [W 5]

As can be seen the accidents are distributed over the curve, starting with number one at km 20.75 and ending with number four at km 20.6. At the second point three accidents are recorded, so that this seems to be the most hazardous position. An important differentiation is the driving direction. Four of the six accidents happened in the downstream direction, while only two happened upstream. At point two the distribution is two downstream and one upstream.

The prevailing weather condition where one time dry road, while four times the road was wet and one time icy. In two of the six accidents darkness was recorded by the police.

To proof the occurrence of safety barriers at this location, the responsible road administration provided the data sheet of this specific road section An additional validation was made, by investigating the location at the spot. This information showed that the curve is equipped with safety barriers on both sides from km 20.65 till 20.8 This includes the five accidents at the points one to three, whereas for one of them no collision with safety barrier was mentioned in the accident database.

The severity of the five accidents was in all cases slightly. This gives a weighted severity of 35, which is the minimum value for accidents with personal damage. Anyhow the occurrence of five accidents with personal damage due to collisions with safety barriers indicates that there is still a risk for ROR accidents. The inspection at the spot showed that the placement of safety barriers is absolutely necessary, since the road is surrounded by trees followed by a steep slope on both sides. This means that the severity of these five accidents would be much more severe without. On the other hand the observation of safety barriers suggest a higher safety level to the driver, so that they can tend to feel safe and adopt their driving behaviour according to the new situation. The entrance into the curve in downstream direction can be seen on following Figure 3.

Figure 3: Accident high-risk site A [Own Picture]

As can be seen the speed limit for the curve is 70 km/h. The sight distance into the curve is disturbed by trees, whereas the end of the curve and possible oncoming vehicles from the other direction can be seen in advance. Additional with the increased safety experience due to the safety barriers, drivers can be tend to drive more unperceptive.

3.2 Accident High-risk site B

The second investigated location is accident high-risk site B, which is most interesting in terms of accident severity. At this location three ROR accidents occurred within the investigated time period, whereas all three ended fatally. This relates to an average severity of 130, which is the highest possible value. The weighted severity was the highest observed value for all ROR accident high-risk sites with 390. In one case additional one severe injured person was recorded.

All three accidents happened at the same recorded position and in the same driving direction (downstream). The corresponding accident type is type 022, leaving in a right bend on the left side. In one case the accident circumstance 17 was checked, which indicates a collision with an obstacle. It can be assumed that the obstacle was a tree, as can be seen on Figure 4. The suggestion is that also the other two fatal accidents were caused by a collision with a tree, but it was not specified in the police report.

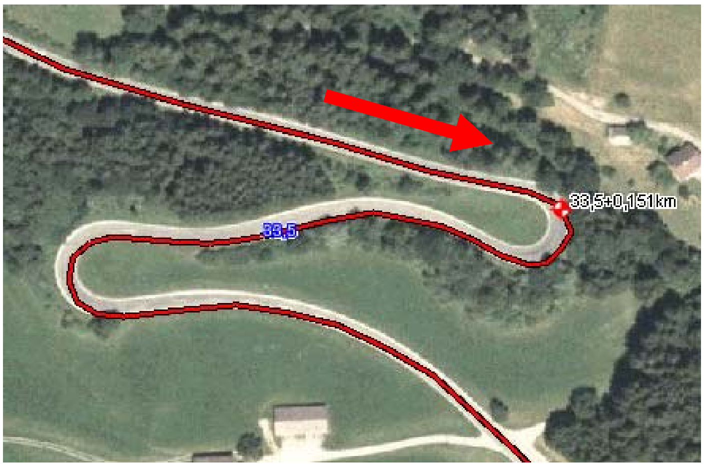

Figure 4: Accident high-risk site B [W 4]

The curve alignment is very sharp, which indicates a higher risk to leave the road due to a lower curve speed threshold. Additional the vehicles are coming from a longer straight section, which is surrounded by trees. This can reduce the perception of the driver, especially in darkness, which is true for two of the three cases. The weather condition had no influence, since in all three accidents a dry road was recorded.

This high-risk site was not inspected at the spot, since the distance was too big and the relevant information, as the type of hazards, are known.

4 Vehicle Infrastructure Interaction Simulation (VISS)

In the following chapter, a ROR accident in a bend on a rural road will be simulated. After the initial accident case, several roadside measures will be applied and the effects will be recorded. Out of this investigation, an assessment of the effectiveness of these measures will be stated, including a cost-benefit analysis.

Two ROR accident high-risk sites were identified and the infrastructure data are prepared for the simulation survey. The first step for establishing a vehicle infrastructure simulation is the simulation model.

4.1 Simulation model

The simulation model consists of three components.

- The road
- The vehicle trajectory
- The vehicle

4.1.1 Road model

As explained in the background, PC Crash is able to import a road model (AutoCad file, dxf), which is created out of the RoadSTAR data. As an example the road model of high-risk site A can be seen on Figure 5. It will be used as first simulation model.

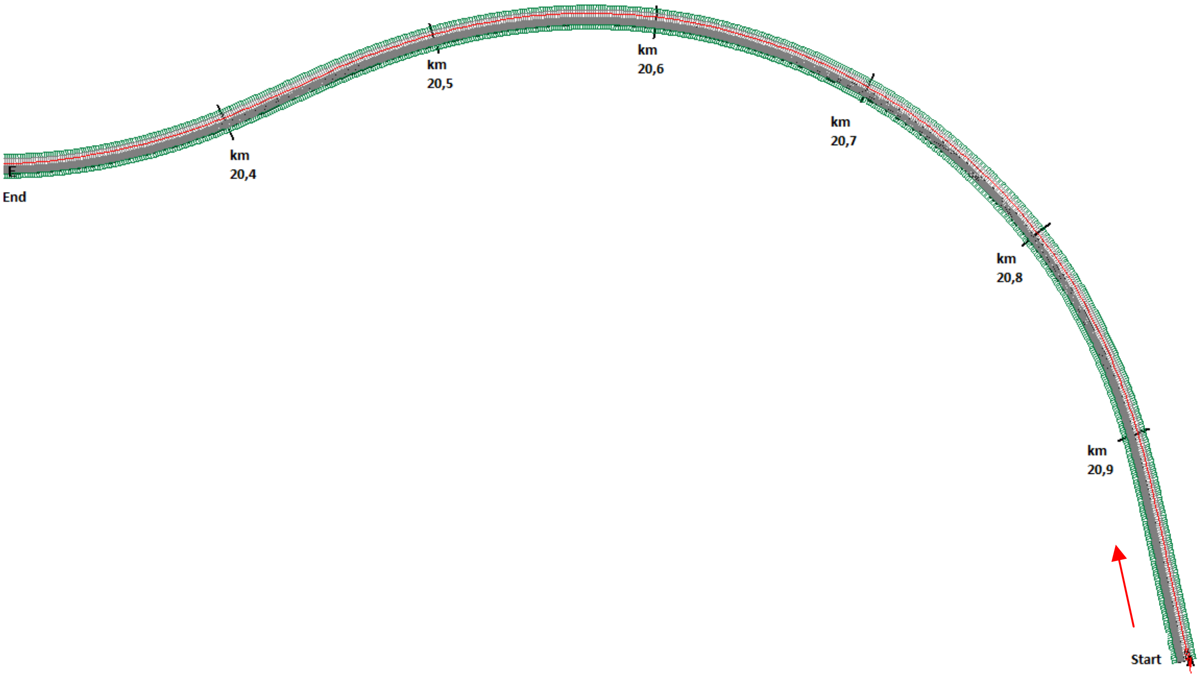

Figure 5: Road Model for High-risk site A

The design of the road model consists of both traffic lanes, whereas the RoadSTAR friction data are only available for one direction, since the measurement of both directions is not cost-worthy. Besides the traffic lanes a 2 meter roadside is added. Figure 6 illustrates a cross section of the road model. Additional to the already mentioned parts also the vehicle trajectory is included.

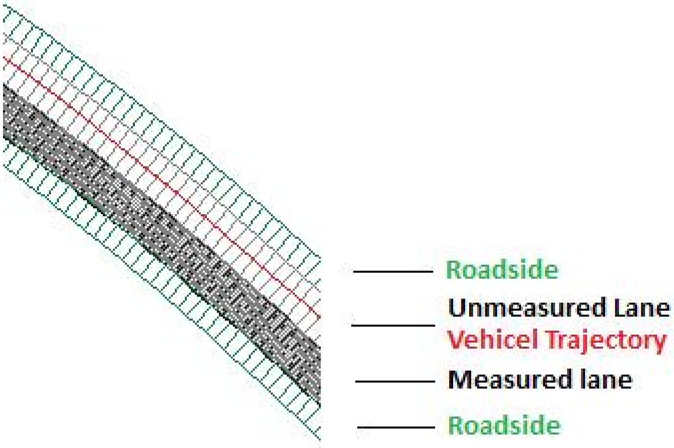

Figure 6: PC Crash Road Model

One of the earlier mentioned problems of the integration of a road model is that slopes and ditches are not implemented in the RoadSTAR data. To deal with this, for the simulation the end of the 2m roadside is considered as the hinge point, where a hypothetical slope starts. This leads additional to a limitation for the roadside measures, since the implementation of a greater safety zone than 2 meter is not possible.

4.1.2 Vehicle trajectory

After the import of the road, the corresponding track has to be applied. To simulate a ROR accident in curves it is first of all necessary to know more about the driver behaviour in these situations. A study to this topic was handled by the ETH Zürich. They investigated the relation of several driving manoeuvres in curves to accident occurrences. The first obvious finding was that it is necessary to distinguish between conscious and unconscious driving manoeuvres. Conscious manoeuvres imply a higher readiness to assume a risk of the driver, for example by exceeding the allowed speed limit. Unconscious manoeuvres on the other hand are often inappropriate reactions of the drivers, like permanently braking and steering, which can lead the vehicle to slip. Especially the combination of braking and steering at the same moment can have much more impacts on the vehicle behaviour than a too high speed. For a deeper analysis the driving behaviour was classified in six groups [P 3].

1. Ideal: The vehicle passes the curve in an symmetric manoeuvre, whereas the vehicle is constantly in an small area around the middle of the traffic lane

2. Typical: The typical driving behaviour implies that the vehicles tend to leave the middle of the traffic lane in wider range and a slightly cutting into the inner side of the curve.

3. Adjust: The vehicle unconsciously drifts to the outside of the curve, leading to a driver reaction to adjust the trajectory. Often the underestimation of the curve radii or length is a factor for this manoeuvre.
4. Cutting: Cutting the curve in the inner side to avoid transverse accelerations.
5. Strike out: The vehicle enters the curve on the outer right side, so that it can exit it on the inner left side.
6. Drift: The vehicle enters the curve at the inner side and drifts though the curve, leaving at the outer side.

For a better understanding Figure 7 illustrates the six types.

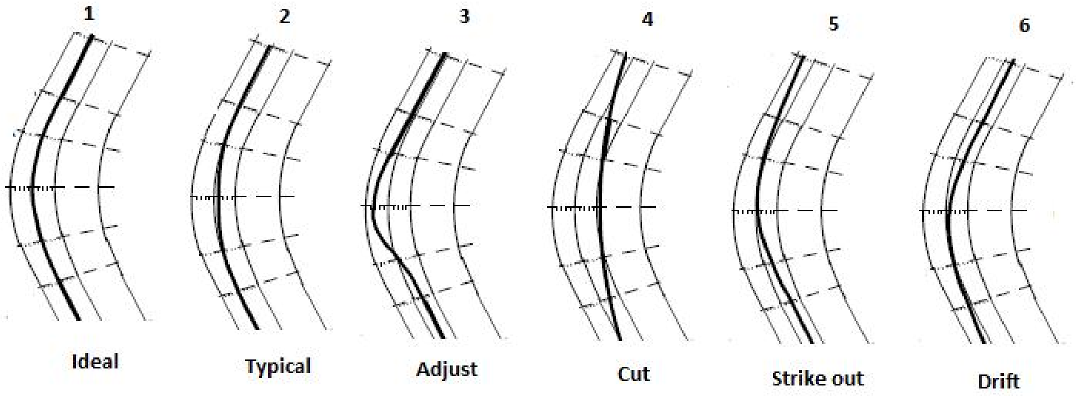

Figure 7: Driving manoeuvres in curves

In the study the of the ETH Zürich the real driving manoeuvres of vehicles in curves was measured. For this purpose 12 ultrasonic sensors where placed along curves to verify the position of the vehicles during the drive through. At total seven curves with different lengths and radii where investigated with the output, that around 37 percent of all vehicles used an inappropriate driving manoeuvre (3, 4, 5, 6), whereas the most common was cutting. Another important finding was that the probability of single vehicle accidents increases with a higher ratio of these manoeuvres. Especially the adjustment manoeuvre (type 3) was found to be a high risk for a single vehicle accident.

4.1.3 Vehicle type

The last part of the simulation model deals with the used vehicle. As already mentioned only ROR accidents of passenger cars were considered. Therefore also the simulation will only include the driving behaviour of a passenger car. According to the data of the Statistic Austria for the passenger cars in Austria (validation date 31.12.2009) diesel engines are with 56 percent more common. The most popular vehicles are Volkswagen with around 880.000 or 20 percent of all announced passenger cars in Austria. The most common vehicle type in the last five years was the VW Golf, hence the simulation vehicle type is a VW Golf IV Diesel with 100 PS from 2003 [W 6]. The distribution of mass is 50/50 between front and rear, as for most of the integrated vehicles in PC Crash.

4.2 VIIS Scenarios

In the next step the different high-risk sites are simulated individually, starting with high-risk site C.

4.2.1 High-risk site A

The first evaluation of roadside intervention will simulate the vehicle behaviour at high-risk site C. As earlier mentioned, accidents occurred mainly in the downstream direction, where in this case no RoadSTAR measurement data are available. For this reason the average of the upstream direction friction was created, which is 0,45. As mentioned in the background the friction is measured for a wet road, whereas a value of 0,45 relates to an acceptable road condition. For the simulation of real accidents at this high-risk site the exact positions of the accidents within the curve were determined. The result is that two of the six accident happened at nearly the same km position with an range from km 20,7 till 20,75. Therefore the simulation will focus on an accident in this section. The road model can be seen on Figure 8.

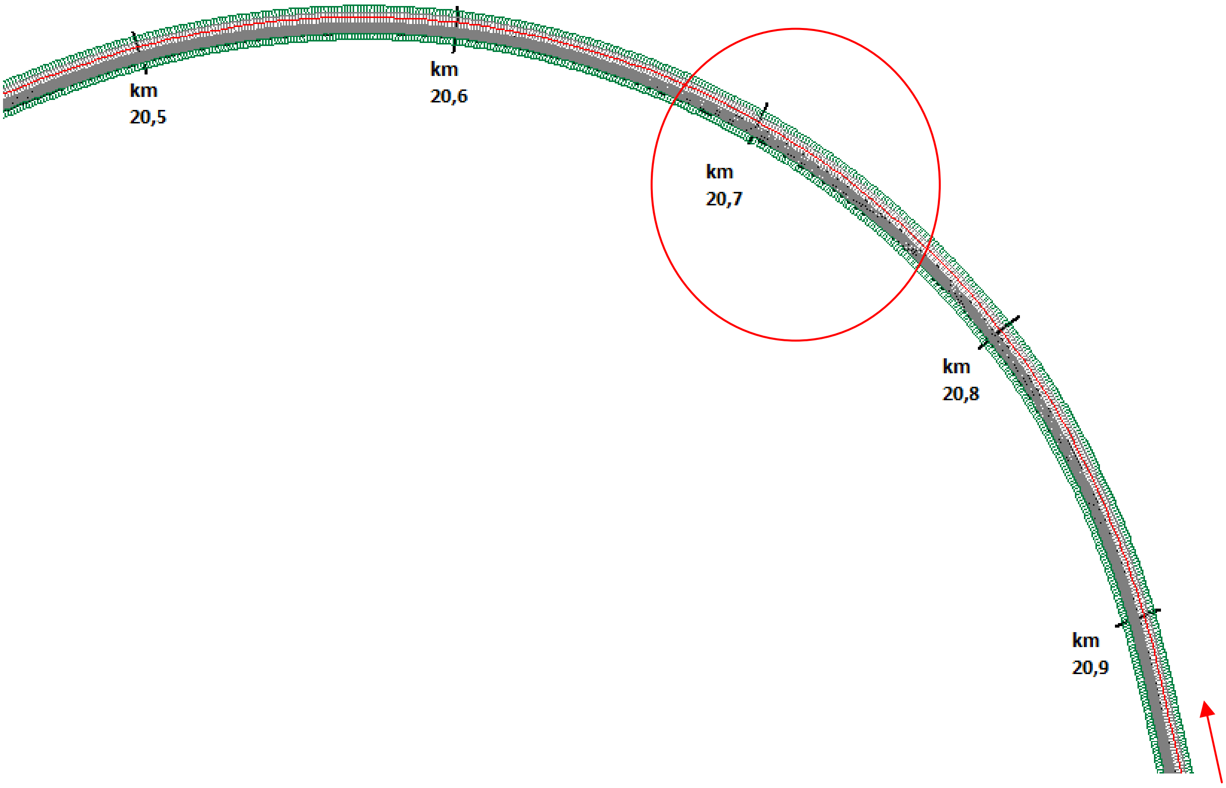

Figure 8: Road Model for accident high-risk site A

About the road alignment it has to be mentioned that:

- The curve has a length of about 400 meter
- It has a wide radius of about 260 meter
- It has an angle of about 90 degree
- It inclines at the beginning and declines at the end

For the simulation of the ROR accidents in the curve of high-risk site A, the first step was to identify a potentially dangerous driving manoeuvre. Therefore an ideal trajectory with a constant vehicle position in the middle of the traffic lane was investigated. For the simulation a constant velocity during the whole curve was assumed, since the curve is drawn out and not very sharp. In the beginning the vehicle has to accelerate a little bit to hold the proposed speed, while in the last sections it has to decelerate. The starting velocity was assumed to be the maximal allowed speed of 70 km/h in the first attempt. With the defined starting velocity, acceleration sequences and trajectory information, PC Crash calculates the vehicle movement. The software tries to keep the vehicle on the trajectory, so automatic steering and braking sequences are performed by the vehicle in inappropriate situations. For the initial case with 70 km/h on an ideal trajectory, no deviation from the original trajectory could be observed. In the next steps the velocity was increased by 10 km/h per step. The first indications for sliding could be observed with 110 km/h when at the km position 20,7 and 20,8 skid marks occurred. Increasing the speed to 120 km/h showed a continuous skid mark for the whole curve section from km 20,8 to 20,7. These two scenarios can be seen on Figure 9.

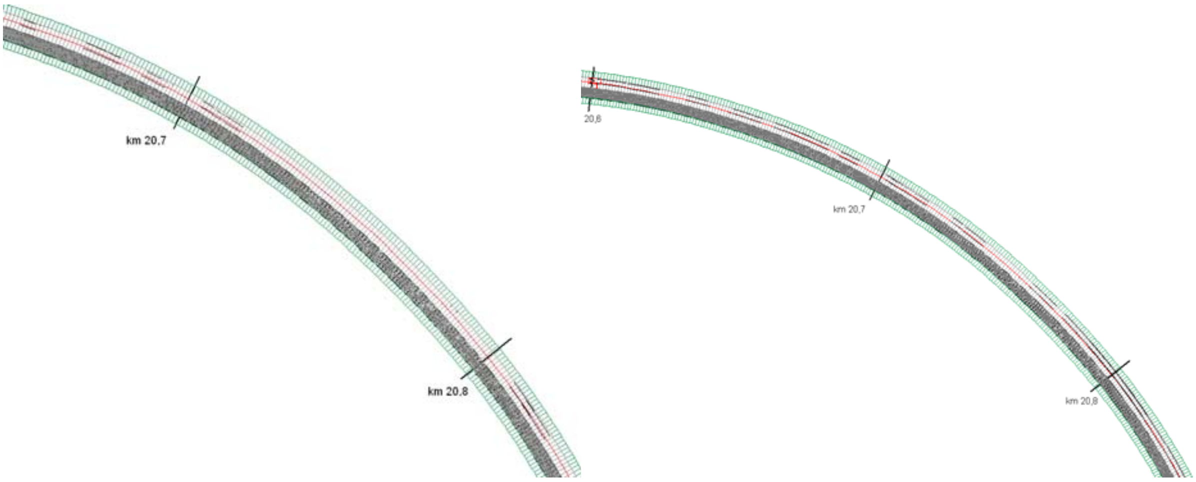

Figure 9: High-risk site A - Ideal Driving Manoeuvre with 110 km/h and 120 km/h

The last investigated speed with 130 km/h lead to an run-off road accident at km 20,8 which is illustrated on Figure 10.

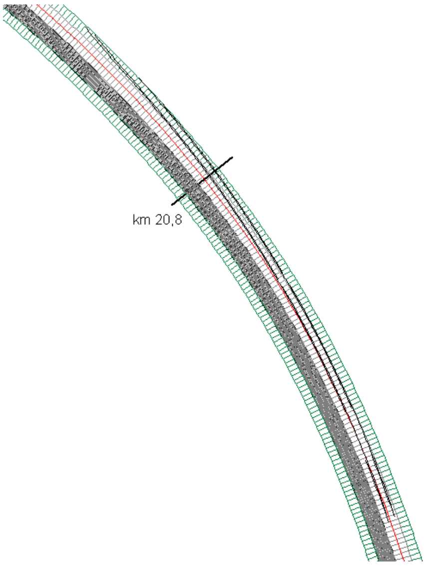

Figure 10: High-risk site A - Ideal Driving Manoeuvre with 130 km/h

Summarizing the observations of the ideal trajectory, it can be assumed that the exceeding of the speed limit is not the only reason for the occurrences of ROR accidents in this curve, since a speed of 110 km/h and higher is not probable. Therefore the already mentioned driving behaviours of the ET Zürich were adopted. Relating to the results of the study, an adjusting manoeuvre for the high-risk site C was created. The position of the manoeuvre was correlated to already mentioned position of km 20,7 to 20,75. Figure 11 shows the adjusting driving manoeuvre through the curve, whereas additional a short braking sequence was implemented at the moment of steering, to increase the probability of sliding.

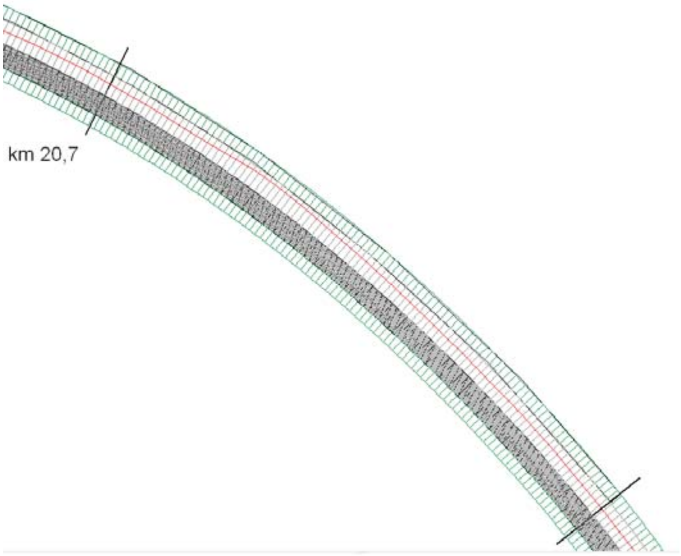

Figure 11: Adjusting Manoeuvre for high-risk site A at km 20,75

After the leaving of the vehicle PC Crash automatically calculates the reaction manoeuvre by steering and braking. No additional driver reactions after the accident will be implemented. The weakness of this is that PC Crash cannot react in the same way as a human being (e.g.

emergency brake). But because of the fact that the interaction of the vehicle and infrastructure is the only importance, the human behaviour will be neglected.

Because of the likehood of drivers to overestimate their driving abilities, and the thus wrong speed adjustment, the speed was chosen with 90 km/h for high-risk site C. Although this speed exceeds the speed limit by 20 km/h it is an appropriate speed on the ideal trajectory as analysed before. The reason why this high speed was applied is the assumption, that most of the drivers are familiar with the curve since they drive there regularly and know the characteristic of it. The assumption can be made, because this road section connects mainly small villages with a bigger town (Korneuburg), from where the next motorway and speedway can be reached (e.g. to reach the 40 minutes away Vienna). So it is mainly used by commuters and local people.

A last constraint is related to the hypothetical ditch after the 2 meter roadside, which has in real for this high-risk site a slope of around 3:1. This causes a higher probability for rollovers, leading to the assumption that accidents have at least severe impacts in cases, where the roadside is exceeded.

The completed framework is valid for all scenarios of high-risk site A and is summarised in Table 3.

Table 3: Framework for High-risk site A

Framework	
Curve Characteristic	Length: 400 m Radius: 260 m Angle: 90°
Height Profile	Inclination in the beginning and declination at the end
Manoeuvre	Adjusting
Velocity	90km/h
Position	km 20,7 -20,75
Roadside Constraint	2 meter, without slopes
Vehicle Movement	No additional manual sequences

Scenario 1: No Forgiving Roadside

The first scenario deals with an ROR accident, where the roadside consists of a 2m wide grass stripe with no shoulder. The friction of the grass area is with 0,1 wet friction low, meaning that the vehicle looses grip when entering the roadside, resulting in an instable vehicle condition. The simulated manoeuvre can be seen on Figure 12.

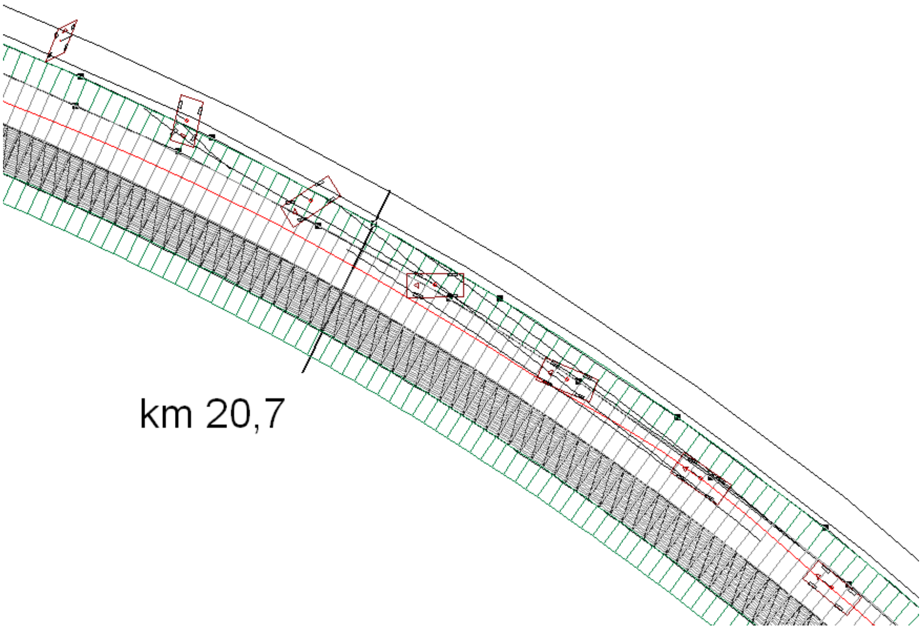

Figure 12: High-risk site A - Scenario1

As can be seen the vehicle is not able to keep on the trajectory and starts to slide. With the low friction of the grass it is not possible to regain control of the vehicle, so that it exceeds the roadside after an approximate distance of 30 meter. The speed at this moment is with 75 km/h very high, so that the accident can be expected to have severe or fatal consequences.

Scenario 2: Soft Shoulder

The first roadside intervention scenario is a soft shoulder. The most common implementation is a gravel stripe, which has more friction than grass, but less than the road. For the simulation a wet friction of 0,3 was used. The effects of a soft shoulder on the vehicle manoeuvre can be seen on following Figure 13

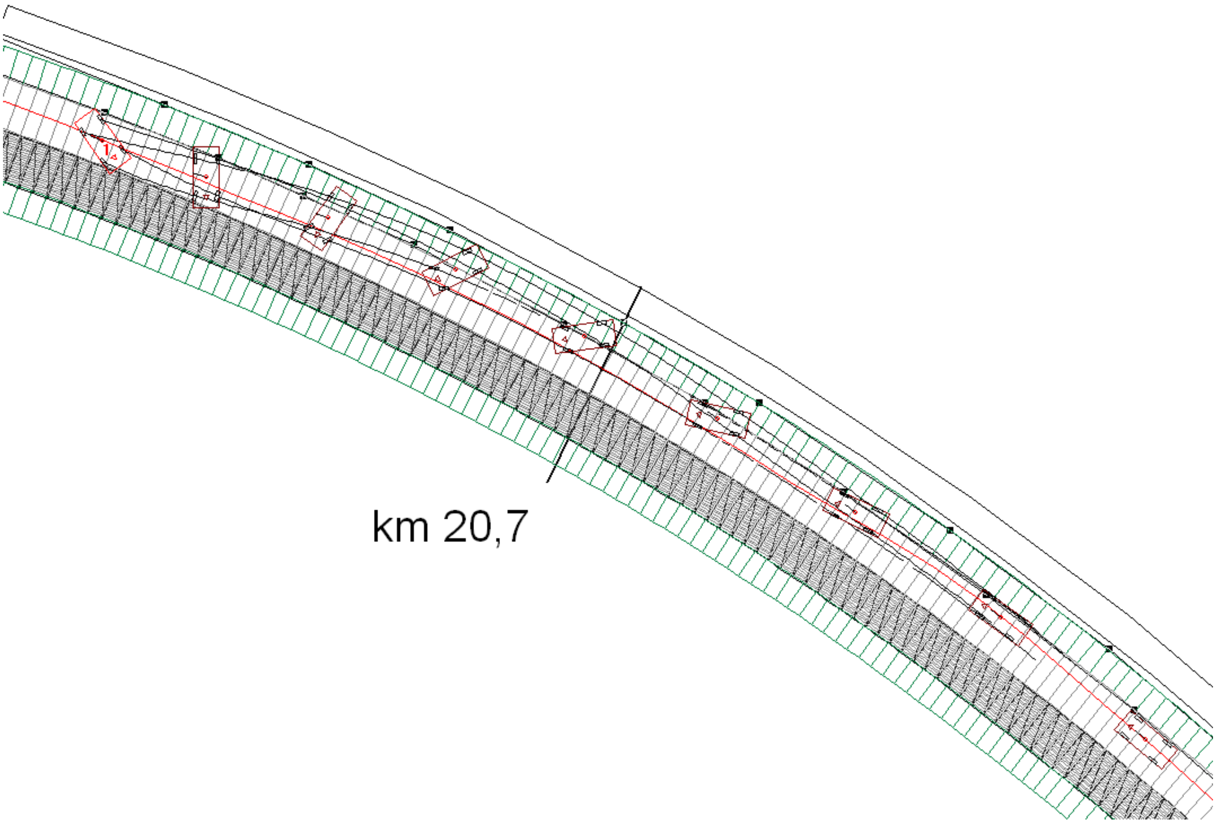

Figure 13: High-risk site A - Scenario2

The figures demonstrate that a soft shoulder would minimize the probability to enter the ditch. On the other hand the vehicle slides along the road, which is a potential danger for other road users.

Scenarios 3, 4 and 5: Hard Shoulder

The scenarios 3, 4 and 5 dealt with an implementation of a hard shoulder. This is realized by matching the friction level of the roadside and the traffic lane. Hence for the whole right part of the road the friction is assumed to be 0,45. In fact also a higher friction of 0,5 to 0,6 can be applied, since the traffic lane in the curve is commonly galled because of the heavy wear, while the roadside is only penetrated in emergency cases. However a friction value of 0,45 showed the expected effects. The vehicle was able to regain control and showed only minimal braking and steering sequences. This was true for all three scenarios, which differ only in the shoulder width. Scenario 3 and 4 with an width of 2 respectively 1 meter show the exact same results, only in scenario 5 with an width of 0,5 m a little bit more steering and braking reactions could be observed.

Scenario 6: Tree

In scenario 6 the same roadside configuration as in scenario 1 was implemented. The only difference is, that an additional tree was placed within the roadside in an distance of 1,5 meter to the traffic lane. The vehicle crashes lateral in the tree with a speed of 70 km/h as can be seen on Figure 14.

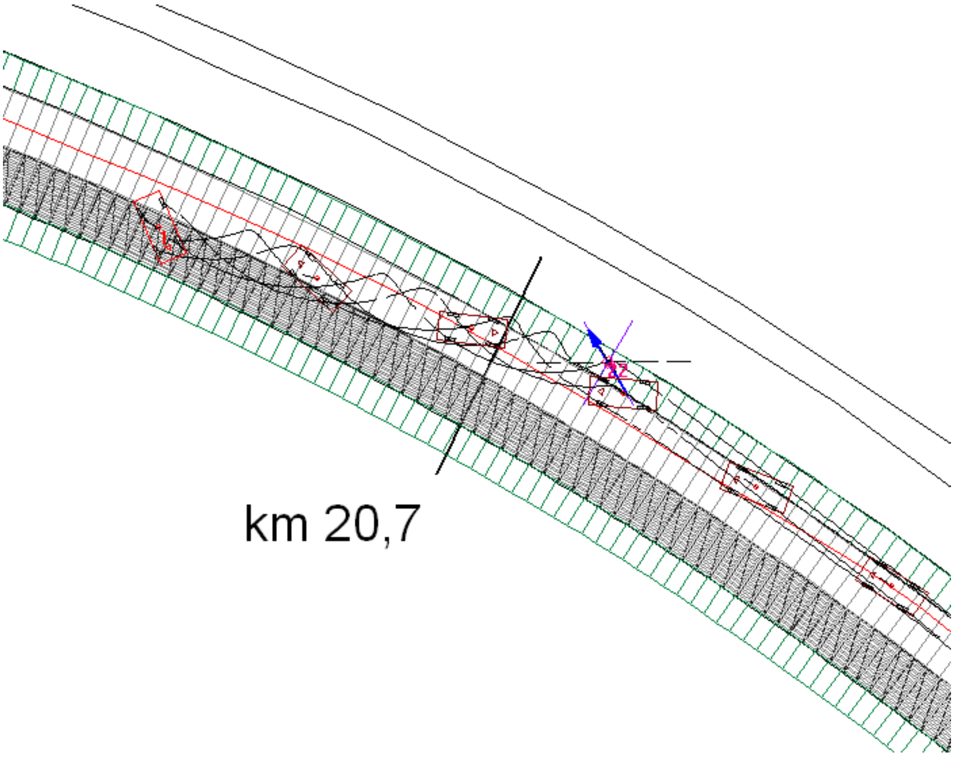

Figure 14: High-risk site A - Scenario 6

The vehicle immediately starts to slide along its own axes until it stops after around 105 meter.

Scenario 7: Safety barrier

The last scenario deals with an implementation of a safety barrier at the position of the accident. This is the real existing case, where nearly over the whole curve a safety barrier is available. As can be seen on Figure 15, the vehicle is shortly colliding with the barrier.

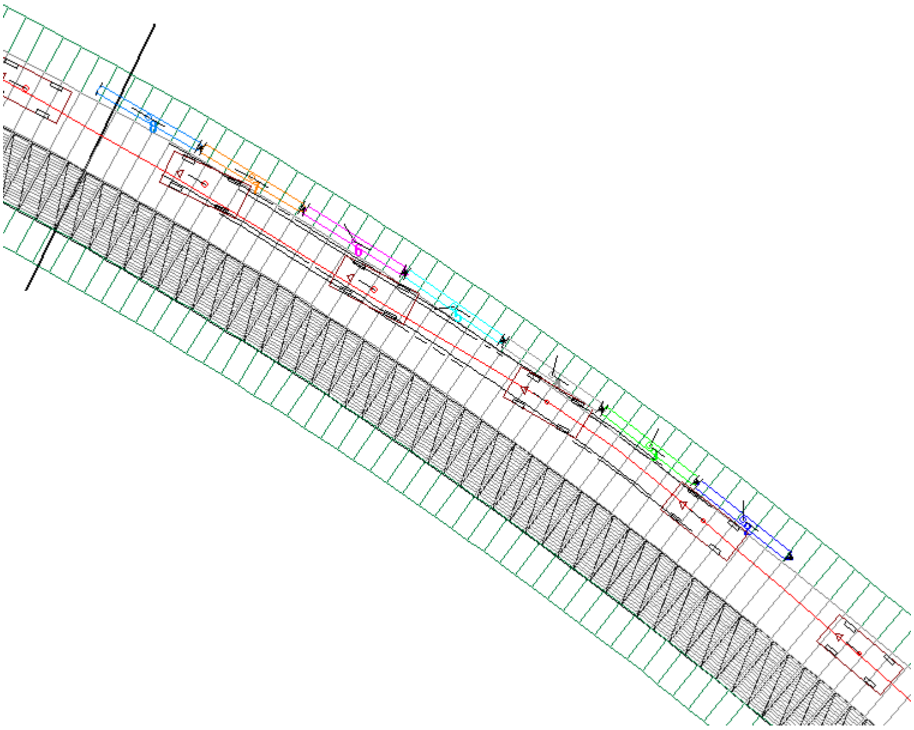

Figure 15: High-risk site A - Scenario 7

This causes on the one hand a reduction of speed, but on the other hand the vehicle is redirected onto its original trajectory, so that it can resume its driving manoeuvre easily.

4.2.2 High-risk site B

The second road model used, to assess the effectiveness of roadside intervention is high-risk site B. As mentioned earlier this high-risk site was the most dangerous one, with three fatal accidents in a time period of five years. Interesting was the fact, that all three accidents happened at the identical position. For one out of the three collisions, a hazardous roadside was recorded, most likely a tree. The occurrence of ROR accidents in this curve are not surprisingly, since the curve radius is very sharp and the vehicle are arriving from a long straight section. Besides the curve radius also a constant declination can be observed. Therefore this high-risk site is an ideal contrast to the prior simulated high-risk site A, since the road alignment plays a much bigger role in this case and the speed will be much less than before.

The road model can be seen on Figure 16, whereas the black arrow illustrates the ROR manoeuvre.

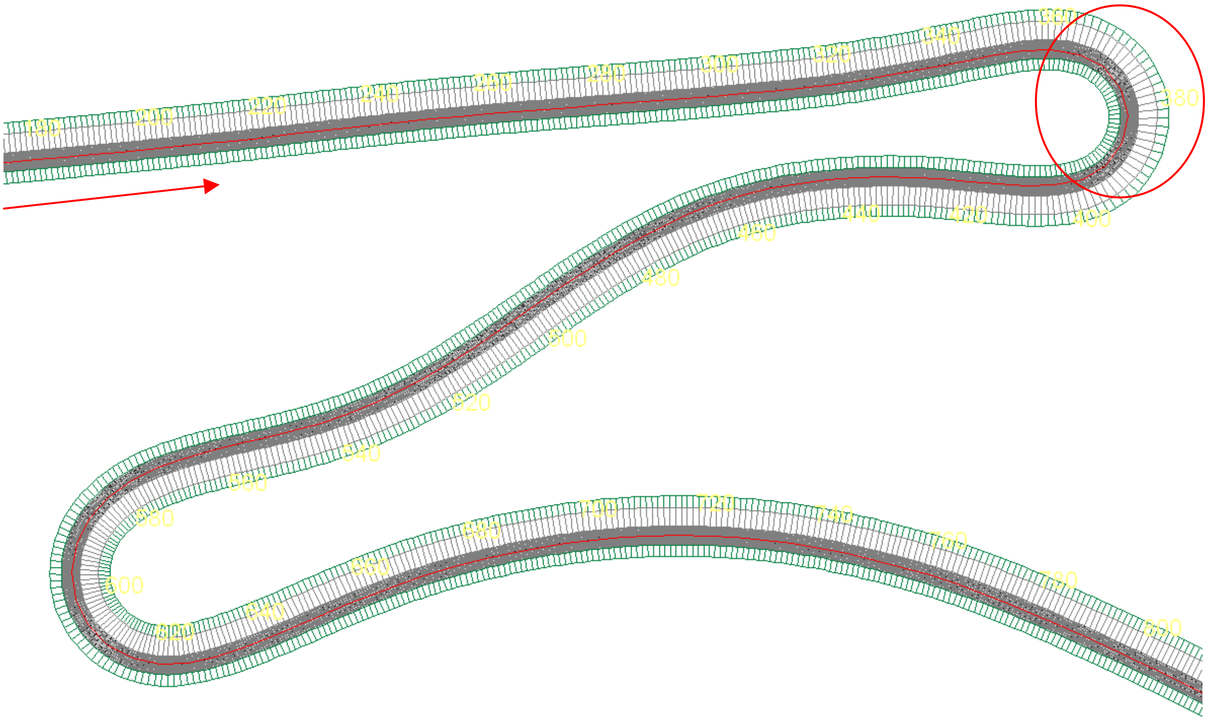

Figure 16: Road Model High-risk site B

In comparison to high-risk site C, the driving direction of the accident vehicles is identical with the RoadSTAR driving direction, so that detailed friction values are available for the used traffic lane. Nevertheless also the opposing traffic lane is of importance, because the vehicle passes through when leaving its lane. It has to be mentioned, that all upcoming scenarios are extremely hazardous for opposing traffic, which is neglected in this study.

As for high-risk site C the wet friction in the most interesting section is with an average value of 0,45 acceptable and will be adopted for the unmeasured lane. As for the prior investigated high-risk site C the roadside is implemented with a width of 2 meters, whereas the above part is handled as steep ditch, which causes severe or fatal accidents (because of the increased probability for rollovers).

After finishing the road model, the next part is the driving manoeuvre. The first assumption is again an ideal driving manoeuvre. The speed limit is unknown but can be assumed to be 50 km/h in the first step, since the vehicle is coming from a long straight section. Important for the speed is the fact that the road declines in the simulated direction. This means that a constant braking sequence is implemented to hold the speed of 50 km/h. It can be observed that the ideal manoeuvre with constant 50km/h is a limit case, since the vehicle is strongly steering and braking, as can be seen Figure 17. As for high-risk site C, no additional human reaction is implanted after the leaving.

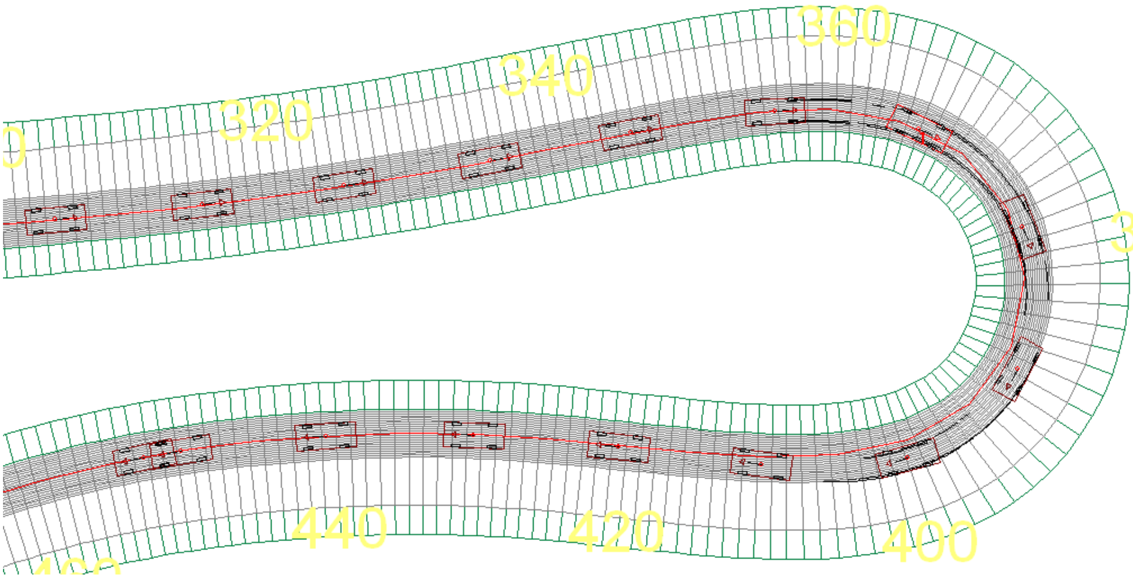

Figure 17: High-risk site B - Ideal Manoeuvre with 50 km/h

Starting with a speed of 55 km/h the vehicle is becoming instable and slides along the roadside. To make the driving scenario more realistic, a strike out manoeuvre is implemented, to increase the radius of the manoeuvre. With this manoeuvre and a speed of 50 km/h the braking and steering reactions could be minimized. Anyhow with a speed of 55 km/h a ROR accidents is not avoidable. Therefore the framework for the scenarios of high-risk site B looks as Table 4.

Table 4: Framework for High-risk site B

Framework	
Curve Characteristic	Length: 40 m Radius: 12 m Angle: 180°
Height Profile	Declination
Manoeuvre	Strike out
Velocity	55km/h
Position	km 33,65
Roadside Constraint	2 meter, without slopes
Vehicle Movement	No additional manual sequences

Scenario 1: No Forgiving Roadside

The first scenario deals with the already mentioned case of an 55km/h strike out manoeuvre. The roadside is considered as grass area, with a wet friction of 0,1. The result is a ROR accident, where the vehicle crosses the opposing traffic lane and exceeds afterwards the roadside, as can be seen on Figure 18.

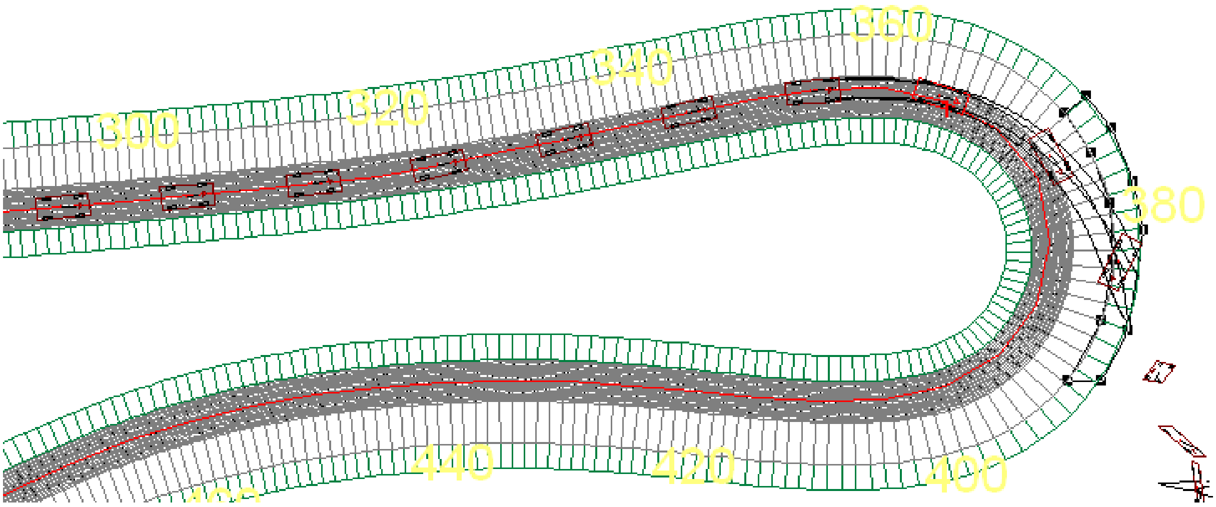

Figure 18: High-risk site B - Scenario1

Scenario 2: Soft Shoulder

Scenario two investigates the effects of an implementation of a soft shoulder. Because of the small radius of the curve, this measure is not helpful at all.

Scenario 3, 4: Hard Shoulder

In scenario three and four the effects of a hard shoulder are analysed. In first step the friction is adopted to the carriageway with a friction of 0,45 (scenario three) Unfortunately no effects on the vehicle behaviour could be observed in comparison to scenario one. Therefore the friction value is further increased to 0,6 (scenario four). This is just for investigation purpose, since it is not probable to have a shoulder, with 30 % higher friction values than on the traffic lane, especially because of the higher dirt probability. Anyhow, simulating this scenario showed an improvement compared to the initial case. The vehicle is now able to stay within the roadside and can resume its driving manoeuvre, as illustrated in Figure 19.

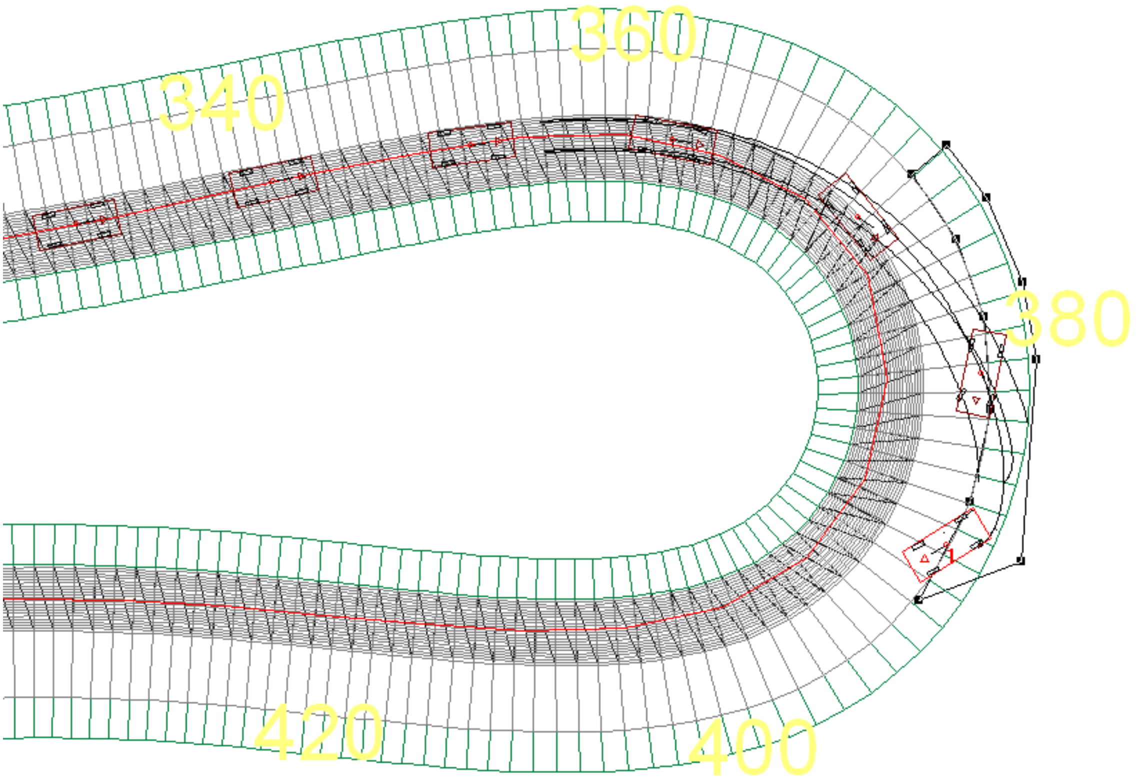

Figure 19: High-risk site B - Scenario 4

Scenario 5: Tree

The fifth scenario for high-risk site B deals with an ROR accident, where the vehicle crashes lateral into a tree, which is 1.5 meter away from the traffic lane. As expected the vehicle is abruptly stopped, leading to strong acceleration forces. The scenario can be seen on Figure 20. The friction value does not have a strong influence on the impact, since the time between entering the roadside and hitting the tree is extremely short.

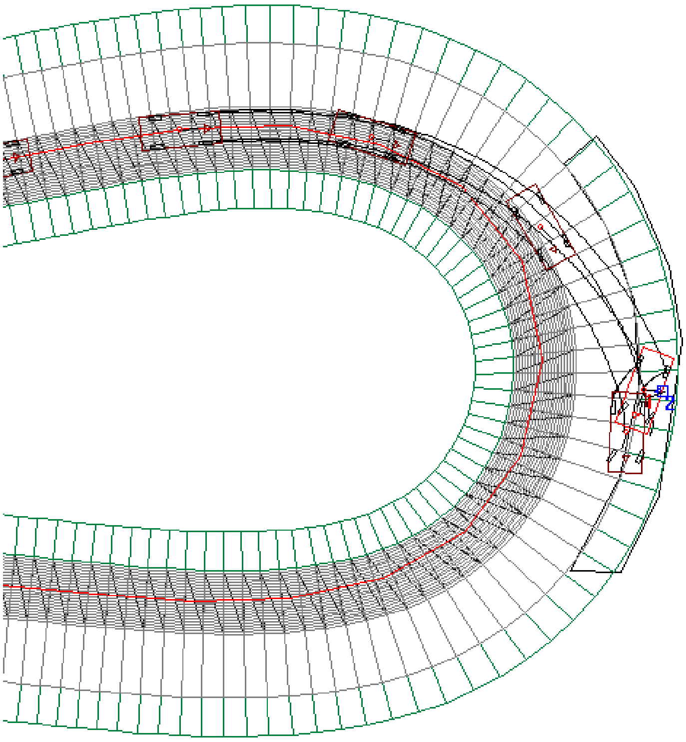

Figure 20: High-risk site B - Scenario 5

Scenario 6: Safety barrier

The last scenario implements a safety barrier to shield the roadside hazards, as trees, from the oncoming traffic. The result is that the vehicle can resume its driving manoeuvre after a short collision phase without sliding, braking or steering indications, as can be seen on Figure 21.

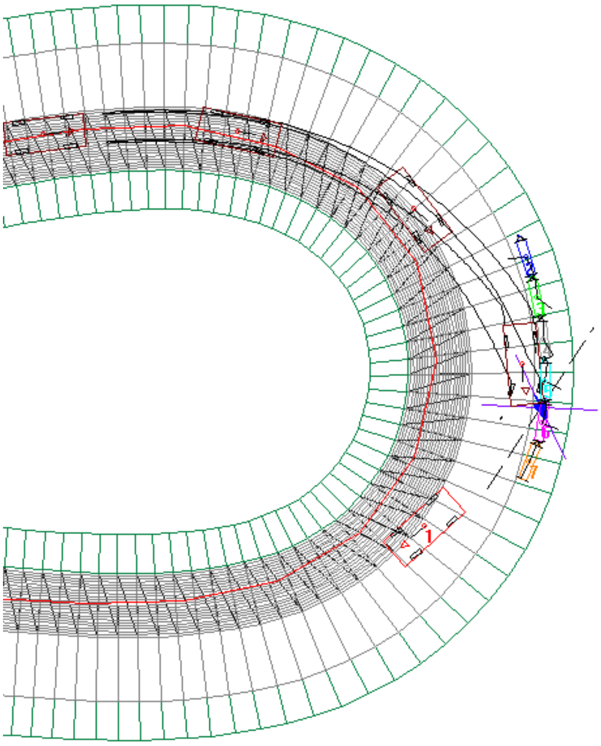

Figure 21: High-risk site B - Scenario 6

5 Assessment of Effectiveness in terms of safety

With the knowledge of the different scenarios it is now possible to analyse the effects of roadside measures on the injury severity. For this purpose several different methods will be used. All methods rely on vehicle data, gathered out of PC Crash during the simulation scenarios. These vehicle information are on the one hand the directly measured collision parameters (e.g. for tree collisions) and on the other hand the overall accelerations and velocities.

5.1 Accident Severity Measurement Methods

The described accident severity measurement methods mainly refer to methods, which are used during crash tests to determine for example the requirements of a traffic barrier, as described in the EN 1317 [P 2] .

5.1.1 Delta-V

The first and easiest method to verify the severity of crash is the Delta-V method. For this procedure, the speed change of the investigated vehicle during a crash is measured. For example a car crashes with 50 km/h into a tree and is decelerated to 20 km/h. The corresponding delta-v is 30 km/h. Taking frontal collisions into account a delta-v value of 15 km/h is assumed to be the limit for no cervical spine injuries For rear-end collisions the limit is reduced to around 10 km/h and for lateral crashes even a delta v of 5 km/h can be dangerous for the occupant on the impact side [B 1]. The problem of this method is that it only works for scenarios, where the vehicle crashes into another object (e.g. vehicle, tree, safety barrier). So it will used additional, but it can´t be used alone.

5.1.2 Energy Equivalent Speed (EES)

The second indicator for a crash severity is the Energy Equivalent speed. The term was introduced in the year 1980 and describes the deformation of a car in terms of the measured kinetic energy [B 1]. It is calculated according to
Equation 1.

$$E_{def} = \frac{m}{2} \cdot EES^{2} \qquad \text{Equation 1}$$

For example for a given deformation energy of 5000 J and a vehicle mass of 1000 kg, an EES of 10 m/s (36 km/h) can be calculated [P 4]. In PC Crash an EES - database with recorded deformations and its EES values is available, so that simulated EES values can be related to real deformations and vice-versa.

5.1.3 Acceleration Severity Index (ASI)

The acceleration severity index is used to determine the acceptance criteria for road restraint systems, according to the EN 1317 1-4 [P 5]. It gives an indication of the severity of the vehicle motion. The ASI is a function looks as Equation 2.

$$ASI(t) = \sqrt{\left[\left(\frac{a_x}{\bar{a}_x}\right)^2 + \left(\frac{a_y}{\bar{a}_y}\right)^2 + \left(\frac{a_z}{\bar{a}_z}\right)^2\right]} \qquad \text{Equation 2}$$

It correlates the acceleration *a* in the body axes x, y, z to a predefined threshold $\bar{a}$ for each direction. The measured accelerations are averaged over a time period of 50 ms. The thresholds determine the limits for an occurrence of severe injuries. Typically the ASI is calculated with the assumption that the occupants wear their seat belts. The limits can be seen in Table 5, whereas the g refers to the acceleration of earth gravity with 9,81 m/s² [P 6].

Table 5: ASI thresholds

Body Axes	Acceleration limit (in g)
Longitudinal x	12
Lateral y	9
Vertical z	10

The ASI is dimensionless quantity, which has only positive values. The risk of severity increases with an increased ASI. For safety barriers two impact severity levels are defined. Level A is reached, when the ASI does not exceed 1,0, while level B ranges till 1,4. All ASI values above are not appropriate values for an implementation of a safety barrier.

5.1.4 Head Injury Criterion (HIC)

The last important term is the head injury criterion. It determines the acceleration acting on the head of the occupant during an accident. It is calculated according to Equation 3

$$HIC = \max\left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a_{res}(t)dt\right]^{2,5}(t_2 - t_1)\right\} \qquad \text{Equation 3}$$

It can be described as the average acceleration over a time period of typically 15 or 36 ms, denoted as HIC_{15} and HIC_{36}. The average acceleration is calculated according to Equation 4.

$$a_{ges} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$ Equation 4

Regarding the HIC_{36} a threshold of 1000 is referred as the limit for severe injuries. The problem is that this value is only consistent with frontal collision. When lateral accidents are investigated, the limit for severe injuries has to be set much lower. This has two reasons. On the one hand, starting with an HIC of 200 the probability of the occupant on the impact side to penetrate the window is significantly higher, which can potentiate the injury [P 5]. On the other hand the cervical spine is not very flexible in the lateral direction, leading to a smaller exposure limit [B 1].

5.1.5 Abbreviated Injury Scale (AIS)

The Abbreviated injury scale is a classification of the injury severity caused by a collision. The six defined levels can be seen in Table 6 [B 1].

Table 6: ASI Levels

ASI Level	Category
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Unsurvivable

Because of the fact that a person can suffer from various injuries, typically the maximum AIS (MAIS) is stated. The problem of this index is that a combination of non-critical injuries can also lead to death, which cannot be detected. However it is a suitable method for the purpose of assessing the injury severity [B 1]

The curve of injury severity can be described as exponential, meaning that it rises steeply after level three. This is illustrated in Figure 22, which relates the AIS level to the lethality rate.

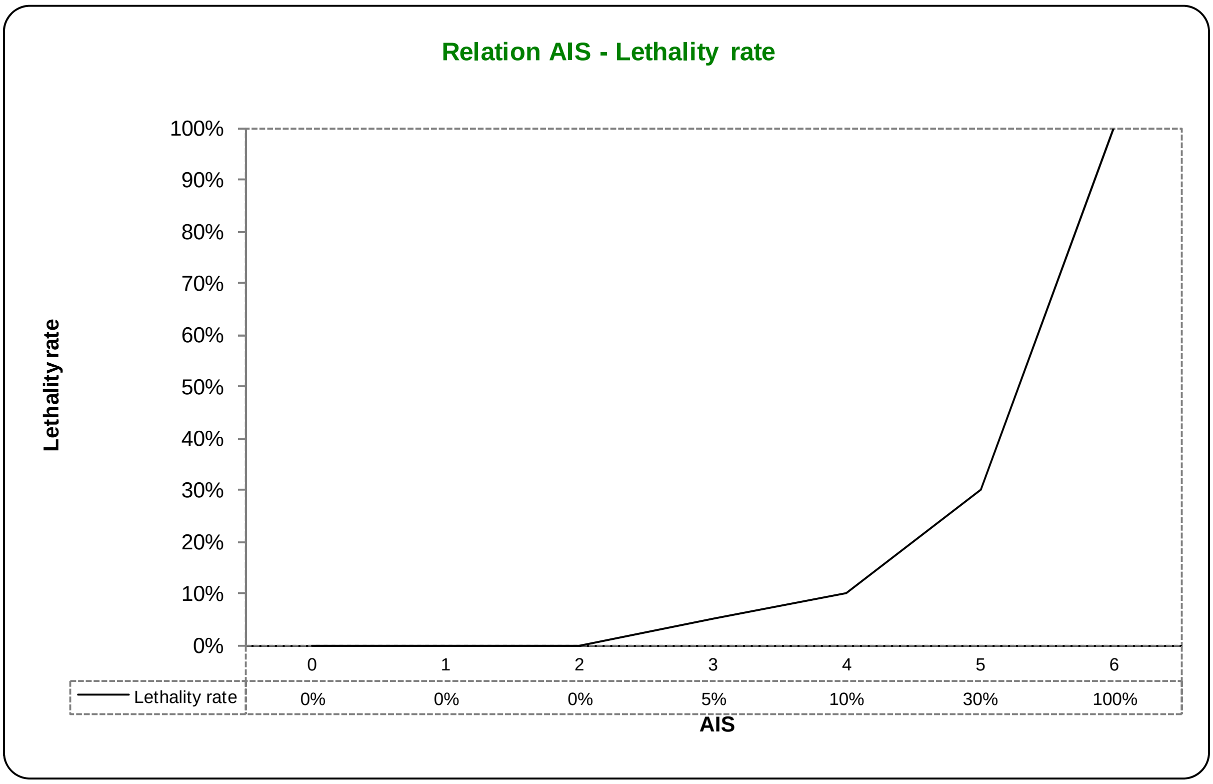

Figure 22: Relation of AIS and Lethality Rate [B 1]

As can be seen level six has a probability of 100 percent for fatality, while it steeply decrease with every level. Level three can be seen as the last crucial AIS level with an expected chance of fatality of 5 percent. Level one and two do not show a life threatening risk for occupants. Therefore a AIS level of maximum tow should be aimed at, when designing a road.

5.2 Assessment of the Roadside Measures

For the assessment of the roadside measures, all prior mentioned methods will be applied on the simulation scenarios. Because of the dependence of the delta-v and the EES method on a collision, they could only be investigated for the tree- and safety barrier-scenarios. Also the ASI is mainly used to determine acceleration forces, caused by a collision with a rigid object and is hence only an additional parameter. Therefore the assessment of roadside intervention effectiveness will rely mainly on the terms HIC and AIS.

According to post mortal experiments a correlation between the two indicators HIC and AIS could be observed [P 5]. The result for head-on collisions can be seen on Figure 23.

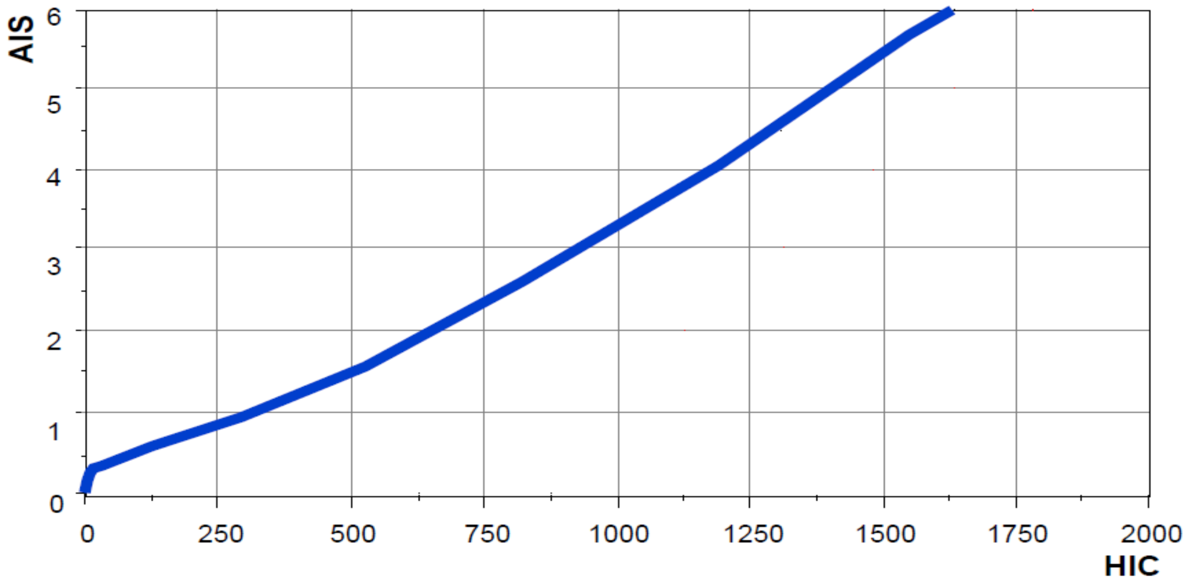

Figure 23: Correlation AIS and HIC [P 5]

The curve describes a nearly linear function, whereas the limit for severe injuries (AIS=3) is reached with an HIC of around 1000, as mentioned before. The limit for fatal consequences according to this study is 1500 [P 5], although some scientists have the opinion that these limits can be set higher [B 1]. Unfortunately no correlation between HIC and ASI for lateral collisions is available yet. Because of the fact that the simulated collisions are not all the time frontal collisions, the severity can only be assed, by applying the earlier mentioned 200 HIC value as limit.

With the assed severities the effectiveness of the measures can be derived. As already mentioned, every AIS level can be related to a specific lethality rate. This means that a decrease of AIS level also decrease the probability of fatalities. Hence Table 7 describes the effects of reducing the ASI.

Table 7: Reduction of AIS Level

AIS Level	Lethality Rate	Effectiveness
6	100 %	-
5	30 %	70 %
4	10 %	20 %
3	5 %	5 %
2	0 %	5 %
1	0 %	0%
0	0 %	0%

This means for example, that a reduction of AIS 6 to AIS 4 reduces the probability for a fatal accident by around 90 %.

5.2.1 Assessment for Accident High-risk site A

Now for the purpose of assessing the effectiveness of roadside intervention, the scenarios were analysed in detail, starting with accident high-risk site A. The scenarios with their results are stated in Table 8. For the ASI the values for seatbelt usage and no seatbelt usage are stated.

Table 8: Simulation results for accident high-risk site A

Scenario	Roadside Friction	Roadside exceeded	dV	EES	ASI	HIC
No forgiving roadside (1)	0,1	Yes	-	-	0,08	6
Soft shoulder (2)	0,3	No	-	-	0,08	7
Hard shoulder (3,4,5)	0,45	No	-	-	0,08	8
Tree (6)	0,1	No	23,56	31,73	0,64	1985
Safety barrier (7)	-	No	1,61	3,69	0,1	10

For all assessments of the injury severity, the estimated MAIS level will be stated. In scenario one, no big accelerations could be observed, but the vehicle exceeded the roadside. The ASI is with 0,08 as well as the HIC of 6 negligible. However the exceeding of the roadside leads to severe or fatal consequences, according to a higher rollover probability. Therefore the MAIS of 6 can be stated.

In scenario two the vehicle is forced to turn by 180 degree. The acceleration forces do not show significant indications for a hazardous situation with an ASI of 0,08 and an HIC of 7. However because of the vehicle rotation a constantly higher acceleration can be observed leading to an increased injury probability. Hence a MAIS value of 2 can be assumed.

The implementation of a hard shoulder, showed an ideal measure. The vehicle shortly reacts and resumes its original driving manoeuvre without any problems. To support this observation, Figure 24, illustrates the longitudinal (red), lateral (blue) and vertical (green) accelerations during this scenario (about 1.5 sec)

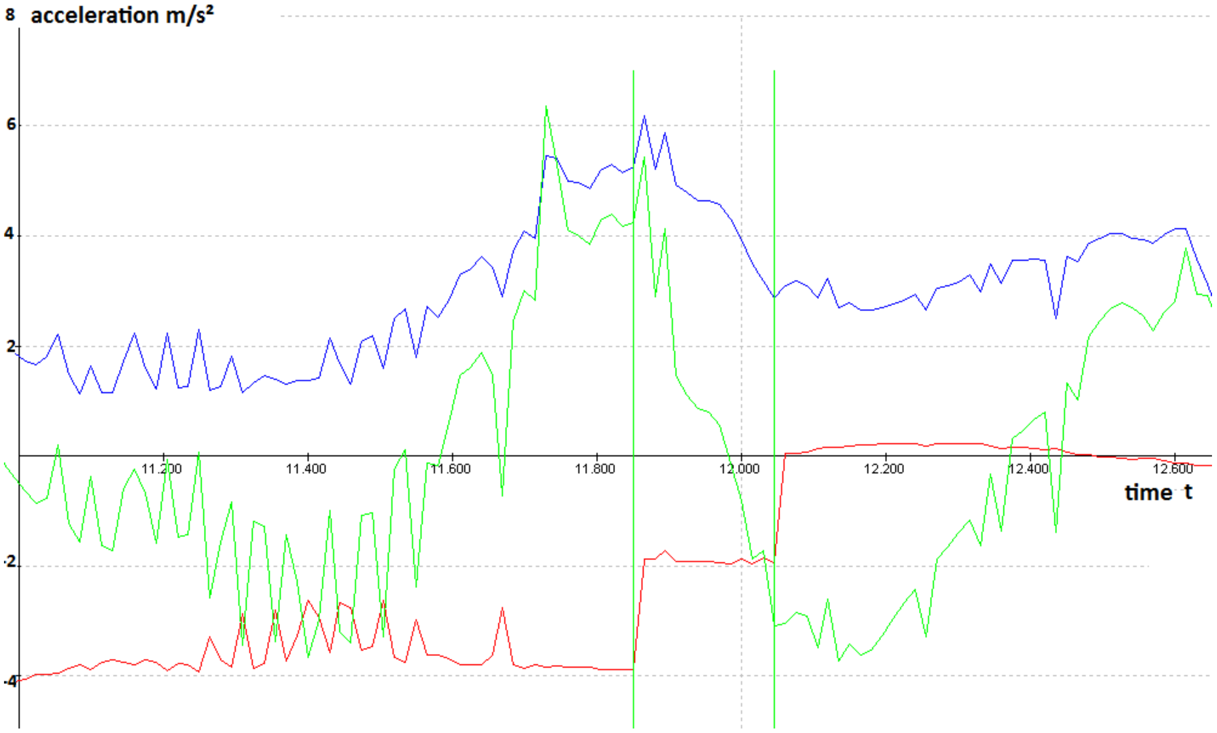

Figure 24: Acceleration forces for scenario 3 (hard shoulder) of accident high-risk site A

As can be seen the separate accelerations do not exceed a value of 6 m/s², so that the maximum average acceleration for this scenario was 9,22 m/s² (at t=11,73). Typically the acceleration during the curve is between 4 and 8 m/s², so it is only slightly increased in this case and can be seen as harmless. The ASI is still 0,08 and the HIC 8 so that no injuries are expected. Hence the MAIS is 0.

In scenario six the consequences of hitting a tree are simulated. Not surprisingly this scenario showed a huge difference to the prior ones. It is the first scenario, where besides the ASI and HIC also the EES and delta-v could be measured efficiently. Figure 25 illustrates the acceleration forces during the lateral impact (about 50 ms), whereas the pre-collision velocity is 70 km/h. The delta-v is with 23.56 in an dangerous region and also the EES of 31.73 km/h indicate a high probability for severe or fatal consequences.

Figure 25: Acceleration forces for scenario 7(tree) of accident high-risk site A

The lateral acceleration reaches its maximum with 80, the longitudinal with – 55 and the vertical with even nearly 105 m/s². The maximum average acceleration is measured with 135 m/s². The ASI value is 0.64, which would be still a suitable value for safety barriers, according to the EN-1317. On the other hand the HIC value is with 1985 in an area, where fatal consequences have to be assumed. This shows that the ASI value is not suitable for lateral collisions, since it is mainly considered to evaluate frontal impacts. Because of the high HIC value an MAIS of 6 can be stated.

The last scenario of accident high-risk site A was the implementation of a safety barrier. As illustrated earlier, the collision is only for a short time and the vehicle is directed in a smooth way back onto its original trajectory. The delta-v of 1.61 and EES of 3.69 support this observation. Also the ASI with 0.1 and the HIC with 10 do not show a significant deviations, leading to a MAIS of 1.

The AIS values and the effectiveness for all scenarios of accident high-risk site A are stated in Table 9., whereas the effectiveness is related to a change between the measure scenario and the non-forgiving roadside scenario one.

Table 9: Effectiveness of roadside intervention for accident high-risk site A

Scenario (Number)	MAIS	Effectiveness
No forgiving roadside (1)	6	0%
Soft Shoulder (2)	2	70%
Hard Shoulder (3,4,5)	0	100%
Tree (6)	6	0%
Safety Barrier (7)	1	90%

Summarizing the results for accident high-risk site A, following can be said:

- The simulation of a tree accident showed high accelerations and deformations at the vehicle. This proves the aim to remove, relocate or shield trees.
- The implementation of a soft shoulder showed an improvement, but it is not suitable for higher speeds, since the vehicle slides along the road in an dangerous way (especially for other traffic users)
- The hard shoulder showed an ideal result, with no injuries and only slight acceleration forces
- The safety barrier was a suitable solution, but it caused a collision, leading to vehicle deformations and slightly increased accelerations

As last note it has to be said that systems as ABS and EPS would be very beneficial for the simulated accident scenarios. Especially the turning manoeuvre in scenario two would not appear with these systems. Nevertheless the simulations showed clear results for the proposed infrastructure measures.

5.2.2 Assessment for Accident High-risk site B

For accident high-risk site B the scenarios show partly big differences compared to accident high-risk site A. First of all again the summary of the scenarios can be seen in Table 10, containing additional the measured parameters.

Table 10: Scenarios accident high-risk site B

Scenario	Roadside Friction	Roadside exceeded	dV	EES	ASI	HIC
No forgiving roadside (1)	0,1	Yes	-	-	0,1	17
Soft Shoulder (2)	0,3	Yes	-	-	0,1	17

Hard Shoulder (3)	0,45	Yes	-	-	0,1	17
Hard Shoulder (4)	0,6	No	-	-	0,1	17
Tree (5)	0,1	No	16,75	13,3	0,31	309
Safety Barrier (6)	-	No	6,6	17,4	0,16	58

As can be seen the first three scenarios have identical values for ASI and HIC, whereas they are not noticeable. The implementation of soft and hard shoulder does not affect the vehicle behaviour in an adequate way. In all three scenarios the vehicle exceeds the roadside, which means a MAIS of 6.

The first positive measure is reached, when applying a hard shoulder, with better friction values than the traffic lane. For this scenario the ASI and HIC values are still the same, but the vehicle is now able to stop before leaving the roadside. The corresponding MAIS is 1, since minor injuries are not impossible.

The collision with the tree (scenario 5) shows again an increased injury severity. The HIC seems to be not very dangerous with a value of 309, since a HIC of 1000 is assumed to be the limit for slight injuries. But taking a closer look at the accident, show that the vehicle crashes lateral into the tree, whereas the driver is seated on the impact side. This means that the probability of the head of the driver to penetrate the side window is high, since this is reached with a HIC of 200. Combining this with the limited flexibility of the head in the transversal direction a fatal accident is not impossible. The impact speed is with 24 km/h not very high, but on the other hand the delta-v is with nearly 17 km/h in a dangerous range. The EES is with 13 absolutely noticeable. Therefore the MAIS level is the 6.

The last scenario is again the implementation of a safety barrier. As for accident high-risk site A the vehicle crashes laterally into the safety barrier. This time at total four collision points could be observed before the vehicle was able to resume its original driving manoeuvre. This caused an overall speed reduction of 17 km/h over a time period of 30 ms. The highest measured impact was the last with a delta-v of 6.6 km/h. The overall deformation for all four impacts is an EES of 17.3 (km/h), so noticeable vehicle deformation can be observed. The ASI is with 0.16 again not high and also the HIC show with 56 not a dangerous situation. Considering the high EES and the four impact points an MAIS of 3 can be assumed. The accelerations for this scenario (about 1 sec) can be seen on Figure 26.

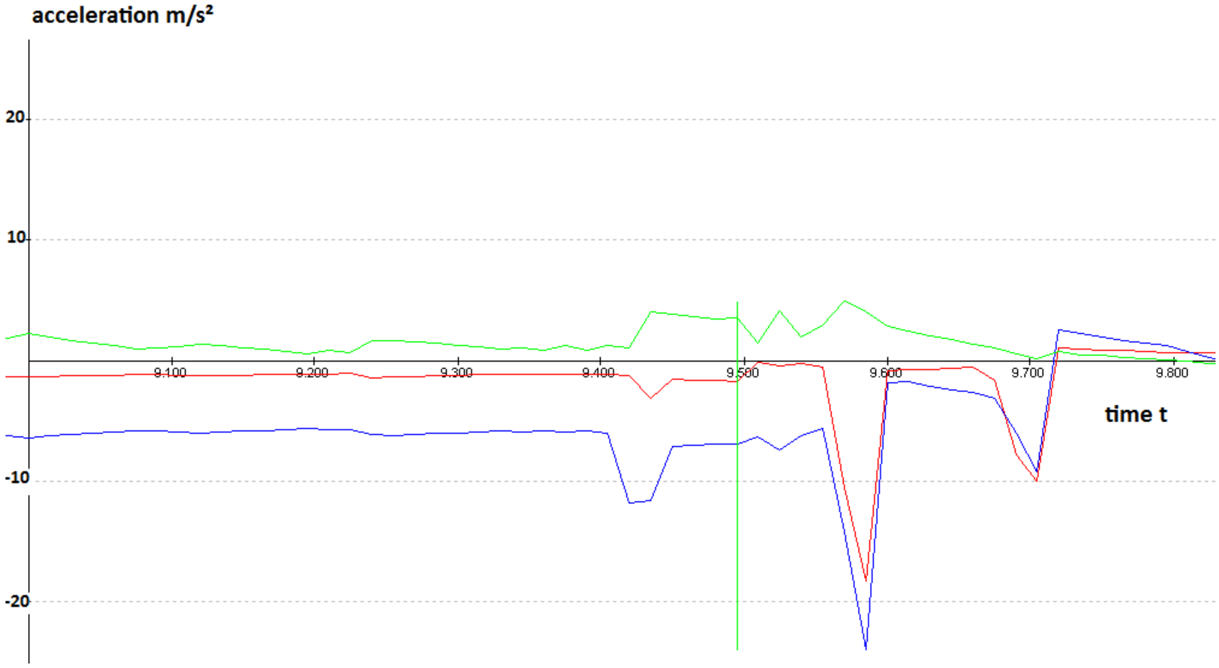

Figure 26: Accelerations for scenario 6 (safety barrier) of accident high-risk site B

Summarizing the observations of accident high-risk site B following can be said:

- Again the tree showed an higher risk potential so that the removing or relocation would be recommended
- The soft shoulder showed no effect at all
- The hard shoulder was only useful with an greater friction than the traffic lane (which is not probable)
- The safety barrier was effective against the tree accident, but it showed strong deformations and accelerations

Table 11 summarizes the observed results.

Table 11: Effectiveness of Roadside Intervention for accident high-risk site B

Scenario (Number)	MAIS	Effectiveness
No forgiving roadside (1)	6	0%
Soft Shoulder (2)	6	0%
Hard Shoulder (3)	6	0%
Hard Shoulder (4)	1	95%
Tree (5)	6	0%
Safety Barrier (6)	3	60%

5.2.3 Summery

The implantation of a soft shoulder can be seen as useless in both cases. It shows an improvement for the drawn-out curve with a reduced probability to exceed the roadside, but on the other hand the risk to slide is increased. This causes a reduction of injury severity, but on the other hand an increased danger for other road users. It can be said that his measure is not appropriate for the speed of 90 km/h and should mainly be used on section with lower speed. Also in sharp curves the implementation of soft shoulder is not suitable, as the second accident high-risk site showed. The vehicle passes the shoulder without any reaction. Therefore this measure was the least effective one in this work.

The second measure, the implementation of a hard shoulder, showed an ideal vehicle manoeuvre for the drawn-out curve. For the case with the same friction value, the shoulder acts as an extended traffic lane. This enables the vehicle to stay on its original trajectory, without strong steering or braking sequences. Therefore the consequences of the ROR were minimized in an optimal way. For the sharp curve, an extended traffic lane was not suitable. Only the implementation of a shoulder with better friction value, than the traffic lane would increase the road safety in an adequate way.

The only suitable measure for both spots was the implementation of a safety barrier. In both cases the safety barrier redirected the vehicle back onto its original trajectory, without any indications of sliding or overturning. However the impact on the barriers caused increased accelerations and deformations at the vehicle. Therefore this measure should be only used in cases, where other measure are not possible, or do not show any positive effect.

The last simulation scenarios handled accidents with trees. As expected, this cases show high decelerations and deformations at the vehicle. Therefore the risk for severe injuries within these accidents is extremely high. The removing of trees in the near surrounding of the traffic lane is strongly recommended. If this is not possible the shielding with safety barriers is a suitable measure, since the severity of the impact is much lower.

The investigated sharp curve (accident high-risk site B) is a good example for a location, where only safety barriers seem to be a suitable measure. On the one hand the other measures are not appropriate and on the other hand the implementation of a safety zone is not possible. Due to the surrounded wood, the space for measures is limited, and the removing of all trees is no alternative. The same is true, when investigating the real surrounding of the drawn-out accident high-risk site A. Because of the placed trees and the steep ditch the space for a hard shoulder is not available, although it would be a suitable measure according to the simulation.

6 Assessment of Cost-effectiveness

In the last chapter shortly the cost-effectiveness of the proposed roadside measures will be analysed. For this purpose a cost-benefit analysis is performed for both identified accident high-risk sites.

6.1 Theory Cost-benefit Analysis

Cost-benefit analysis is a common tool in the transportation sector to evaluate the viability of various alternative measures. Practical criteria are time savings and reduction of crashes or injuries. For this reason, benefits have to be transformed into monetary values, so that costs and benefits can be compared. The first approach for a cost-benefit analysis is the net social benefit NSB, which simply is the difference between benefits (B) and costs (C), as $NSB = B - C$ Equation 5 states [P 9].

$$NSB = B - C \qquad \text{Equation 5}$$

A project can be seen as cost-efficient if the NSB is greater than zero, which means that the benefits exceed the project costs. Since road projects have a certain lifetime, it is necessary to address cost and benefits for a longer time period. This is handled by introducing the net present value into the NSB calculation, as $NPV = \sum_{t=0}^{T} (B_t - C_t) \bullet (1+r)^{-t}$ Equation 6 shows.

$$NPV = \sum_{t=0}^{T} (B_t - C_t) \bullet (1+r)^{-t} \qquad \text{Equation 6}$$

Parameter *T* represents the project duration and *r* the rate of social discount. Typical durations for road infrastructure projects are 25-30 years and a discount rate of 5 % in the European Union [P 10].

A second frequently used method, when speaking of cost-benefit analysis, is the benefit/cost ratio ($\frac{B}{C} = \frac{\sum_{t=0}^{T} B_t \bullet (1+r)^{-t}}{\sum_{t=0}^{T} C_t \bullet (1+r)^{-t}}$ Equation 7).

$$\frac{B}{C} = \frac{\sum_{t=0}^{T} B_t \bullet (1+r)^{-t}}{\sum_{t=0}^{T} C_t \bullet (1+r)^{-t}} \qquad \text{Equation 7}$$

For a cost-effective measure, benefit/cost ratio has to be greater than one.

6.1.1 Accident costs:

The prior assessed benefits from the simulation are related to a reduction of ROR-accident severity. It is therefore necessary to transform these benefits into monetary values. In the year 2007 an accident cost accounting for Austria was performed, where the direct and indirect costs of road accidents for national economy were determined. Looking at the current trends in this field, especially in the European Research Framework Programs, the value of human suffering due to road accidents was included in this calculation [P 7]. For this purpose the so-called Willingness-To-Pay concept was applied, which estimates the value people would pay to reduce the risk of loss of life [P 8].

The total costs of road accidents contain following cost types:

- Medical treatment costs
- Production losses (for the current and consecutive years)
- Human suffering
- Material damages
- General costs (police, fire department, insurance costs, etc.)
- Costs related to accidents with injuries (ambulance, time losses due to traffic congestion etc.)

The calculated accident costs can be seen on Table 12.

Table 12: Average Accident Costs including human suffering [P 8]

Degree of Severity	Value (in €)
Fatality	2,676,374
Severe Injury	316,722
Slight Injury	22,722
Vehicle damage	4,431

6.1.2 Roadside measure costs:

The cost for road infrastructure measures is calculated according to data of the International Road Assessment Programme (iRAP) [P 14]. They provide a list of measures in Malaysia, containing information about installation costs and length of each measure (see Appendix). To be able to compare these costs, they have to be converted from local currency (Malaysisan Ringgint, RM) to € with a course of 4.18 (state 25.11.10) [W 8]. The values can be seen on Table 13.

Table 13: Installation costs of roadside measures

Measure	Installation Costs per meter[1]

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[1] For soft and ard shoulder a width of 2 meter is assigned

Soft shoulder	19 €
Hard shoulder	60 €
Safety barrier	72 €

6.2 Cost-effectiveness of roadside measures

The cost-effectiveness of roadside measures will be performed at the two simulated accident high-risk sites. The benefits are related to reductions in accident costs. The potentially saved accident costs due to the measures correlate to the ASI-results from the prior simulations of each measure (Table 9, Table 11). For the calculation of accident costs it is necessary to transform the ASI levels into its correlated accident severity as Table 14 shows.

Table 14: Transformation ASI to accident severity level

ASI	Accident severity
1 **2**	Slight
3 **4** **5**	Serious
6	Fatal

With this data it is possible to verify the potentially saved accident costs, due to a roadside measure implementation.

The performed analysis will be slightly different to typical applications. Traditionally cost-effectiveness is used to analyse future benefits of a measure. This quite difficult in this case, since ROR accidents are stochastic events, which are not predictable. For this reason the analysis will instead rely on the real existing accidents of the past five years (2005-2009), as for the evaluation of the accident high-risk sites.

6.2.1 Accident High-risk site A:

At this high-risk site, five accidents with personal damage occurred within the investigation period. The original roadside design of accident high-risk site A (chapter3.1) includes already a safety barrier along the whole bend (about 200 meter per direction), which protects the vehicles from the behind placed trees. Beneath trees also the slope on both sides can be seen as hazardous with a slope rate of about 3:1.

The original severity data reflect, as already mentioned, on an implementation of a safety barrier. At total five accidents occurred from 2005 to 2009, whereas all of them have slight injury causes. Unfortunately it is not possible to determine the overall effect of this measure, since no data about avoided accidents (in terms of accidents without personal damage) due to the safety barrier are available. Anyhow, transforming the known accidents to a roadside design without any roadside measure could lead in worst case to five fatal accidents, according to the simulation results (chapter 5.2.1). The implementation of a hard shoulder would reduce the severity of ROR accidents to zero, while a soft shoulder showed again slight injuries, as for the safety barrier scenario. Summarized the results can be seen on Table 15.

Table 15: Accident severities for measures at high-risk site A

Accident High-risk site A					
Measure	**ROR- accidents**	**Severity**			**Length (m)**
		Fatal	**Serious**	**Slight**	
No forgiving roadside	Total	**5**	0	0	200
	Annual	**1**	0	0	200
Soft shoulder	Total	0	0	**5**	200
	Annual	0	0	**1**	200
Hard shoulder	Total	0	0	0	200
	Annual	0	0	0	200
Safety barrier	Total	0	0	**5**	200
	Annual	0	0	**1**	200

As can be seen the annual number of ROR accidents is one, when looking at the five years of investigation, which is the further the reduction potential for this time period.

The installation cost for each measure over the whole section on both sides (400 meter) of the road can be seen on Table 16.

Table 16: Cost for roadside measures at accident high-risk site A

Measure	Costs
Soft shoulder	7,600 €
Hard shoulder	24,400 €
Safety barrier	29,200 €

As mentioned in the beginning of this chapter, the cost-effectiveness in this work is related to the last five years. The reduction potential for this time period is one accident per year, which gives following result for the first year of installation (Table 17).

Table 17: B/C ratio for the installation year 0

Measure	Accident costs	Benefit	Inst. Costs	B/C
No forgiving roadside	2.676.374 €	-	-	-
Soft shoulder	22.722 €	2.653.652 €	7.656 €	347
Hard shoulder	0 €	2.676.374 €	24.101 €	111
Safety barrier	22.722 €	2.653.652 €	28.708 €	92

As can be seen the benefit to cost ratio show a significantly high value for the installation year, and assuming that the yearly maintenance costs are low for this short section, the ratio would even increase for a time period of five years. The high value can be explained by the short time. As mentioned a typically lifetime of road infrastructure projects is 25 years, so detailed statements can only be gathered after this time.

Noticeable is that the benefit/cost ratio is mainly effected by the installation costs, since benefits are nearly the same for all three measures. This is directly related to the simulation results, which showed similar safety performances for all three measures. Therefore this result is not very meaningful.

6.2.2 Accident High-risk site B:

The original roadside design of accident high-risk site B does not include a safety barrier along the 40 meter long curve. Next to an existing (but not further specified) shoulder, trees are planted along the curve. As for high-risk site A also a slope can be assumed, although the slope rate is not determined.

According to the simulation results of this accident high-risk site, the measures soft- and hard shoulder did not improve safety compared to the scenario without forgiving roadside. So this lack of information does not influence the assessment of cost-effectiveness. Originally three fatal accidents occurred in the five years of investigation. With the implementation of a safety barrier the severity in the simulations could be reduced to at least serious. Therefore following numbers can be stated (Table 18)

Table 18: Accident severities for measures at high-risk site B

Accident High-risk site B					
Measure	ROR- accidents	Severity			Length (m)
		Fatal	Serious	Slight	
No forgiving roadside	Total	**3**	0	0	40
	Annual	**0,6**	0	0	40
Soft shoulder	Total	**3**	0	0	40
	Annual	**0,6**	0	0	40
Hard shoulder	Total	**3**	0	0	40
	Annual	**0,6**	0	0	40
Safety barrier	Total	0	**3**	0	40
	Annual	0	**0,6**	0	40

For this accident high-risk site the reduction potential is 0.6 ROR accidents per year.

The installation cost for each measure over the whole section on both sides (80 meter) of the road can be seen on Table 19.

Table 19: Installation cost for roadside measures at accident high-risk site A

Measure	Costs
Soft shoulder	1,520 €
Hard shoulder	4,880 €
Safety barrier	5,840 €

As for accident high-risk site A the cost-effectiveness relates to last five years(2005-2009), whereas the reduction potential is with 0.6 accidents per year little bit smaller. The results for this high-risk site can be seen on Table 20.

Table 20: B/C ratio for the installation year 0

Measure	Accident costs	Benefit	Inst. Costs	B/C
No forgiving roadside	1.605.824 €	-	-	-
Soft shoulder	1.605.824 €	0 €	1.531 €	0

Hard shoulder	1.605.824 €	0 €	4.820 €	0
Safety barrier	190.033 €	1.415.791 €	5.742 €	247

Referring to the results from the simulation, only the safety barrier is an appropriate choice for this high-risk site. Therefore only for this measure a benefit/cost ratio can be given. Because of the short time frame and the low installation cost, again the ratio is very high. As for the first scenario the results are ambiguous because of lacking information about accident occurrences.

6.2.3 Summary

The output of the cost-effectiveness analysis is very ambiguous. The values of the benefit/cost ratio are high, and differences between measures are mainly related to different implementation costs.

The problem for the assessment of cost-effectiveness of measures at the two identified accident high-risk sites is that the potential of safety improvements is hard to evaluate, since accidents are random events. It is not possible to predict the amount of accidents, which can be avoided with the implementation of roadside measures, so that only assessments based on currently obtained accident data can be performed.

Secondly the time period of five years is too less to achieve suitable results. This can be seen in two ways. On the one hand the observation period influences the result in a tremendous way. Expanding the investigation time to the last 20 years, show only the already observed five ROR accidents at high-risk site A. This means that the reduction potential would be reduced form one accident per year to 0.25, which is significantly smaller. In second meaning the lifetime of road infrastructure measures is typically 25 years, so that future accident occurrences have to be considered. This means that some kinds of predictions are necessary.

The last problem for the assessment of cost-effectiveness in this work is the relation to the simulation results. The simulation dealt just with one possible ROR accident in the curve. For this manoeuvre the measures showed similar results, which lead to similar accident costs. But looking at various manoeuvres the performances of the measures will differ in wider ranges so that more suitable results can be expected.

Conclusion

The two simulated high-risk sites showed quite different results for roadside measures against ROR accidents in bends. For a drawn-out curve (accident high-risk site A) the implementation of a two meter hard shoulder, which acts as extended traffic lane, is an appropriate choice. Also the implantation of a safety barrier showed positive effects on road safety, but because of increased accelerations and the observed deformations this measure is only suitable, when space is limited and the removing of hazardous objects (e.g. trees) is not possible. For the sharp curve of accident high-risk site B the modifications of the shoulder were not effective. Only a shoulder with a 30 % higher friction than the traffic lane would increase the probability to regain control of the vehicle. However this is not valid for real world roads, so that these measures have to be discarded. The implementation of safety barriers on the other hand assures a better safety performance in this case, although again deformations and accelerations at the vehicle have to be expected. Especially in comparison to accidents with trees the proposed measures show significant improvements. The implementations of roadside measures increase road safety, by mitigating the consequences of ROR accidents. The cost-effectiveness indicates a potential in accident cost reduction, but the results are too ambiguous for further statements.

According to the Austrian Road Safety Program 2002-2010, the implementation of Forgiving Roadsides is one the main objectives in the area of road infrastructure. The accident analysis of car ROR accidents in rural bends confirmed this goal. ROR accidents accounted about 5 % of all car accidents in the years 2005 to 2009, whereas the percentage of corresponding fatalities is over 10 %. Especially the accident circumstance with the code 17, which indicates a collision with a fixed object, was found to be dangerous, with a 60 % higher average accident severity compared to typical ROR accidents in bends. This is a direct relation to the guideline draft on “Protection from accidents with stationary objects” (Austrian guideline, RVS).

The final aim of that work was related to a necessity for improvements of roadside information in the Austrian road accident database. The only possibility to gain corresponding information is the accident circumstance, which determines the event of the accident in more detail. For the purpose of roadside design two circumstances were interesting. The first circumstance determines “collisions with guidance / safety facilities” (circumstance 15), while the second one deals with “collisions with fixed objects” (circumstance 17). For circumstance 15 it has to be said that the terminology is not suitable, since guidance facilities (e.g. guidance poles) have completely different functions than safety facilities (e.g. safety barrier). The mixture of these two groups in one circumstance is not appropriate. Completely missing are information about shoulder, slopes and ditches. Information about the shoulder can be seen as unnecessary for the event of accident, but it would be an advantage for road accident analysis to have all relevant information in one database. The existence of slopes and ditches, particularly when they affect the event of accident (e.g. rollovers), on the other hand are definitely necessary information. So the hypotheses is confirmed, that road accident data have to be improved, especially when determine run-off-road accidents

Outlook & Recommendations

To asses better performances of the measures it is one possibility to simulate various alternative driving manoeuvres through the bend. This would lead to more realistc information, since accidents are individual scenarios.

To improve the quality of roadside simulations, the RoadSTAR measurements can be expanded. It is advisable to image the roadside for all roads in Austria either by activating the video systems all the time or, as discussed at the moment, by installing a 3D-laser scanning system. The advantage of the second method is an easier extraction of objects, by automatic algorithms. Second improvement is the library for roadside objects in PC-Crash. The standard version contains only simplified objects as safety barriers, but it could be interesting to implement different types (e.g. rigid, semi rigid). Also special hazards as terminals and transitions of safety barriers could be interesting extensions.

Also the evaluation of occupant injury risk can be improved. One possibility is to implement the MADYMO software tool, which deals with occupant simulations. This would lead to more precise statements about the injury risk. For the evaluation of injury risk out of the vehicle dynamics, as done in this work, more research has to be done. The used methods are typically used in crash tests, which rely on collision between two objects. Problematic are situations, where no collision exists (e.g. turning of the vehicle). The problem is that these manoeuvres have less acceleration amplitudes over a longer duration, which can`t be detected with the used methods. Another problem is the type of collision. For frontal collisions the body movement can be predicted, while for lateral collisions it is dependable on several factors. First of all the degree and side (driver/co-driver) of the impact determine the injury risk. Moreover the level of surprise is a key factor for injuries. Is the driver aware of the hazardous situation, he can take safety precautions immediately. The last factor for the injury risk in lateral collisions is the cervical spine, which is much more flexible in the longitudinal direction. Including all these facts, more severe injuries have to be expected in lateral collisions, but it is not possible to state direct relations between HIC and AIS as for frontal collisions. Therefore theses considerations have to be implemented manually at the moment.

For the accident analysis it would be beneficial to have more specified roadside information in the road accident database. The first recommendation is to split the circumstance “collisions with traffic guidance /safety facilities” in two separate parts or eliminate the guidance facilities completely. Secondly it would be useful to have a separate circumstance for accidents, which includes slopes and ditches (e.g. rollover). The last recommendation for the accident database is the implementation of shoulder information in the road description. Having all these information in one database, would increase the efficiency of accident reconstructions. Possible applications are road safety audits, where detailed information about the event of accidents and road design are beneficial.

Implementing all the prior mentioned recommendations contribute to an increased quality and usability of VIIS. It can be used as support for road safety audits and inspections, since real road sections can be analysed more easily. It is a cost worthy and time saving tool to assess the effectiveness of measures on real roads. With the combination of VIIS and MARVin it is possible to detect weaknesses in the road network, so that future accidents can be avoided in advance.

As already mentioned the cost-effectiveness analysis is ambiguous at the moment. With better results from the simulation, also the quality of this part could be improved. However, the biggest problem is the uncertainty about the reduction potential. One approach is to implement an accident prediction model for these particular spots, which takes into account factors as traffic flow, alignment, sight distances, road parameter and much more. With an evaluation of potential future accidents it is possible to determine the cost-effectiveness of measure at particular spots. In fact also other factors as land use and environmental impacts (e.g. cutting of trees) have to be included in this evaluation, but this was not part of this work.

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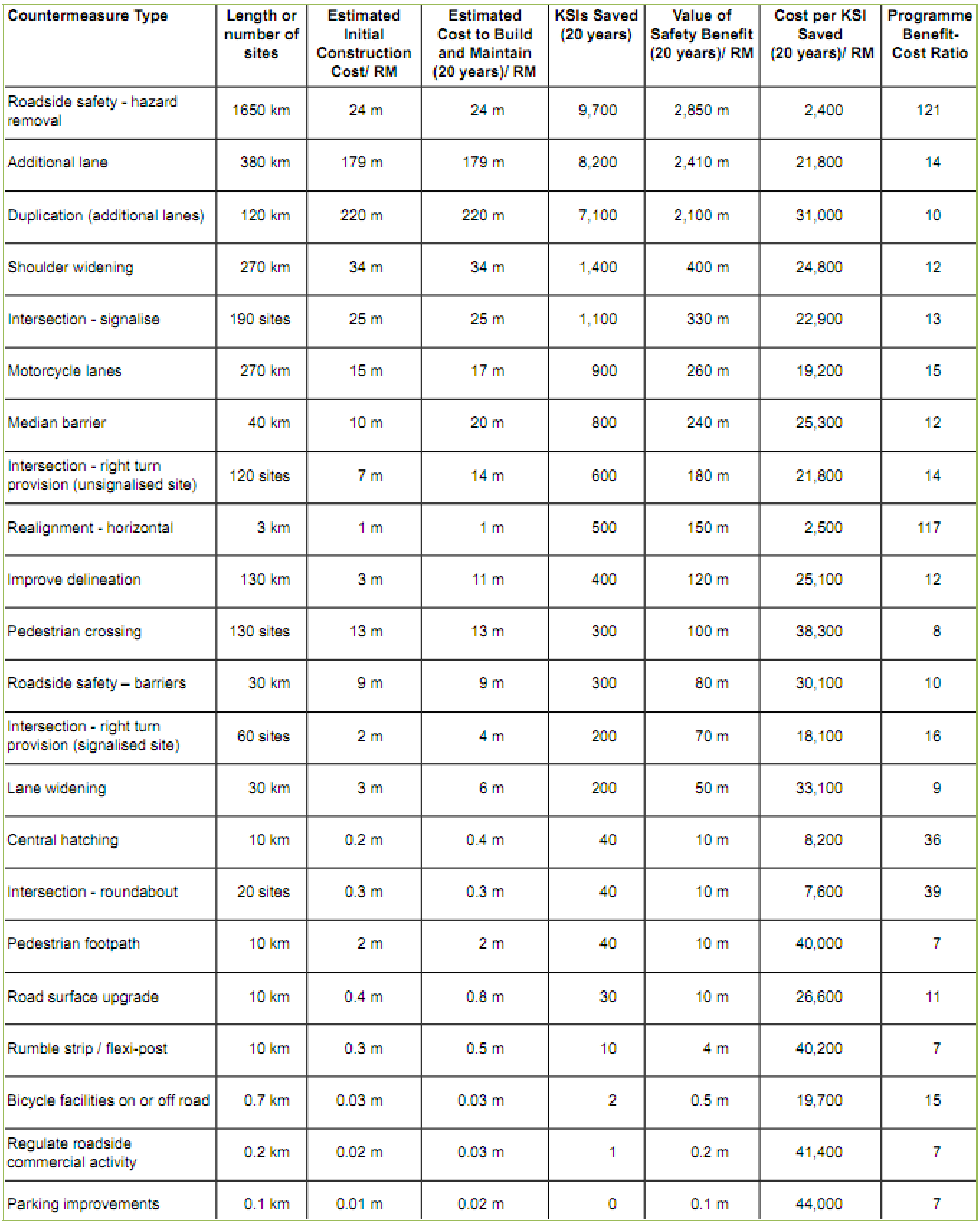
List of Abbreviations

AADT	Annual Average Daily Traffic
AASHTO	American Association of State and Highway Transportation Officials
AID	Accident Identifier
AIS	Abbreviated Injury Scale
AIT	Austrian Institute of Technology
ASI	Acceleration Severity Index
CEDR	Conference of European Road Directors
DGPS	Differential global positioning system
DOT	Department of Transport
EES	Energy Equivalent Speed
FARS	Fatality Analysis Reporting System
FSV	Forschungsgesellschaft Straße – Schiene - Verkehr
HIC	Head Injury Criterion
IMU	Inertial Measurement Unit
iRAP	International Road Assessment Programme
KFV	Kuratorium für Verkehrssicherheit
MAIS	Maximum AIS
MARVin	Model for assessing risks of road infrastructure
NPV	Net Present Value
NSB	Net Social Benefit
RISER	Roadside Infrastructure for Safer European Roads
ROR	Run-Off-Road
RSA	Road safety audit
RSI	Road safety Inspections
RVS	Richtlinien und Vorschriften für das Straßenwesen
StGB	Strafgesetzbuch
SVA	Single-Vehicle-Accident
UPS	Unfall mit Personenschaden

Appendix



Countermeasure Type	Length or number of sites	Estimated Initial Construction Cost/ RM	Estimated Cost to Build and Maintain (20 years)/ RM	KSIs Saved (20 years)	Value of Safety Benefit (20 years)/ RM	Cost per KSI Saved (20 years)/ RM	Programme Benefit-Cost Ratio
Roadside safety - hazard removal	1650 km	24 m	24 m	9,700	2,850 m	2,400	121
Additional lane	380 km	179 m	179 m	8,200	2,410 m	21,800	14
Duplication (additional lanes)	120 km	220 m	220 m	7,100	2,100 m	31,000	10
Shoulder widening	270 km	34 m	34 m	1,400	400 m	24,800	12
Intersection - signalise	190 sites	25 m	25 m	1,100	330 m	22,900	13
Motorcycle lanes	270 km	15 m	17 m	900	260 m	19,200	15
Median barrier	40 km	10 m	20 m	800	240 m	25,300	12
Intersection - right turn provision (unsignalised site)	120 sites	7 m	14 m	600	180 m	21,800	14
Realignment - horizontal	3 km	1 m	1 m	500	150 m	2,500	117
Improve delineation	130 km	3 m	11 m	400	120 m	25,100	12
Pedestrian crossing	130 sites	13 m	13 m	300	100 m	38,300	8
Roadside safety – barriers	30 km	9 m	9 m	300	80 m	30,100	10
Intersection - right turn provision (signalised site)	60 sites	2 m	4 m	200	70 m	18,100	16
Lane widening	30 km	3 m	6 m	200	50 m	33,100	9
Central hatching	10 km	0.2 m	0.4 m	40	10 m	8,200	36
Intersection - roundabout	20 sites	0.3 m	0.3 m	40	10 m	7,600	39
Pedestrian footpath	10 km	2 m	2 m	40	10 m	40,000	7
Road surface upgrade	10 km	0.4 m	0.8 m	30	10 m	26,600	11
Rumble strip / flexi-post	10 km	0.3 m	0.5 m	10	4 m	40,200	7
Bicycle facilities on or off road	0.7 km	0.03 m	0.03 m	2	0.5 m	19,700	15
Regulate roadside commercial activity	0.2 km	0.02 m	0.03 m	1	0.2 m	41,400	7
Parking improvements	0.1 km	0.01 m	0.02 m	0	0.1 m	44,000	7