Road Infrastructure Safety Management Evaluation Tools (RISMET)

Applying speed prediction models to define road sections and to develop accident prediction models: A German case study and a Portuguese exploratory study

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1 Introduction

Traditional concepts of accident prediction models and safety performance functions are based on certain input values derived from infrastructure and accident occurrence. Usually, driving behaviour is not taken into account even though its impact is known (Shinar, 2008; Porter et al., 2011). So far, an implementation of driving behaviour in APM fails due to missing valid behaviour data. Collecting driver and driving behaviour data is time consuming and expensive. Therefore, often, only small parts of road networks are investigated or where a small number of samples are available.

Nevertheless, in order to understand accident occurrence better and more accurately it is necessary to develop a scientific methodology that considers at least these aspects of driving behaviour, which already has been investigated and for which appropriate models have been derived. This is the case for speed behaviour which was shown in numerous research studies (e.g. Durth et al. 1986, Glennon et al. 1985, Biedermann 1994, Lippold 1997, Sosouhmihen 2001, Bakaba 2003, Steyer 2004, and Ebersbach 2006).

Within the framework of work package 10 of the RIPCORD-ISEREST project an approach was developed that considers speed behaviour together with infrastructure parameters (Dietze et al. 2007). In contrast to other approaches, driving behaviour was not implemented as an additional model factor, but was rather used to classify the alignment based on its impact on speed. The results have shown that the implementation of speed behaviour is useful and improves models to predict accident occurrence.

The approach of RIPCORD-ISEREST (Dietze et al. 2007) has been taken up again and was further developed by applying an improved speed prediction model. This model was used to detect driving behaviour related geometric elements and element combinations for the analysis of accident data.

2 Driving Behaviour

Weller et al. (2006) define driving behaviour as the outcome of the interaction between the driver and the vehicle in the environment. Driving behaviour is the measurable movement of a human-controlled vehicle within time and space. Two general variables of driving behaviour are distinguished:

- Longitudinal control with the variables speed, acceleration and longitudinal distance to other objects, and
- Lateral control with the variables lateral speed, acceleration and lateral distance to a relevant path.

Driving behaviour can be analysed by solely recording the position of the vehicle within time and space. In contrast, driver behaviour needs the monitoring of the driver and his actions: where does he look? Which buttons does he press, etc.? Driver behaviour is the visible result of top-down and bottom-up processes and driver states and traits, described in more detail in Weller et al. (2006) and Weller (2010).

A model which combines the various processes involved in determining driving behaviour was developed by Weller (2010), see Figure 1.

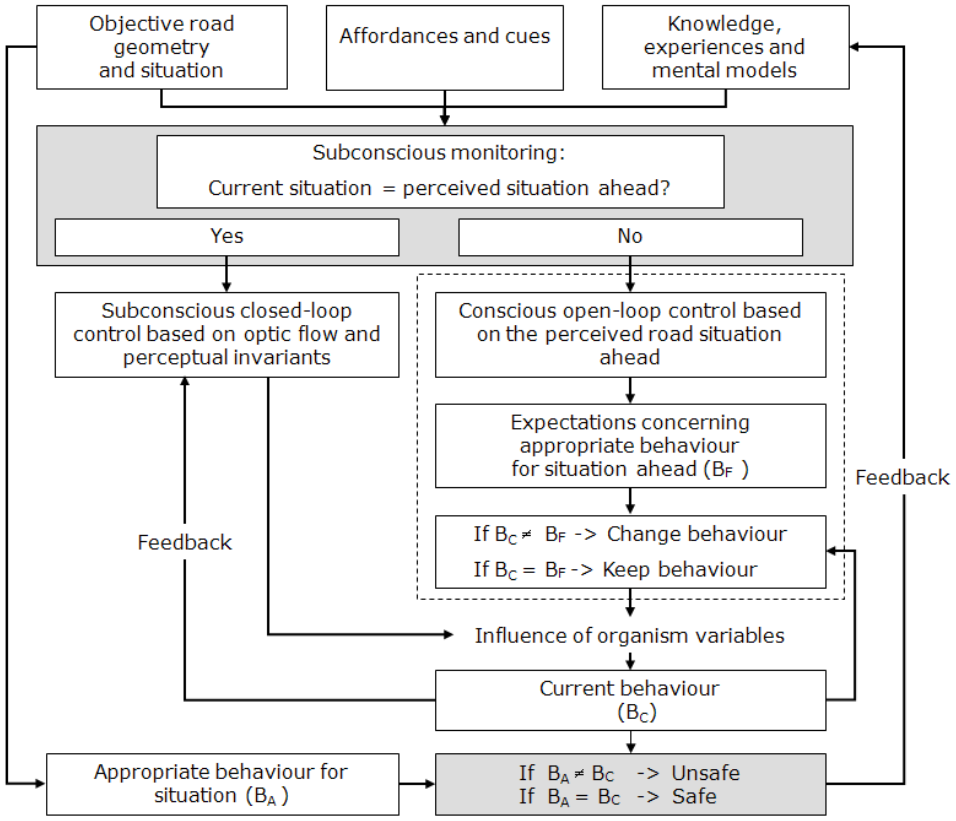


Figure 1: Driver and driving behaviour model for rural roads (Weller, 2010)

Speed is chosen freely by the driver via the man/vehicle interface and has a huge impact on accident likelihood and accident severity (Aarts & Schagen, 2006). On rural roads, inappropriate speed accounts for about 30% of fatal accidents (ERSO, 2011; Weller, 2010) and is thus the most relevant contributing factor to single vehicle accidents on rural roads (Statistisches Bundesamt, 2011). In a highly influential model developed by Fuller (2005), speed is the sole driving behaviour variable. Together with vehicle and environmental characteristics and human factors, speed determines task demand and finally – depending on driver capability - accidents.

As is shown in Figure 1, behaviour - and thus speed - is a function of the perceived road geometry. Ideally, perceived and actual road geometry match and speed can be predicted as a function of actual road geometry. If perceived and actual road geometry do not match, actual speed can be higher than appropriate speed, making the situation unsafe. Whether an accident results in this unsafe situation depends on additional factors such as the ones described in the model by Fuller (2005).

In order to determine whether a road element is unsafe, appropriate and actual behaviour have to be compared. Because of the characteristics of accidents (see Weller et al. 2006) a large amount of data has to be collected to derive at valid conclusions. Because this is at best time and resource consuming, other ways have to be found to approximate actual behaviour and to determine whether a situation is safe or not.

Approximating actual behaviour can be done with so called speed prediction models. The results of such geometry-based speed prediction models vary with the quantity and quality of the data analyzed and also between different countries (Lamm et al., 2007; Lamm, Psarianos, & Mailaender, 1999). An elaborated overview of speed prediction models was carried out in Workpackage 10 of RIPCORD-ISEREST (Dietze et al. 2005; Dietze et al., 2007). A Portuguese model was developed by Cardoso (1998, cited in Cardoso, 2011) and is applied in RISMET (Cardoso, 2011).

The speed prediction algorithm used in this report is based on models developed by Lippold (1997). These models were chosen as they were developed with German data.

Since actual speeds are being approximated from geometry based speed prediction models, the approach introduced in Figure 1 is no longer applicable. This is because both actual and appropriate speed would be based on the same parameters. Therefore, another approach was developed which is based on speed differences between consecutive elements.

At this stage, it is important to point out that (predicted) speed will not be used as an independent explanatory variable in an accident prediction model (APM). Rather, speed differences between consecutive elements will be used to classify road sections on which the APMs will later be based. The exact procedure is explained in chapter 3.

3 Impact of road geometry on driving behaviour

Aiming at the improvement of road safety, many studies have investigated the impact of road geometry on safety. The geometry as a design value gives engineers the possibility to influence the speed of drivers. Therefore, modern design guidelines include more or less strict rules for the design of the roads (including horizontal and vertical alignment; cross-sectional elements etc.).

Correlations with speed have been found for the following design parameters (e.g. Durth et al. 1986, Glennon et al. 1985, Biedermann 1994, Lippold 1997, Sosouhmihen 2001, Bakaba 2003, Steyer 2004, and Ebersbach 2006, Table 1):

Design element(s)	*Parameter*	*Correlation*
Single curve	Radius R	High
Consecutive elements	Curvature Change Rate CCR	High
Road width	Width RW	Moderate
Vertical grade	Grade VG	Less
Crest	Radius R	High
Sags	Radius R	Moderate

Table 1: Design elements and their correlation with speed

Most studies are focused on the relation of single curves and speed (Figure 2). Single curves are often not adapted to connecting elements and therefore cause speed difference that might be dangerous. Lippold (1997) pointed out that it is rather speed differences that are unsafe than a certain speed level. Roads with high speed levels (in this case: rural roads excluding motorways) are safer if design elements (especially of the horizontal alignment) are adapted to each other. On roads with general lower speed levels and a non-adapted (horizontal) alignment, unsafe speeds occur and often cause accidents with severe consequences. Speeds in combination with the alignment (especially in single curves) and the speed differences resulting from non-adapted alignment make roads safer or more unsafe.

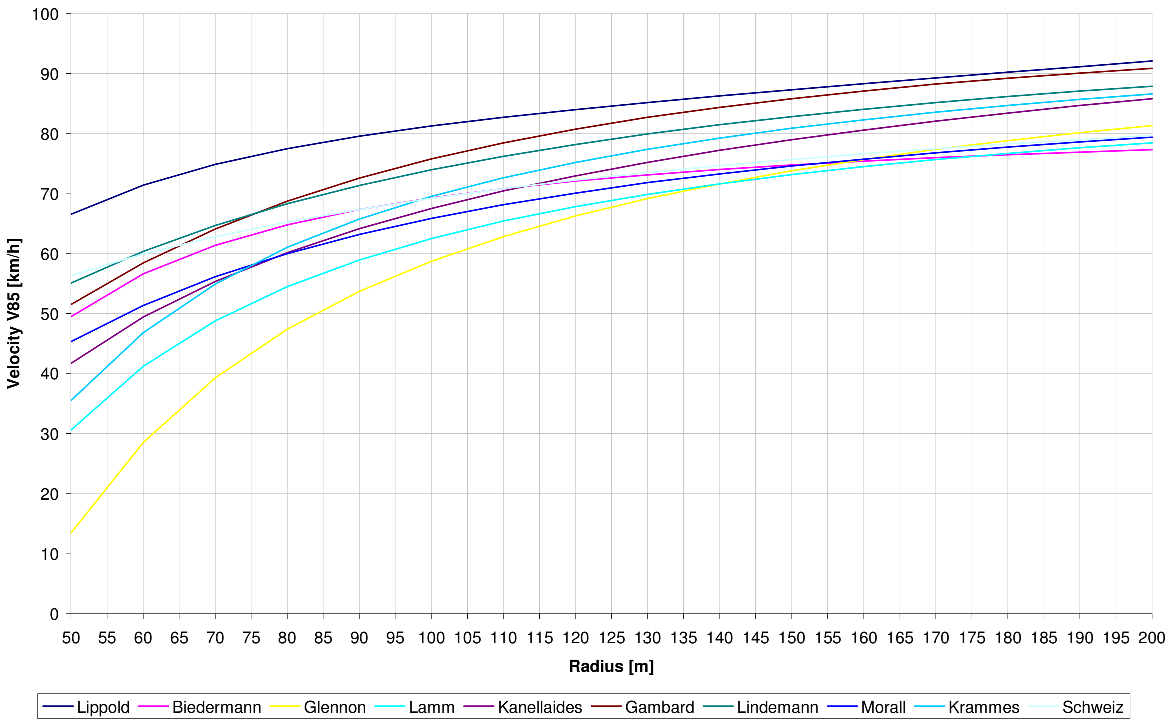


Figure 2: Speed models for single curves

Consecutive elements can influence the speed across an entire road stretch. Such sections with several consecutive elements are often described by the parameter Curvature Change Rate (CCR). CCR is the sum of the deviations related to the section length. Within such sections, an almost constant speed level is measured.

In the approach developed in RIPCORD-ISEREST (Dietze et al. 2007) a general differentiation in road sequences was defined: single curves that cause high speed differences and sequences that are characterised by an almost constant speed.

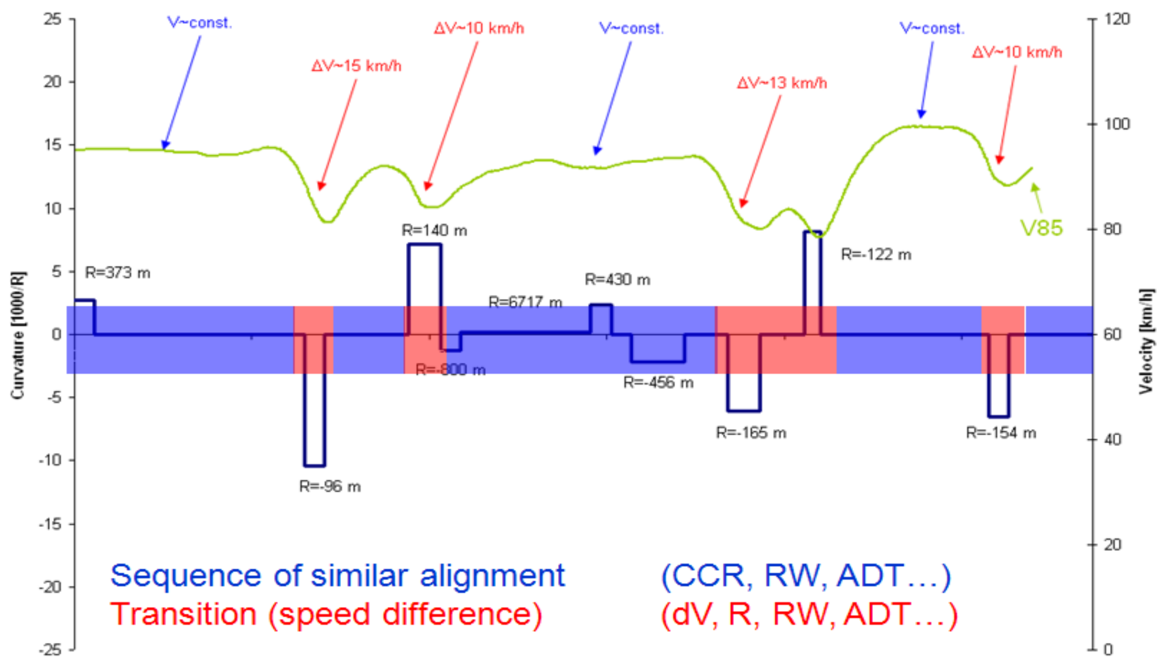


Figure 3: Typical speed profile with single and consecutive elements.

Figure 3 shows a typical free flow speed profile of a low classified rural road with an alignment that evolved from historical changes rather than being developed according to modern guidelines. The speed profile shown is based on measured speeds of drivers that passed this section undisturbed by other road users. The driving speeds were chosen from inputs such as the geometric design, surrounding conditions (daylight, dry) and their own motivation.

The speed profile illustrates the adaption of speed caused by the geometric alignment. Both the first curve (R=-96 m) and the second curve (R=140 m) cause a speed change of more than 10 km/h. The distance between the two curves is long enough so that the curves can be regarded as single curves. After the first curve drivers accelerate and brake later for the second curve.

Other parts of the speed profile show sections where speed is almost constant. Within these sections the design elements do not have an influence on speed as single curves but rather cause a constant speed level as sequence of single curves. This effect depends on whether the curves within these sections have radii below a specific limit. This limit depends on the characteristics of the adjacent elements. How it is defined is described in the next chapters. Independent of these limits they might cause a speed difference at the beginning/ end of the sequence but over a certain length the level of speed is constant.

4 Investigation Methodology

As described in chapter 3, there is a relation between geometric alignment, driving behaviour, and accident occurrence. If road safety is investigated including driving behaviour, the impact of the geometric alignment on this behaviour must be taken into account.

Driving behaviour is characterised by different parameters but speed is the most appropriate variable for this study. So speed and particularly speed difference have a central meaning for the model to be developed. Both indicators must be considered by their relation to geometric alignment.

Regarding the geometric alignment different types of elements and element combinations must be distinguished:

- Single curves (curves) that cause large changes in speed ,
- Sequences of closely spaced single curves (linked single curves) that cause a large speed reduction but are characterised by a relatively constant speed within that sequence and
- Straight sections that include all other elements which have no significant impact on driving speed.

The development of an accident prediction model that implements results from driving behaviour research in terms of speed behaviour requires the consideration of precisely selected accident types. With speed behaviour being the indirect target of this research only accidents that are related to speed behaviour must be selected. Since a speed prediction model will be implemented that was developed to predict speeds of free flowing traffic, all other accidents should be excluded. Based on the German accident classification system, the following accident types were selected for this study:

- Driving accidents or single vehicle accidents (accident type one according to the German classification system): this accident type includes only accidents that happen without an impact of third parties and are mostly caused by speeding. This means that the driver did not choose an appropriate speed with respect to the geometric design and the surrounding conditions.
- Accidents in longitudinal direction: this accident type includes accidents caused by conflicts of road users that drive in the same or opposite direction such as overtaking accidents or rear-end collisions. Since within the project only road stretches outside urban areas excluding junctions are investigated overtaking accidents are the most likely accidents of this type. Rear-end collision are more typical accidents that happen

in junctions. The majority of accidents occurring on roads outside urban areas excluding junctions are characterized by risky overtaking manoeuvres. It is often caused by drivers underestimating the current sight distance which in turn depends on the geometric alignment. Further, for long passing distances needed at high speeds, no direct estimations of real closing speeds are made. Passing decisions are rather based on assumptions regarding expected (average) closing speeds and distances; this increases the error probability, especially when speed distributions are not uniform.
Within the report this accident type is thus named "accident type six" or "overtaking accidents".

Both accident types have in common that they are caused by inappropriate driver behaviour in relation to the geometric design.

To take all these assumptions into account a strict analysis algorithm must be applied. Such an algorithm should work stepwise as will be described in the next sections.

4.1 Detection of Sequences

In a first step the horizontal alignment is analysed with the goal to detect one of the defined sequence types: single curves, curved sequence or straight section. Since there are no speed data available for an entire road network an adequate speed prediction model is used (Lippold 1997):

$$V=82.461+2.817\cdot w-0.084\cdot R+0.0005\cdot R^2-0.0000005092\cdot R^3-1559.506/R$$

V…85% speed [km/h], w…road width [m], R…curve radius [m]

This speed model predicts speed for single curves based on the radius and the road width. In this first step, each curve is considered a single curve in order to predict a possible maximum speed in terms of driving dynamics. Applying such a speed prediction model for a given horizontal alignment results in a static speed profile (see Figure 4). The speed for straights and large radii above 500 m radius is set to 115 km/h which represents the maximum speed.

This is just a theoretical prediction since it does not consider acceleration and deceleration of drivers. Therefore, the speed profile gives unrealistic and wrong speed differences between linked design elements and ultimately makes the detection of sequences as needed for this study impossible.

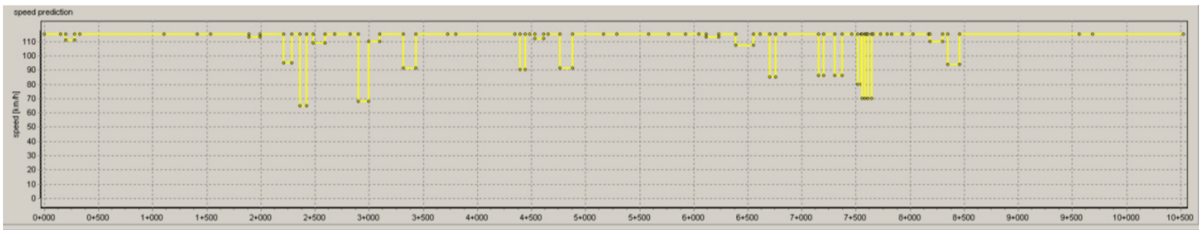


Figure 4: Static speed prediction based on the model by Lippold 1997

Therefore, in a second step a 'dynamic' speed profile must be calculated that results in a more realistic profile (see Figure 5). Such a profile makes it possible to detect

- the start of an appropriate deceleration to approach a curve with a safe speed,
- which curve is relevant for drivers deceleration,
- how fast drivers can drive between consecutive curves, and
- what the differences between driving directions are.

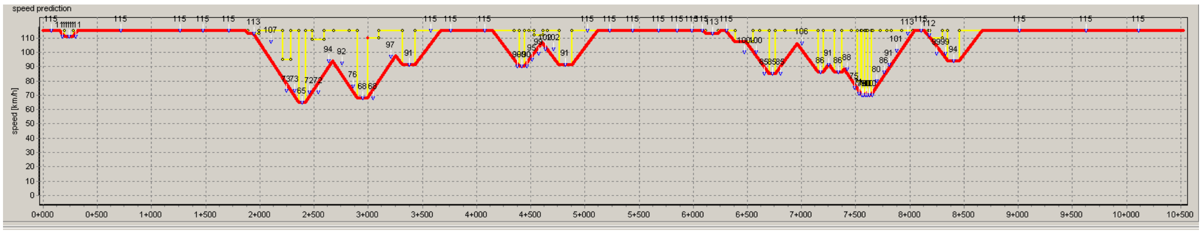


Figure 5: Dynamic speed profile

The dynamic speed profile is based on a simplified approach. It is assumed that drivers change the speed linearly by the same value of 0.8 m/s² for both deceleration and acceleration. For each curve with a predicted static speed a de- and acceleration distance is calculated (see Figure 6). The required breaking distance is calculated as follows.

$s = (V_{max}^2 - V_{element}^2)/(25.92 \cdot a)$

s…breaking distance [m], V…speed [km/h], a…acceleration [m/s²]

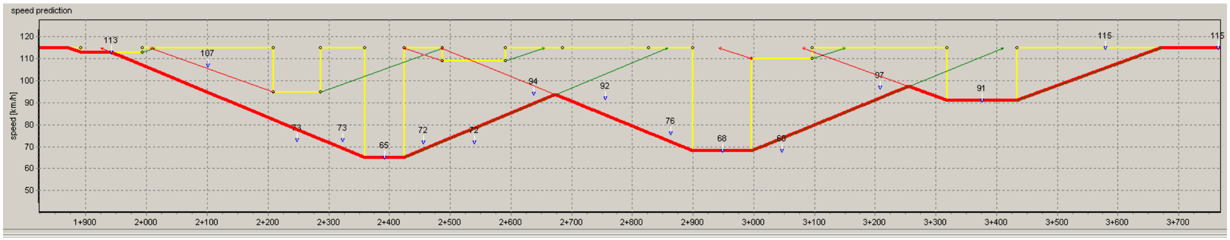


Figure 6: Calculated deceleration and acceleration distances

Finally, the crossing points of each de-/acceleration line define the resulting speed profile.

Despite this simplified model, the results show an improvement in the speed profile. Figure 6 shows the curve at around 2+250 m already causes a reduction of more than 10 km/h (static speed prediction) but only the next curve (at 2+400 m) is relevant for the resulting speed profile. This is because a driver must start to brake quite early in order to safely approach the second curve. That means that in this case the first curve does not have an effect as a single curve.

Based on the dynamic speed profile the sequence detection works in three steps:

1. Each element that causes a speed reduction of at least 10 km/h and is longer than 40 m is set to the status 'Single Curve'. Elements shorter than 40 m are excluded from the analysis because they are too short to be perceived as an element at all. This limit has been chosen with respect to the investigated part of the road network where especially the L-roads (Landstraßen) are characterised by a horizontal alignment that does not meet the requirements of modern design guidelines.
2. Each single curve detected in step one is further analysed to see if there are any other curves within a distance less than 200 m. If so, these elements are linked and are characterised by the minimum radius and the curvature change rate. They are set temporarily to the status 'Connected Single Curves'.
3. In the last step of sequence detection it is analysed if connected single curves build a sequence that is longer than 250 m. If so, their status is changed to the status 'Curved Sequence' and is characterised by the curvature change rate (CCR). Otherwise they keep the status 'Single Curves' and are characterised by the minimum radius. Detected single curves already detected in prior steps keep their status. All other elements that were not analysed so far – because their impact on driving behaviour is insignificant – are connected to 'Straight Sections' characterised by CCR and consist of straight or less curvy sequences.

Figure 7 shows the stepwise sequence detection schematically.

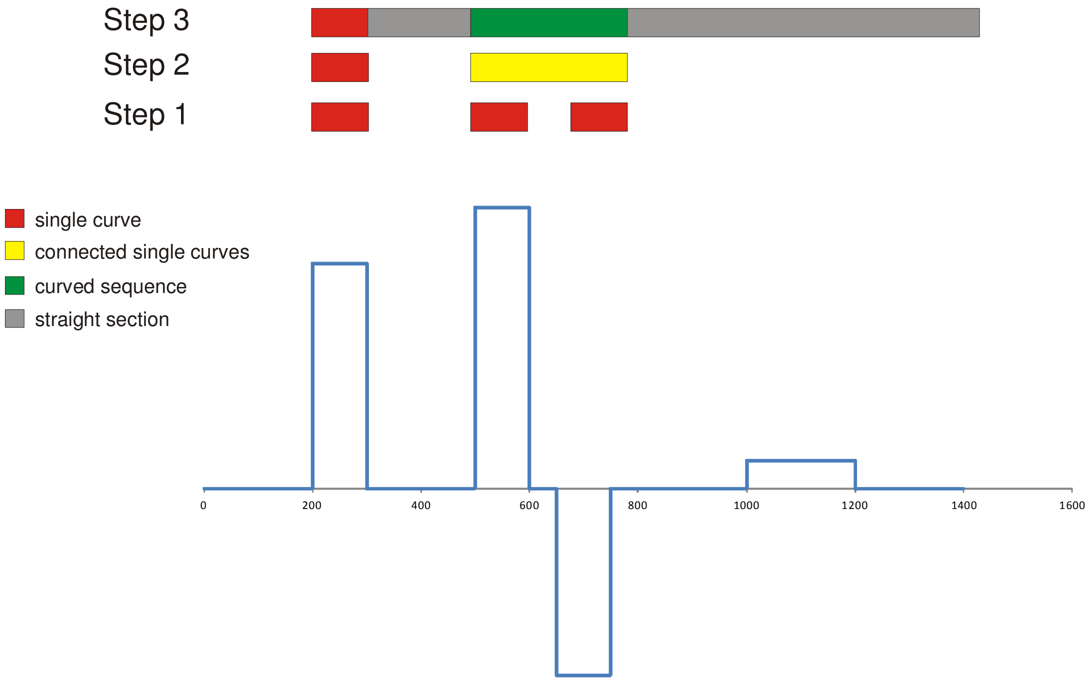


Figure 7: Schematic illustration of sequence detection

The sequence detection is separately done for both driving directions. This is important since the impact of elements might be different because it highly depends on the element configuration.

Finally for both driving directions different sequences are detected and distinguished by three types:

- Single curve:
  a single curve that causes a reduction in speed of at least 10 km/h,
- Curved sequence:
  a sequence longer than 250 m consisting of two or more single curves that cause a reduction of speed of at least 10 km/h,
- Straight section:
  consists of straights and curves which have no significant impact on speed. For the most part, these sequences are almost straight.

4.2 Accident Mapping

For each detected sequence the accidents of type one and six (definitions, see preceding chapter) are mapped onto it (Figure 8). Similar to the sequence detection, the accident mapping has to be done separately for each driving direction.

Inaccuracies such as the geographic position of accidents, or vehicles that stopped beyond the curve after an accident must be considered when accidents are mapped to sequences. Therefore, the accident mapping is done in two steps: first, accidents are mapped to all single curves and secondly, to all other sequences.

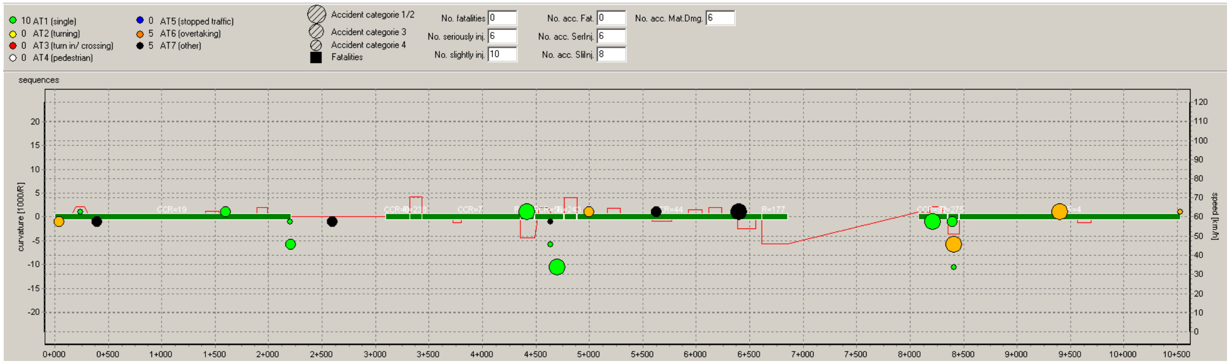


Figure 8: Detected sequences and accident mapping

When accidents are mapped several accident parameters are computed:

- Number of involved persons, fatalities, seriously injured persons, slightly injured persons,
- Accident type and the numbers each for accident type,
- Accident categories and the numbers for each accident category
- Date, surrounding conditions like weather
- Driving while intoxicated,
- Driving direction.

Furthermore, for each sequence accident parameters are calculated. These accident parameters are standard parameters developed by FGSV (2003) and are commonly used in Germany. Thus, a discussion of their validity is beyond the scope of this report. Single curves are handled as spots therefore their length is not considered (FGSV 2003). For all other sequences the length is taken into account because they consist of more than one element and thus are longer than a single curve.

The accident parameters are (FGSV, 2003):

- Accident cost rate
  - Single curves $ACR = (1000 \cdot AC)/(365 \cdot AADT \cdot t)$
    ACR…accident cost rate, AC…accident costs, AADT…traffic volume, t…time period
  - Other sequences $ACR = (1000 \cdot AC)/(365 \cdot AADT \cdot t \cdot L)$
    AR…accident rate, AC… accident costs, AADT…traffic volume, t…time period, L…length

Since the consideration of driving behaviour is one of the aims of this investigation, only accidents that belong to one of the following types were taken into account: Single vehicle accident or overtaking accident.

4.3 Model Development

The objective of this approach is to consider aspects of driving behaviour to predict safety. As was shown in the previous chapters, such behavioural aspects have already been taken into account for the sequence detection. However, driving behaviour must also be part of accident data analysis.

An example along which this approach can be explained are curves: Whereas it is known that sharp curves are more dangerous than wide curves (Lippold 1997, Elvik & Vaa 2004, Ebersbach 2006), a small curve radius is not a sufficient condition for danger. Many road safety studies have shown that sometimes small curves are critical, and sometimes they are not. Thus, the radius plays an important role but is not the sole relevant variable. To take this fact into account, the variable “speed difference between curve and preceding element” must be considered in addition to the radius.

In order to simulate realistic speed differences a dynamic speed model has been used. The model used determines how drivers decelerate and accelerate and which upper speed level is generally reached between curves or on straights. Thus, its predictions can be used as additional variables to the radius.

The defined sequence types have different impacts on driving behaviour (see chapter 3). Therefore, it is also necessary to consider these differences for the model development. The most important differences are:

- A single curve significantly reduces speed on a certain spot compared to the speed on the preceding element. There is no further impact from other single curves. However, it is assumed that the prior sequences have an influence on how drivers pass the single curve.
- A curved sequence consists of several single curves which are situated close together. They impact driving behaviour over a certain distance (corresponding to the length of the sequence). Within the sequence the speed is almost constant. However, the first element in the sequence will affect speed in a similar manner to a single curve. Nevertheless, it can be assumed that drivers perceive such a curvy stretch and adapt their behaviour in another way compared to single curves.
- A straight section of road can consist of several elements that do not themselves have an impact on speed behaviour. These sequences are relatively straight or with gentle curves with low CCR values. Speeds on these sections are comparatively high. Another behavioural effect - besides this effect on speed - is that drivers are particularly likely to overtake other vehicles on these stretches.

Because of these impacts on behaviour, the accident analysis and model development considers the following parameters for the different sequence types:

- Single curves
  - curve radius,
  - speed difference derived from the dynamic speed model,
  - prior geometry → length of the prior sequence (with respect to the definition of single curves a prior sequence is straight or almost straight)
- Curved sequences
  - curvature change rate
- Straight section
  - curvature change rate

In addition, the subsequent parameters are considered for the overall model:

- road category (as the model is developed solely for rural roads, this categorisation comprises subcategories of rural roads)
- traffic volume
- road width

The following accident types are analysed (accident type numbers are according to the German classification):

- Accident type 1 (driving accident)
- Accident type 6 (overtaking accident).

With respect to the model development two different approaches were followed:

- one type of analysis was conducted with Generalised Linear Models (GLM), and
- another type of analysis was conducted with accident cost rates, which were analysed with linear regression models.

The subsequent result chapters are divided firstly by the element types as described above. Secondly, they are subdivided within the element sections into these two different analysis approaches. These two approaches will now be explained in more detail:

The first approach is the analysis based on Generalised Linear Models (GLM) using Poisson regression approaches. Poisson models are especially suited for data with a high number of zero values (i.e. very much elements with no accidents at all). Because the Poisson approach requires discrete countable data, the number of accidents is an appropriate value to be predicted. Although accident severity is implicitly considered because only accidents with personal damage are taken into account, there is no further differentiation between fatal accidents and accidents with slightly injured persons. Because of this weakness, the second approach was developed (see subsequent paragraphs). To successfully predict injury accidents from geometric values, traffic volume must also be taken into account as was already mentioned above. As base for the development the following model has been chosen (Reurings et al. 2005, Lopes at. al. 20011, Schermers et al. 2011):

$$AF_k = \eta_k \rho_k = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{X_i \beta_i}$$

where: AF_K expected accident frequency of accident type k, η_K computed exposure function for accident type K , ρ_K accident rate for accidents of type K, V_i AADT at site i, L_i length of road at site i, X_i set of characteristics of site i, α, β parameters to be estimated for accident type K

With regard to the defined sequence types separate models were developed considering the parameters mentioned above.

sequence type	*model*
single curves (radius)	$AF_{SE,R} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 R}$
single curves (radius & L_{prior})	$AF_{SE,R,L_{prior}} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 R+\beta_2 L_{i-1}}$
single curves (dV)	$AF_{SE,dV} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 dV}$
single curves (dV & L_{prior})	$AF_{SE,dV,L_{prior}} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 dV+\beta_2 L_{i-1}}$
Curved sequence	$AF_{SES,CCR} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 CCR}$
elements sequence	$AF_{ES,CCR} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 CCR}$
	AF: expected accident frequency, V_i: AADT at site I, L_i: length of road at site i, β_j parameters to be estimated, R: curve radius, L_{i-1}: length of prior sequence, CCR curvature change rate

Table 2: Models based on GLM

After these explanations for the first approach, the second approach will be explained. This second approach was used in addition to the Poisson based models to get more information on accident severity. Considering the sum of all injury accidents as an absolute number does not reveal anything about the severity of accidents. Therefore, analysis models have been developed that are based on accident cost rate (ACR) which considers the accident severity due to calculated economic losses. ACR are weighted numbers of accidents with respect to AADT, length and defined accident costs. Since ACR are weighted data consisting of non-countable values a Poisson regression is not suitable and cannot be applied. For that reason a simplified statistical analysis has been conducted.

In order to consider the high number of zero values in the data the analysis was structured in several steps:

1. The available data were subdivided into classes. A strict class definition has been applied. This definition groups data values on the abscissa in the same classes with a constant increment.
    a. radii classes: min 50 m, max 500 m, increment 50 m
    b. speed difference classes: min 10 km/h, max 40 km/h, increment 5 km/h
    c. curvature change rate classes:
        i. curved sequences: min 100 gon/km, max 300 gon/km, increment 50 gon/km
        ii. straight sections: min 0 gon/km, max 150 gon/km, increment 5 gon/km.
2. Within each class the 95%-quantile was calculated as representative class value. This was done to give additional weight to severe accidents.
3. The calculated 95%-quantiles per class were integrated in the regression analysis.

5 Data base

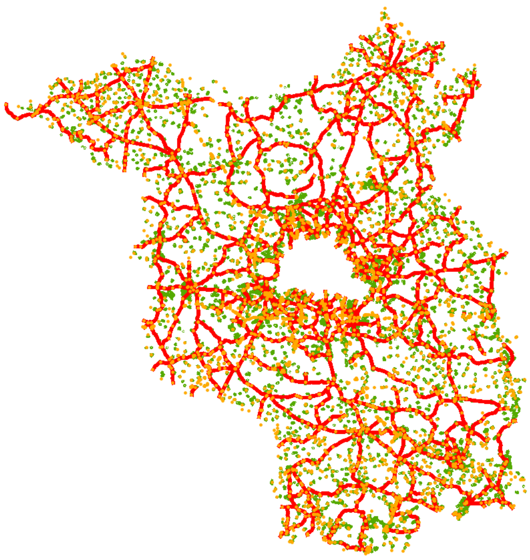


Figure 9: Map of investigated road network in Brandenburg, Germany

As base for the analysis and model development a large part of the road network of the German federal state Brandenburg was used. Only classified roads were taken into account:

- Federal highways B “Bundesstraßen” (no autobahns)
- State roads L “Landesstraßen” (secondary rural roads)

The length of the investigated network is about 4,912 km and consists of 1,921 node links. This length includes rural stretches as well as urban areas. For the analysis only rural areas were accepted and built up areas were completely excluded. Table 3 shows the remaining road network to be investigated.

road type	total length incl. urban areas (single direction)	total length rural areas only (single direction)	percentage of rural areas to total length (single direction)	rural areas to be investigated (both directions)
B	2,211 km	1,364 km	62 %	2,729 km
L	2,701 km	1,600 km	59 %	3,201 km
total	4,912 km	2,964 km	60 %	5,930 km

Table 3: Total length, percentage of rural areas of the investigated road network and total length of investigated rural links in both driving directions

5.1 Alignment

For all node links the following data were available:

- Geometric design elements for horizontal alignment
  - straights, curves (radii), clothoids,
- Road width taken from the road database
- Traffic volume taken from the road database
- Rural sections
- Nodes by coordinates
- Node links as definition based on nodes

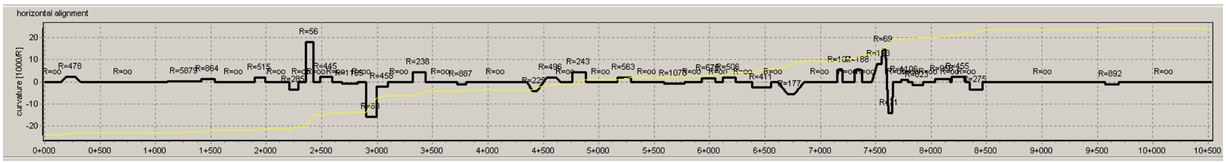


Figure 10: Example for horizontal alignment data

5.2 Accident data

For the roads investigated 18,870 accidents with injuries of the years 2005, 2006, and 2007 were used in the analysis. All in all 672 people were killed, 7,220 people were seriously injured, and 17,653 were slightly injured.

	accident data base							
	number of accidents		number of injury victims					
	total		fatalities		serious injuries		slight injuries	
AT 1	4,923	26%	327	49%	2,655	37%	3,431	19%
AT 2	2,470	13%	25	4%	673	9%	2,483	14%
AT 3	3,655	19%	40	6%	1,018	14%	36	20%
AT 4	598	3%	36	5%	248	3%	379	2%
AT 5	179	1%	3	0%	44	1%	163	1%
AT 6	5,496	29%	194	29%	1,867	26%	6,279	36%
AT 7	1549	8%	47	7%	715	10%	1,318	7%
total	18,870		672		7,220		17,653	

Table 4: Distribution of accident types of all accidents occurred in the investigation area

Table 4 shows the distribution of all accidents by accident types. Again, it emphasises the importance and the need of accident models that consider driving behaviour since accident type 1 (single vehicle accident) and accident type 6 (overtaking accident) together have a total share of 55 % of the total number of accidents and 78 % of all killed persons. These two accident types are the most frequent and the most severe accident types.

Each dataset includes the required information mentioned in chapter 4.2.

6 Results

The results are based on the analysis of about 5,930 km out of 6,612 rural road sequences. Table 5 shows the distribution of road sequence types defined earlier.

Sequence type	*total number*	*total length*
Single curves	1,952	227 km
Curved Sequence	57	22 km
Straight sections	4,603	5,681 km
Total	6,612	5,930 km

Table 5: Number of samples of sequence types

Overall, 1,952 single curves are available for the analysis. Unfortunately, the sample for the sequence type “curved sequence” is relatively small. This is because the state Brandenburg is situated in the north of Germany in flat terrain and the network is characterised by long straights and single curves. 4,603 samples for Straight Sections are available.

For the study 1,778 accidents of type one (driving accident) and 1,300 accidents of type six (overtaking accident) of rural sections were analysed; that were mapped to the 6,612 detected sequences. All in all, in these accidents 186 people were killed, 1,390 were seriously injured and 2,250 were slightly injured.

With respect to the model development, the accident rate and the accident cost rate were used. Especially the accident cost rates are informative regarding the severity of accidents and are therefore appropriate for the safety prediction.

6.1 Accident types

As described in chapter 4 the models will be developed with the main focus on speed behaviour. It is known that different geometric configurations cause different types of accidents (see preceding chapters). In single curves driving accidents are more important and likely than accidents caused by overtaking. In contrast, on almost straight stretches (called here straight sections) overtaking accidents should be more important. Table 6 shows the distribution of investigated accident types for the defined sequence types.

Sequence type	*Samples*	*AT 1*		*AT 6*		*Total*
	number	number	percentage	number	percentage	
Single Curves	1,952	315	80%	81	20%	396
Curved sequence	57	12	86%	2	14%	14
Straight sectionss	4,603	1,451	54%	1,217	46%	2,668
	6,612	1,778		1,300		3,078

Table 6: Distribution of number of accident type AT1 and AT6 with injuries concerning sequence types

In general, the results show that different geometric configurations as defined by sequence types are related to a different accident occurrence when the accident types are taken into account:

- On single curves driving accidents dominate. In the most cases they are caused by driver faults (e. g. speeding).
- Similar, in curved sequences, the most common accident type is a driving accident. With respect to the sequence definition applied here, curvy stretches above 100 gon/km were analysed, where the CCR already influences driving speed.
- Straight sections, which are (almost) straight stretches, are characterised by a higher number of overtaking accidents compared to the other sequence types (see Table 6). This is because, since less curvy or straight parts are used to overtake slower vehicles.

6.2 Single Curves

The analysis of single curves is based on three hypotheses:

- The radius has an important impact on road safety.
- There is an impact of the length of the prior section on road safety in relation to single curves.
  It is know that the length of the preceding horizontal alignment has an influence on driving behaviour. Especially long straight sections might be safety critical (Lippold 1997). It is known that long straights allow drivers to increase speed and – when driven over a longer distance - the drivers might pay less attention (Lippold 1997). Often that causes accidents with severe consequences. Many design guidelines include a rule to restrict especially the length of straight road sections before curves. For this reason the model is further extended by the length of the prior sequence and it is assumed that the impact can be shown for both the number of accidents with injuries and the accident cost rate. Due to the definition and detection of sequence types, prior sequences of single curves are either less curvy or are even straight sections.
- There is an impact of the speed reduction caused by single curves on road safety.
  Speed differences caused by single curves are an important parameter to describe the impact on driving behaviour. As already discussed in chapter 4.1 the impact of a single curve on driving behaviour depends on its position and configuration within the alignment. For example, short straight sections do not allow drivers to reach a maximum speed; consequently the speed difference is lower. Thus, speed difference is likely to be a more appropriate parameter than curve radius when investigating and analysing the impact of single curves on driving behaviour and road safety.

6.2.1 Model for Number of Accidents with injuries

6.2.1.1 Curve radius, AADT and curve length

During the 3 year analysis period no accidents were registered at the majority of sites with curves (Figure 11)

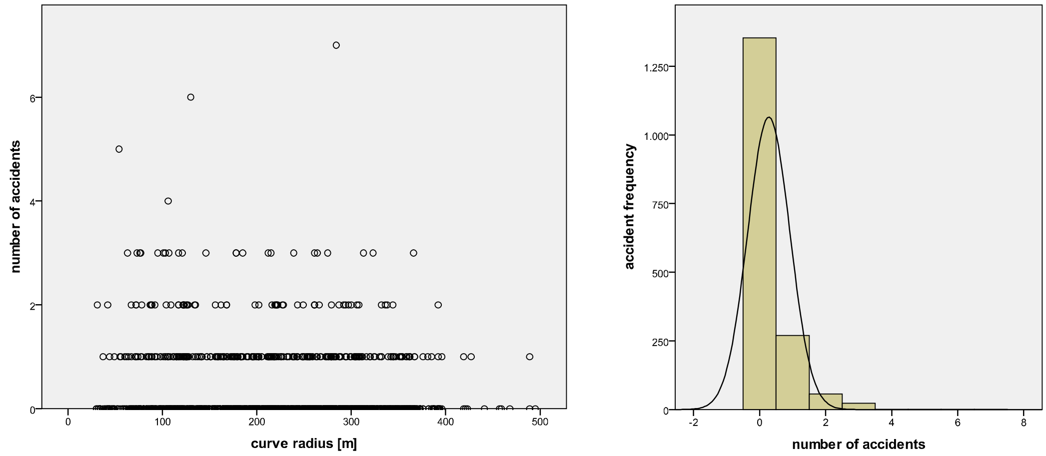


Figure 11: Distribution of number of accidents for single curves and curve radius ("accident frequency" on the ordinate denotes the frequency of locations with the respective accident numbers on the abscissa)

Based on these data the following model was developed along the principles outlined in chapter 4:

$$AF_{SE,R} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0 + \beta_1 R}$$

parameter	regression coefficient	standard error	95% Wald- confidence interval		hypothesis testing		
			lower value	upper value	Wald-Chi-quadrat	df	sig.
(const. term)	-6.488	0.9021	-8.257	-4.720	51.730	1	0.000
radius	-0.004	0.0007	-0.006	-0.003	32.586	1	0.000
ln(length)	0.347	0.1403	0.072	0.622	6.129	1	0.013
ln(traffic)	0.562	0.0869	0.391	0.732	41.765	1	0.000
(skala)	1.084[a]						
(negativ binomial)	1						

$$AF_{SE,R} = V^{0.562} L^{0.347} e^{-6.488-0{,}004R}$$

(30 m ≤ R ≤ 495 m, 40 m ≤ L ≤ 559 m, 511 ≤ AADT ≤ 20,750)

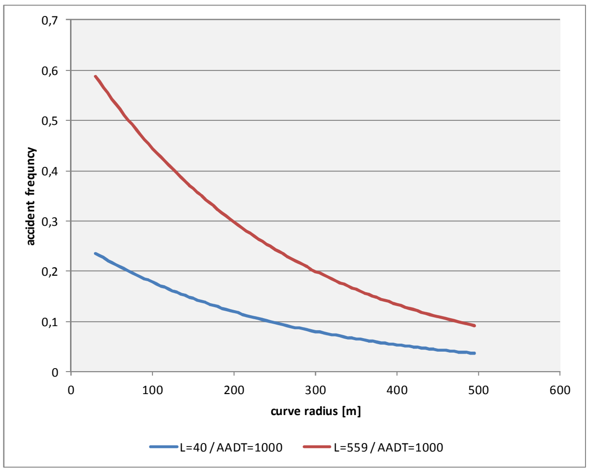
R…radius of single curve, V…AADT, L…length of single curve

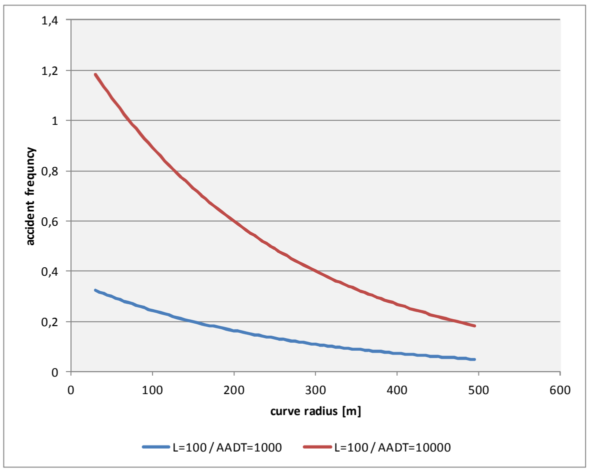
n=1,708

Table 7: Results of model development for radii of single curves

Table 7 shows the results of the model computation. The radius and the length of single curves as well as the traffic volume have a statistically significant impact on the number of accidents (at the 95% confidence level).

Figure 12 shows graphs of the computed model. In the left diagram the length of the single curve is varied between 40 m to 559 m and in the right diagram the AADT is varied between 1000 veh./24hrs and 10,000 veh./24hrs in order to show their impact on accident frequency.





impact of length of single curve impact of AADT

Figure 12: Model AF ~ curve radius

The model indicates the following impacts:

1. With increasing curve radius the accident frequency decreases.
2. The longer the single curve the higher the number of accidents in curves of the same radius.
3. The number of accidents increases with increasing traffic volume. The effect becomes smaller as the radius increases. With increasing traffic volume the probability of AT 1 decreases and it is assumed that there is no further impact of overtaking accidents in single curves, especially in small radii. To prove this, further investigations are required.

6.2.1.2 Curve radius, AADT, curve length and length of prior sequence

The following model has been set up:

$$AF_{SE,R,L_{prior}} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 R+\beta_2 L_{i-1}}$$

For the model development the number of investigated single curves has been reduced by limiting the length of the prior sequence. Preliminary results within this project showed that the impact of the length of the prior sequence cannot be shown for stretches above 1,400 m length. This is due to the fact that the approaching speed increases with increasing length of the (almost) straight preceding sequence. Due to the applied speed model the maximum possible speed on straight sections is set to 115 km/h. This means that after a certain length of stretch this maximum speed is reached by the dynamic speed model. After this point, the speed difference will always be the same for the same curve radii.

Table 8 shows the results of the model for the number of accidents with the explanatory variables curve length, traffic volume, curve radius and length of the prior sequence. All explanatory variables have a significant impact.

parameter	regression coefficient	standard error	95% Wald-confidence interval lower value	95% Wald-confidence interval upper value	hypothesis testing Wald-Chi-quadrat	hypothesis testing df	hypothesis testing sig.
(const. term)	-7.046	1.0354	-9.075	-5.017	46.313	1	0.000
radius	-0.004	0.0008	-0.006	-0.003	28.731	1	0.000
len_prior	0.001	0.0002	0.000	0.001	11.101	1	0.001
ln(traffic)	0.638	0.0976	0.446	0.829	42.666	1	0.000
ln(length)	0.260	0.1574	-0.049	0.568	2.723	1	0.099
(skala)	1.037[a]						
(negativ binomial)	1						

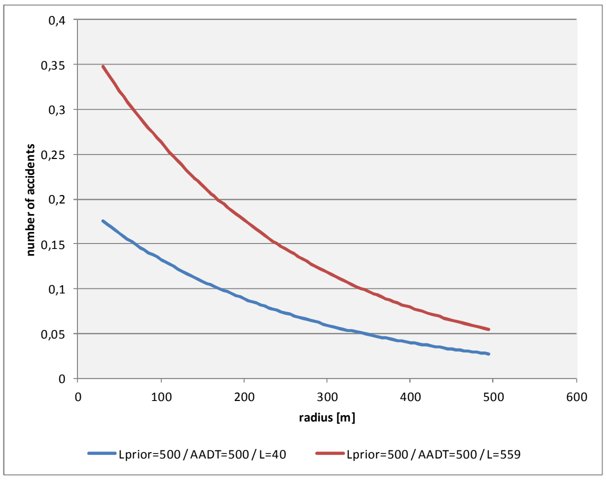
$$AF_{SE,R} = V^{0.638} L^{0.260} e^{-7.046-0{,}004R+0.001L_{prior}}$$

(30 m ≤ R ≤ 489 m, 40 m ≤ L ≤ 559 m, 511 ≤ AADT ≤ 16,137, 100 m ≤ L_{prior} ≤ 1,400 m)

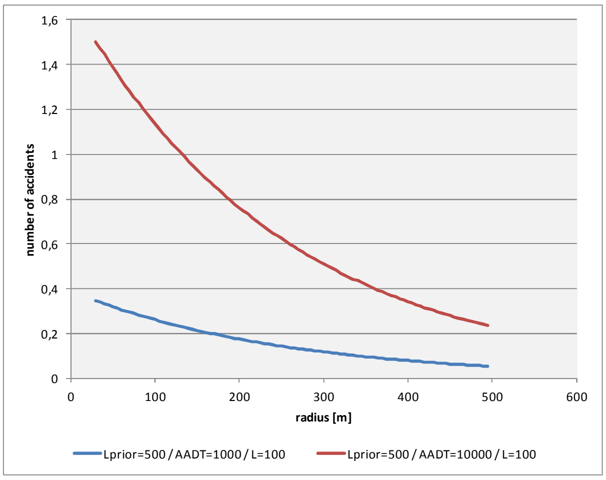
R…radius of single curve, V…AADT, L…length of single curve, L_{prior} …length of prior sequence

n=1,346

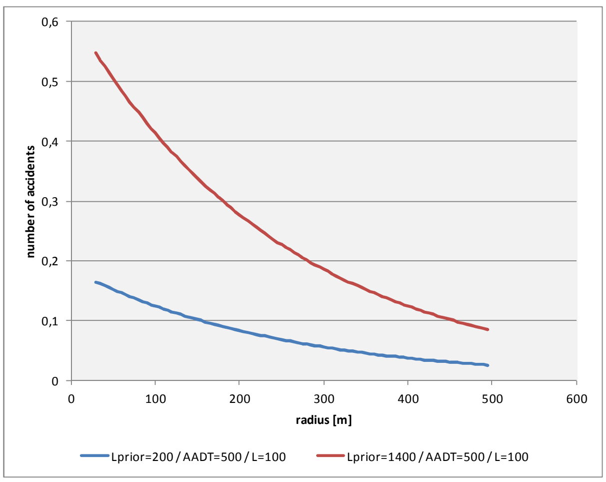
Table 8: Results of model development for radii of single curves considering the length of prior sequence



impact of length of single curve



impact of AADT



impact of length of prior sequence

Figure 13: Model AF ~ curve radius considering length of prior sequence

Figure 13 shows the graphs and impact of the variables length of prior sequence, curve length and traffic volume. Similar to the model in chapter 6.2.1.1 for curve radius, AADT and curve length this model also indicates the general impact of the curve radius. However, in addition, it also shows the assumed impact of the length of the prior sequence. In short, the model indicates the following impacts:

1. With increasing curve radius the accident frequency decreases.
2. The longer the single curve the higher the number of accidents in curves of the same radius.
3. The number of accidents increases with growing traffic volume. Again, with increasing traffic volume the probability of AT 1 decreases. A further impact of overtaking accidents is not assumed but has to be investigated in further investigations.
4. The longer the prior sequence the higher the number of expected accidents.

6.2.1.3 Speed reduction, curve length and AADT

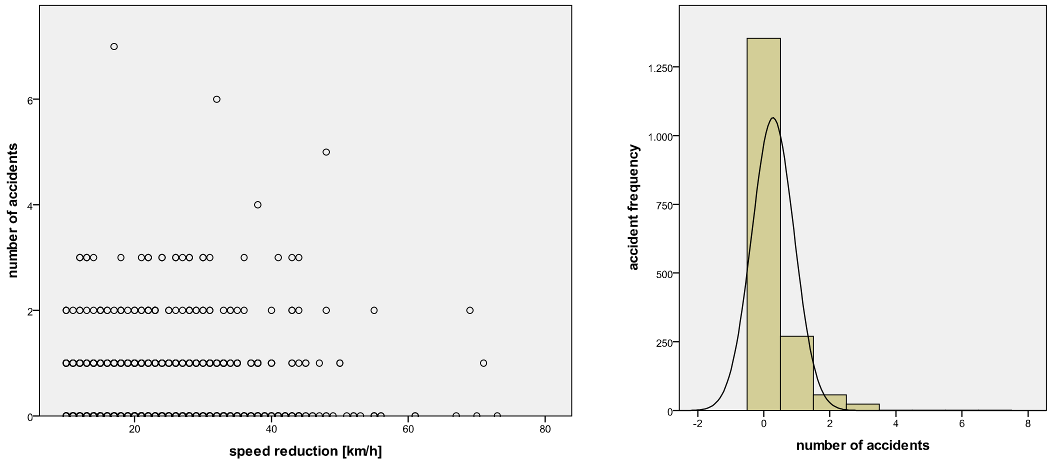


Figure 14: Distribution of number of accidents for single curves and speed reduction

Figure 14 shows the distribution of accidents in relation to speed reduction. Again the majority of sites with speed reductions of more than 5 km/h had no accidents registered during the 3 year investigation period. The following model was set up which considers traffic volume and curve length beside speed reduction.

$$AF_{SE,dV} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0 + \beta_1 dV}$$

Table 9 and Figure 15 show the results and graphs of the model developed. All considered explanatory variables are significant. The model shows the following impacts:

1. Higher speed reductions cause more accidents.
2. The longer the curves the more accidents happen.
3. The number of accidents increases with increasing traffic volume. Here, with increasing traffic volume the probability of AT 1 decreases and an impact of overtaking accidents is not assumed for single curves.

parameter	regression coefficient	standard error	95% Wald-confidence interval lower value	upper value	hypothesis testing Wald-Chi-quadrat	df	sig.
(const. term)	-7.713	0.9911	-9.655	-5.770	60.564	1	0.000
dv_prior	0.033	0.0061	0.021	0.045	29.864	1	0.000
ln(traffic)	0.585	0.0872	0.414	0.756	44.933	1	0.000
ln(length)	0.216	0.1311	-0.041	0.473	2.708	1	0.100
(skala)	1.072						
(negative binomial)	1						

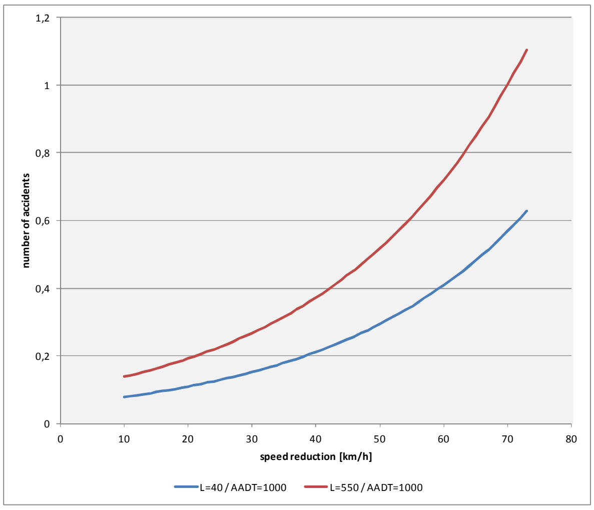
$AF_{SE,dV} = V_i^{0.585} L_i^{0,216} e^{-7.713+0.033dV}$

($10\ km/h \leq dV \leq 73\ km/h$, $40\ m \leq L \leq 559\ m$, $511 \leq AADT \leq 20{,}750$)

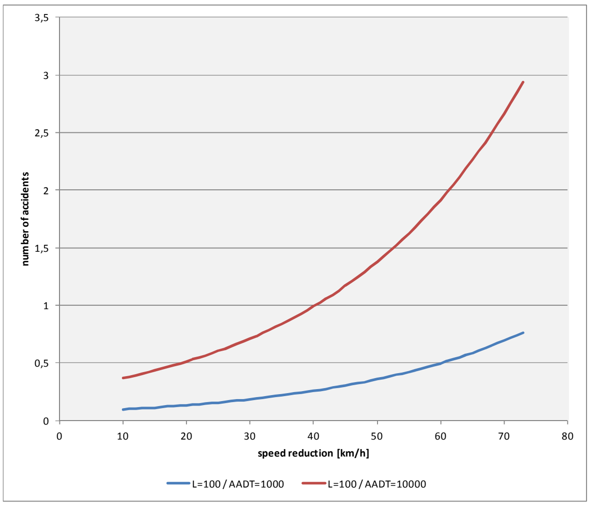
dV…speed reduction, V…AADT, L…length of single curve

n=1,708

Table 9: Results of model development for speed reduction of single curves



impact of length of single curve



impact of AADT

Figure 15: Model AF ~ speed reduction

6.2.1.4 Speed reduction, curve length, AADT and length of prior sequence

Analogous to the radius model the impact of the length of the prior sequence was also investigated for speed reduction. Again, the number of analysed samples has been limited to samples with a length of the prior sequence of 600 m. The same effect occurred caused by the applied dynamic speed model: since the length of the prior sequence is decisive for reaching the maximum speed the calculated speed difference depends on it. The longer the preceding sequence the more likely the maximum speed is reached. After this point, the speed reduction depends only on the curve radius.

For the model for speed reductions including the length of the prior sections the subsequent results were found:

$$AF_{SE,dV,L_{prior}} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 dV+\beta_2 L_{i-1}}$$

parameter	regression coefficient	standard error	95% Wald- confidence interval		hypothesis testing		
			lower value	upper value	Wald-Chi-quadrat	df	sig.
(const. term)	-7.936	1.5553	-10.984	-4.888	26.038	1	.000
dv_prior	0.022	0.0091	0.004	0.040	5.913	1	.015
len_prior	0.001	0.0007	-0.001	0.002	1.110	1	.292
ln(traffic)	0.716	0.1421	0.438	0.995	25.404	1	.000
ln(length)	0.018	0.2034	-0.380	0.417	0.008	1	.929
(skala)	1.019[a]						
(negative binomial)	1						

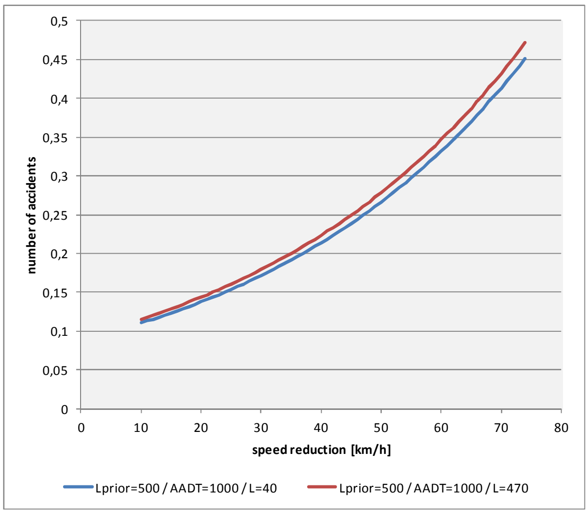
$AF_{SE,dV,L_{prior}} = V_i^{0.716} L_i^{0.018} e^{-7.936+0.022dV+0.001L_{prior}}$

(10 km/h ≤ dV ≤ 73 km/h, 40 m ≤ L ≤ 471 m, 511 ≤ AADT ≤ 15,031, 100 m ≤ L_{prior} ≤ 600 m)

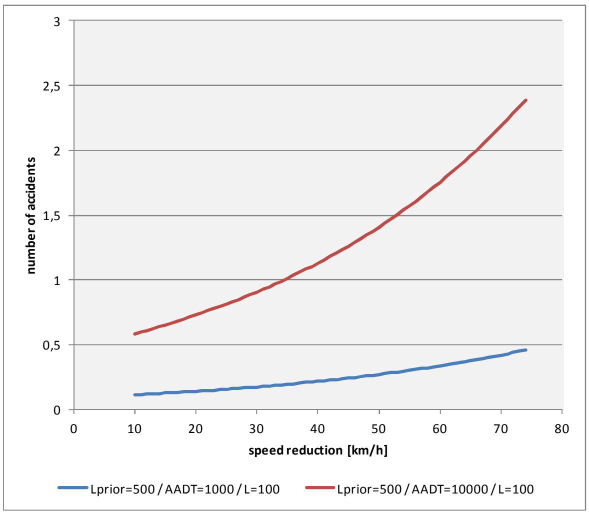
dV…speed reduction, V…AADT, L…length of single curve, L_{prior} …length of prior sequence

n=719

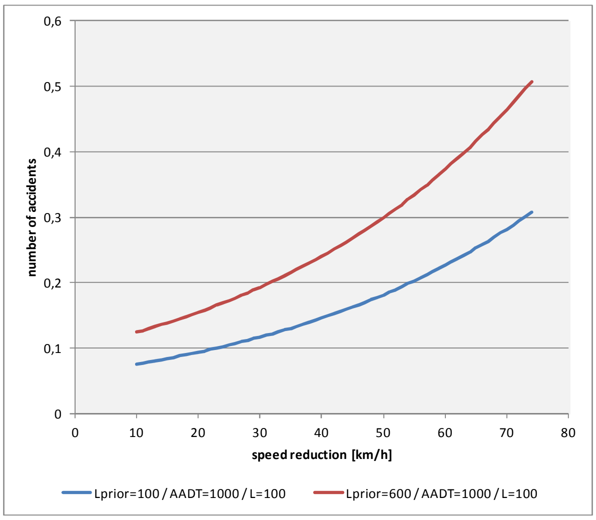
Table 10: Results of the model development for speed reduction of single curves considering the length of the prior sequence



impact of length of single curve



impact of AADT



impact of length of prior sequence

Figure 16: Model AF ~ speed reduction considering length of prior sequence

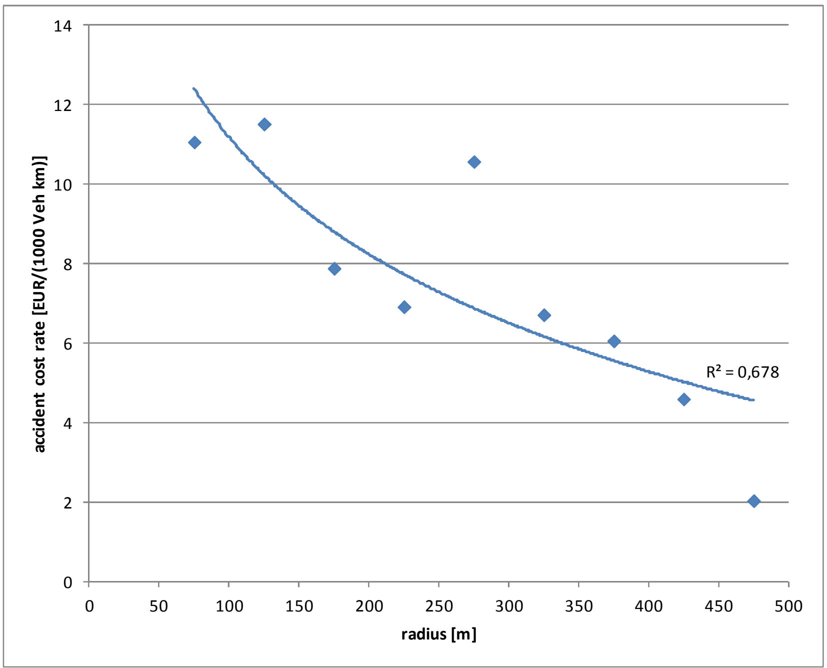
Table 10 and Figure 13 show the model development results. As assumed, the length of the prior sequence and the length of the curve have a less significant impact. On the one hand this is due to the applied speed prediction model. On the other hand, speed reduction is a result of the approaching speed and the curve speed which in turn depends on curve radius and length of curve. Therefore, the reduced explanatory quality of this model is conceptional. However, the model shows the following relations:

1. With increasing speed reduction the number of accidents also increases.
2. Higher traffic volume results in a higher number of accidents.
3. The longer the length of the prior sequence the higher the expected number of accidents up to a certain value (here 600 m) at the same speed reduction.

6.2.2 Model for Accident Cost Rate

6.2.2.1 Curve Radius

Figure 17 shows the relation between curve radius of single curves and the accident cost rate.



class value	min	max	acr	number of sample
radius	50	100	11.064	145
radius	100	150	11.5199	247
radius	150	200	7.8879	317
radius	200	250	6.9205	328
radius	250	300	10.5748	353
radius	300	350	6.7182	283
radius	350	400	6.0613	130
radius	400	450	4.598	10
radius	450	500	2.039	9

ACR = -4.256 * ln(Radius) + 30.785

n = 1,822

R^2 = 0.678

Figure 17: Model ACR ~ curve radius

As was expected the severity of accidents increases with decreasing curve radius. This means that the accident severity is higher in small curves. With respect to the available range of investigated curve radii a decrease in radii from 450 m to 100 m is related to a threefold increase in the accident cost rate.

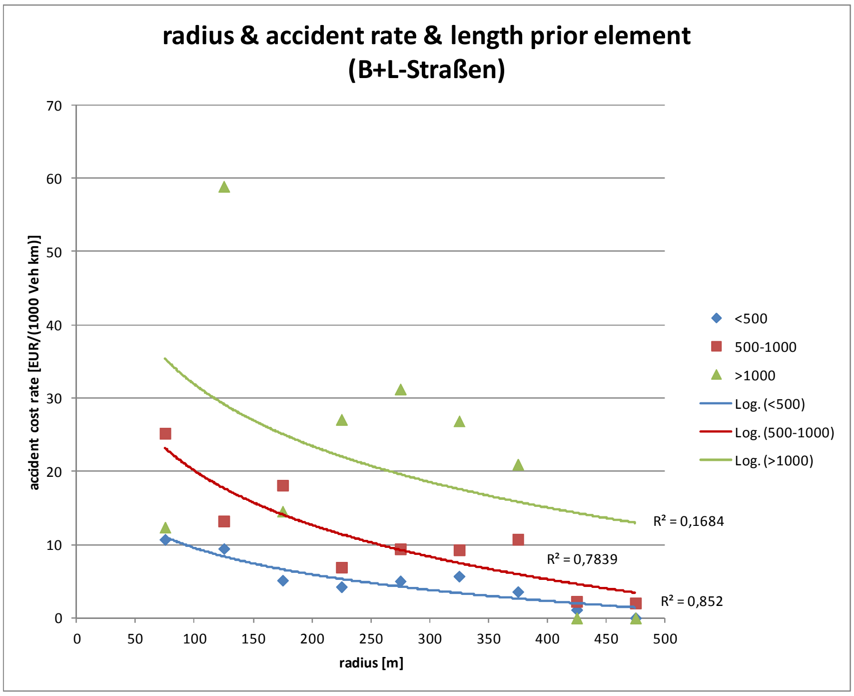
6.2.2.2 Curve Radius and Length of prior Sequence

In a first step three classes of length of prior sequences were defined:

- class 1: < 500 m
- class 2: 500 m – 1,000 m
- class 3: >1000 m

Figure 18 includes the relation between accident cost rate and curve radius of single curves separated by length of prior sequences. The results show an impact of the length of the prior sequence. Generally speaking, the severity of accidents does not only depend on the curve radius, but is also affected by the length of the prior sequence. The consequences are more severe for the same curve radius if the prior sequence is longer.

There is a considerable difference between the model for less than 500 m and 500 m to 1,000 m. Obviously, the relation becomes weak above 1,000 m. The reason might either be the combined analysis of state roads and federal highways or it might be that above a length of 500 m the section length does not make a further difference. Normally, such long straight sections are an exception on federal highways since the design standards are stricter for those roads (FGSV 1995) and a large part has been redesigned in the last years. In contrast, federal state roads are still characterised by a historical alignment.



Lprior < 500 m

class value	min	max	acr	Number of sample	
radius	50	100	10.717	60	ACR = -5.227 * ln(radius) + 33.622 n = 639
radius	100	150	9.4727	101	R^2 = 0.852
radius	150	200	5.1414	122	
radius	200	250	4.2612	107	
radius	250	300	5.0373	113	
radius	300	350	5.7052	93	
radius	350	400	3.5879	35	
radius	400	450	1.1327	5	
radius	450	500	0	3	

500 m < Lprior < 1000 m

class value	min	max	acr	Number of sample	
radius	50	100	25.208	30	ACR = -10.7 * ln(radius) + 69.353 n = 471
radius	100	150	13.217	68	R^2 = 0.7839
radius	150	200	18.11	71	
radius	200	250	6.9205	91	
radius	250	300	9.4255	95	
radius	300	350	9.3082	68	
radius	350	400	10.73	44	
radius	400	450	2.2749	2	
radius	450	500	2.039	2	

Lprior > 1000 m

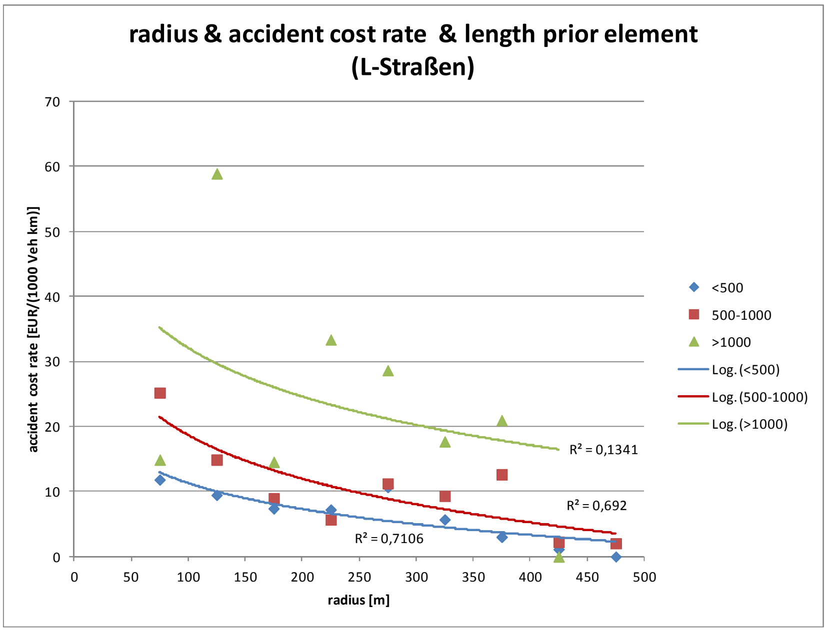
class value	min	max	acr	Number of sample
radius	50	100	12.377	43
radius	100	150	58.913	62
radius	150	200	14.56	93
radius	200	250	27.101	112
radius	250	300	31.233	119
radius	300	350	26.889	107
radius	350	400	20.96	44
radius	400	450	0	1
radius	450	500	0	1

ACR = -12.14 * ln(radius) + 87.778
n = 582
$R^2 = 0.1684$

Figure 18: Model ACR ~ curve radius considering length of prior sequences (3 classes)

Therefore a separate analysis has been undertaken in order to investigate possible differences between the two road categories.

Figure 19 shows the results for the separate analysis for state roads only. Again, the models show the same relationship. The accident severity is higher for smaller radii on state roads compared to the combined analysis of both road categories. The correlation above 1000 m prior length is weak again.



Lprior < 500 m

class value	min	max	acr	number of sample
radius	50	100	11.825	44
radius	100	150	9.4727	69
radius	150	200	7.3958	97
radius	200	250	7.2337	69
radius	250	300	10.701	73
radius	300	350	5.7052	67
radius	350	400	3.0276	28
radius	400	450	1.1327	5
radius	450	500	0	1

ACR = -5.763 * ln(radius) + 37.827
n = 453
$R^2 = 0.7106$

500 m < Lprior < 1,000 m

class value	min	max	acr	number of sample
radius	50	100	25.208	27
radius	100	150	14.896	61
radius	150	200	8.9735	56
radius	200	250	5.6709	64
radius	250	300	11.236	65
radius	300	350	9.3082	42
radius	350	400	12.645	34
radius	400	450	2.2749	2
radius	450	500	2.039	2

ACR = -9.71 * ln(radius) + 63.405
n = 353
R^2 = 0.692

Lprior > 1,000 m

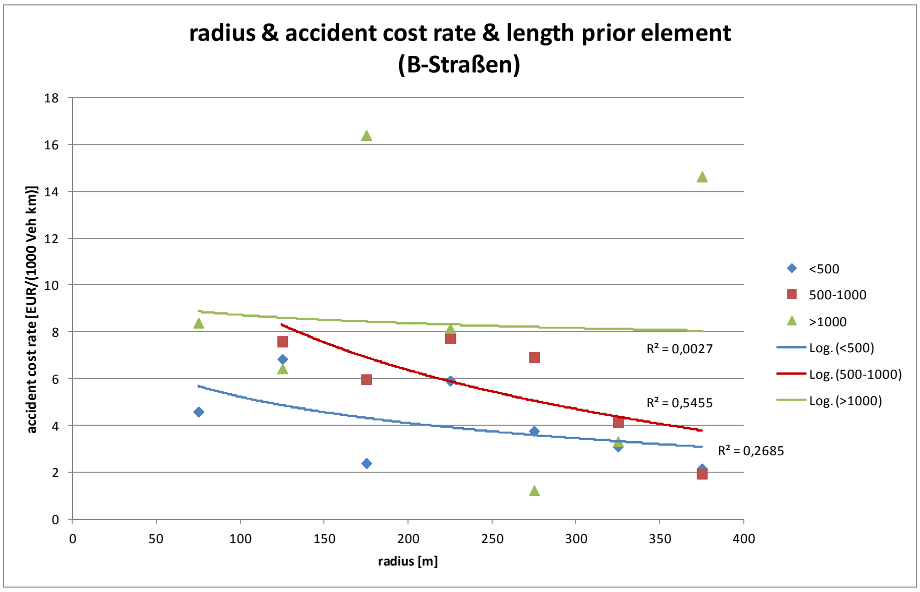
class value	min	max	acr	number of sample
radius	50	100	14.892	33
radius	100	150	58.913	46
radius	150	200	14.56	68
radius	200	250	33.363	71
radius	250	300	28.657	60
radius	300	350	17.706	57
radius	350	400	20.96	33
radius	400	450	0	1

ACR = -10.78 * ln(radius) + 81.732
n = 369
R^2 = 0.1341

Figure 19: Model AR ~ curve radius considering length of prior sequences (3 classes) for state roads (Landstraßen)

The results shown in Figure 20 for federal highways confirm the suggestions. Also on higher categorised roads an influence of length of prior sequences with respect to single curves is given. Above 1,000 m the correlation is weak.

For both road categories the impact of prior length and curve radius was shown. Above 1,000 m the variance between radius classes is high. That might indicate that the major impact already starts at shorter lengths.



Lprior < 500 m

class value	min	max	acr	number of sample	
radius	50	100	4.5969	16	ACR = 1.611 * ln(radius) + 12.644 n = 184
radius	100	150	6.8462	31	R^2 = 0.2685
radius	150	200	2.3996	25	
radius	200	250	5.9216	39	
radius	250	300	3.7749	41	
radius	300	350	3.1056	25	
radius	350	400	2.1686	7	
radius	400	450		n/a	
radius	450	500		n/a	

500 m < Lprior < 1,000 m

class value	min	max	acr	number of sample	
radius	50	100		n/a	ACR = -4.103 * ln(radius) + 28.107 n = 118
radius	100	150	7.5928	7	R^2 = 0.5455
radius	150	200	5.9743	16	
radius	200	250	7.735	26	
radius	250	300	6.9244	30	
radius	300	350	4.1495	26	
radius	350	400	1.9472	10	
radius	400	450		n/a	
radius	450	500		n/a	

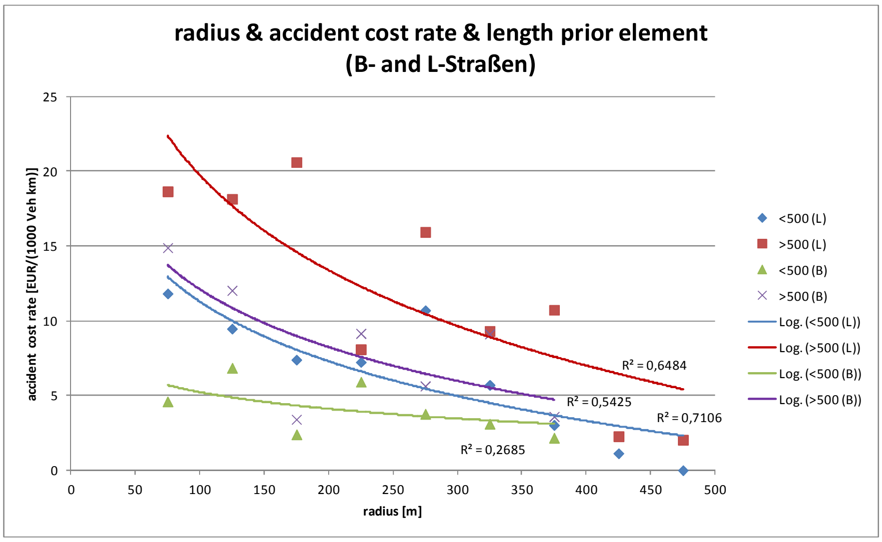
Lprior > 1,000 m

class value	min	max	acr	number of sample	
radius	50	100	8.388	10	ACR = -0.509 * ln(radius) + 11.064 n = 212
radius	100	150	6.4414	15	R^2 = 0.0027
radius	150	200	16.4062	25	
radius	200	250	8.164	42	
radius	250	300	1.2331	59	
radius	300	350	3.3251	50	
radius	350	400	14.6378	11	
radius	400	450		n/a	
radius	450	500		n/a	

Figure 20: Model AR ~ curve radius considering length of prior sequences (3 classes) for federal highways (Bundesstraße)

To improve the results, the same analysis was repeated with only two prior length classes:

- Length prior < 500 m
- Length prior > 500 m.



L-roads, Lprior < 500 m

class value	min	max	acr	number of sample	
radius	50	100	11.825	44	ACR = -5.763 * ln(radius) + 37.827 n = 453
radius	100	150	9.4727	69	R^2 = 0.7106
radius	150	200	7.3958	97	
radius	200	250	7.2337	69	
radius	250	300	10.701	73	
radius	300	350	5.7052	67	
radius	350	400	2.5439	28	
radius	400	450	1.1327	5	
radius	450	500	0	1	

L-roads, Lprior > 500 m

class value	min	max	acr	number of sample	
radius	50	100	18.658	61	ACR = -9.197 * ln(radius) + 62.103 n = 722
radius	100	150	18.154	107	R^2 = 0.6484
radius	150	200	20.614	124	
radius	200	250	8.0952	134	
radius	250	300	15.94	125	
radius	300	350	9.3082	99	
radius	350	400	10.73	67	
radius	400	450	2.2749	3	
radius	450	500	2.039	2	

B-roads, Lprior < 500 m

class value	min	max	acr	number of sample	
radius	50	100	4.5969	16	ACR = 1.611 * ln(radius) + 12.644 n = 184
radius	100	150	6.8462	31	R^2 = 0.2685
radius	150	200	2.3996	25	
radius	200	250	5.9216	39	
radius	250	300	3.7749	41	
radius	300	350	3.1056	25	

radius	350	400	2.1686	7
radius	400	450		n/a
radius	450	500		n/a

B-roads, Lprior > 500 m

class value	min	max	acr	number of sample
radius	50	100	14.895	13
radius	100	150	12.034	22
radius	150	200	3.4022	41
radius	200	250	9.154	68
radius	250	300	5.6371	89
radius	300	350	9.12	76
radius	350	400	3.5917	21
radius	400	450		n/a
radius	450	500		n/a

$ACR = -5.589 * \ln(radius) + 37.845$
$n = 330$
$R^2 = 0.5425$

Figure 21: Model ACR ~ curve radius considering length of prior sequences (2 classes) for state roads (Landstraßen) and federal highways (Bundesstraßen)

The assumption that the influence of lengths above 1,000 m are characterised by a higher inconsistency seems to hold true.

Figure 15 shows the result for the two class analysis for both state roads (L) and federal highways (B). The difference between both road categories is striking. Thus, the severity of accidents on sub classified roads is several times higher than on high classified roads even though the same geometric configuration is compared. It seems to indicate that there are further influences of other design elements, such as cross section. Concerning the number of samples it must be concluded that such a geometric combination of single curve and straight preceding sequence are rarely found on federal highways compared to state roads. Obviously, in general, the alignment seems to be better designed and adapted. Single curves that cause significant speed reductions (see chapter 4) can be avoided by a modern design and in the past a large part of federal highways has been improved.

However, the results show a clear impact of curve radius and length of prior sequence. Explicitly, it makes a difference when drivers approach a curve after a longer straight sequence: Then accidents become more severe. This effect is known and therefore, rules in design guidelines restrict maximum lengths of straights and respectively minimum radii, depending on the length of the straights (e. g. RASL-L 1995). From psychological and driving behaviour studies it is known that drivers adapt behaviour depending on various inputs (Weller 2010). One is the experience made on the last stretch of road. Others are expectations, individual motivation, general experiences and surrounding conditions. It can be assumed that as long as the driver experiences a similar alignment that is only interrupted by short straight sections their expectations regarding the following alignment will not change. But if the distance becomes longer between geometric elements the speed choice may change (become inappropriate) as might expectations regarding following curves, resulting in harsh and possibly dangerous breaking manoeuvres.

6.2.2.3 Speed Difference

Figure 22 shows the results for the relation between accident cost rate and speed difference. The graphs show three models: B- and L-roads combined and separately. All models indicate the same relationship: an increasing speed difference and an associated increase in accident severity. There is only a small difference between the model for L-roads and the combined model, with both correlation coefficients being high. Regarding the model for B-roads, the correlation is weaker. The variation in the data is higher and makes an interpretation more difficult. For speed differences above 30 km/h fewer samples are available (see Figure 22). That might indicate that high speed differences rarely occur on higher classified roads which could be explained by the better adapted alignment.

B- and L-roads

class value	min	max	acr	number of samples	
dV	10	15	3.3002	429	ACR = 4.735 * ln(dV) – 9.2038
dV	15	20	4.1871	388	n = 1,584
dV	20	25	4.499	326	R^2 = 0.78
dV	25	30	4.6641	214	
dV	30	35	7.9848	156	
dV	35	40	8.8491	71	

L-roads

class value	min	max	acr	number of samples	
dV	10	15	1.8648	292	ACR = 5.4179 * ln(dV) – 11.509
dV	15	20	4.5909	234	n = 1,090
dV	20	25	4.8357	232	R^2 = 0.9
dV	25	30	5.1454	154	
dV	30	35	7.9848	120	
dV	35	40	8.2792	58	

B-roads

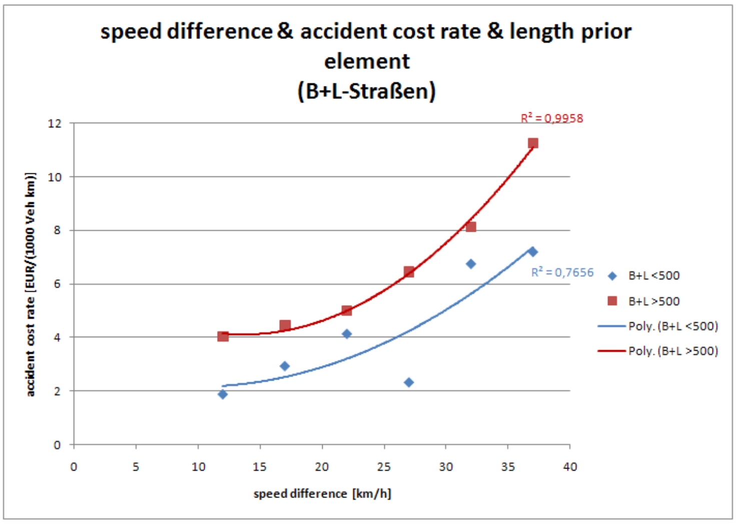
class value	min	max	acr	number of samples	
dV	10	15	4.5777	137	ACR = 6.4955 * ln(dV) – 13.962
dV	15	20	3.5141	154	n = 494
dV	20	25	3.8661	93	R^2 = 0.47
dV	25	30	3.3754	60	
dV	30	35	11.7964	37	
dV	35	40	11.0935	13	

Figure 22: Model ACR ~ speed difference for state roads (Landstraßen) and federal highways (Bundesstraßen)

6.2.2.4 Speed Difference and Length of prior Sequence

As was already done for curve radius, the impact of the length of the prior sequence was also investigated for speed difference. It was concluded in chapter Curve Radius and Length of prior Sequence that the influence of the length of the prior sequence on accidents is the result of differences in driving behaviour. This effect should be replicated with the speed difference model. This is because the speed difference should be a more appropriate explanatory variable.

Based on the results from chapter 6.2.2.2 the prior length is divided into two classes: L_{prior} < 500 m and L_{prior} > 500 m.



B- and L-roads, Lprior < 500 m

class value	min	max	acr	number of samples	
dV	10	15	1.8665	184	ACR = 0.007 * dV² - 0.1379 * dV + 2.8302
dV	15	20	2.9211	154	n = 604
dV	20	25	4.1252	118	R² = 0.77
dV	25	30	2.3118	73	
dV	30	35	6.741	53	
dV	35	40	7.187	22	

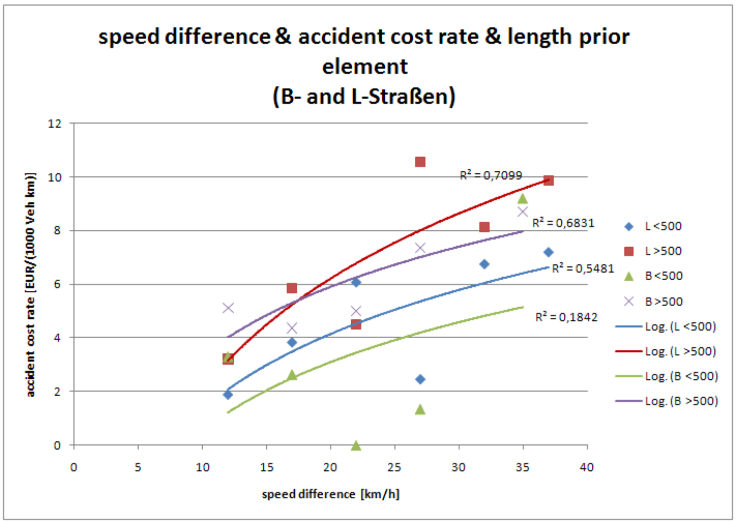
B- and L-roads, Lprior > 500 m

class value	min	max	acr	number of samples	
dV	10	15	4.0258	245	ACR = 0.0129 * dV² - 0.3521 * dV + 6.5203
dV	15	20	4.4379	237	n = 985
dV	20	25	5.006	208	R² = 0.99
dV	25	30	6.4428	141	
dV	30	35	8.1338	105	
dV	35	40	11.2476	49	

Figure 23: Model ACR ~ curve radius considering length of prior sequences (2 classes) combined for state roads (Landstraßen) and federal highways (Bundesstraßen)

Figure 23 shows the results for the combined investigation of both road categories. As assumed, the same effect is indicated again. Beside the speed difference also the length of the prior straight sequence has a significant impact on accident severity. Thus, the same speed difference causes a higher accident severity if the prior straight sequence is longer. Both models are characterised by a high explained variance indicated by the high R^2 values.

The results of the separate analyses for B- and L-roads are given in Figure 24. For both road categories the direction of the correlation between speed difference and accident severity separated by prior sequence length is the same: the higher the speed differences the more severe are accident consequences.



L-roads, Lprior < 500 m

class value	min	max	acr	number of samples	
dV	10	15	1.8648	135	ACR = 4.0408* ln(dV) – 7.9638
dV	15	20	3.8158	100	n = 428
dV	20	25	6.062	86	R^2 = 0.55
dV	25	30	2.4396	52	
dV	30	35	6.741	37	
dV	35	40	7.187	18	

L-roads, Lprior > 500 m

class value	min	max	acr	number of samples	
dV	10	15	3.197	158	ACR = 5.9834 * ln(dV) – 11.714
dV	15	20	5.8359	136	n = 667
dV	20	25	4.499	145	R^2 = 0.71
dV	25	30	10.5513	105	
dV	30	35	8.1338	83	
dV	35	40	9.876	40	

B-roads, Lprior < 500 m

class value	min	max	acr	number of samples	
dV	10	15	3.3002	49	ACR = 3.666 * ln(dV) – 7.8935
dV	15	20	2.6355	54	n = 176
dV	20	25	0	33	R^2 = 0.18
dV	25	30	1.347	21	
dV	30	40	9.1937	19	

B-roads, Lprior > 500 m

class value	min	max	value	number of samples	
dV	10	15	5.1082	87	ACR = 3.6873 * ln(dV) – 5.147
dV	15	20	4.3587	101	n = 318
dV	20	25	5.006	62	R^2 = 0.68

dV	25	30	7.3443	38
dV	30	40	8.717	30

Figure 24: Model ACR ~ curve radius considering length of prior sequences (2 classes) separated for state roads (Landstraßen) and federal highways (Bundesstraßen)

Again, there is a considerable impact of the prior sequence length. Longer prior straight sequences cause more severe accidents. This is another indication that speed behaviour is different and that it influences road safety depending on the geometric configuration.

There are differences between B-roads and L-roads. With the same speed differences the accident severity on L-roads is higher than on B-roads. This effect is also an indication of the general lower standard of design regarding the horizontal alignment and cross section of L-roads.

6.3 Curved Sequences

Based on the definition of curved sequences (see chapter 4) several single curves were connected to a longer stretch. Within the sequence drivers keep an almost constant speed. The sequence of several single curves within a relative short distance also influences driving behaviour and especially speed, but in a different way than on single curves. Drivers do not adapt their speed predominantly to the single curves within a sequence, but to the entire sequence. The impact on driving behaviour is different so a separate investigation is needed.

However, the combination of several elements makes the analysis more difficult. The curvature change rate is an appropriate parameter to describe the geometric relations. That value gives information about the median deviation per length and is thus adequate to discuss effects within the sequence. However, at the beginning, the first curve might affect driving behaviour similar to a single curve since the driver has to approach the first curve with an appropriate speed. On the other hand, drivers should perceive the alignment ahead and realize that the alignment is getting curvy. It seems that a combination of both effects is responsible for the results.

Due to the definition of sequence types (see chapter 4) and furthermore due to the general geographic situation of Brandenburg, the road network is mainly characterised by long straight lines and single curves. Table 5 shows the number of available samples. For the sequence type “curved sequence” only 57 samples were detected (B- and L-roads). This is not enough for a detailed statistical analysis. However, for exploratory purposes, an analysis was performed nevertheless for L-roads. B-roads had to be excluded because there were only 15 samples.

6.3.1 Model for Number of Accidents with injuries

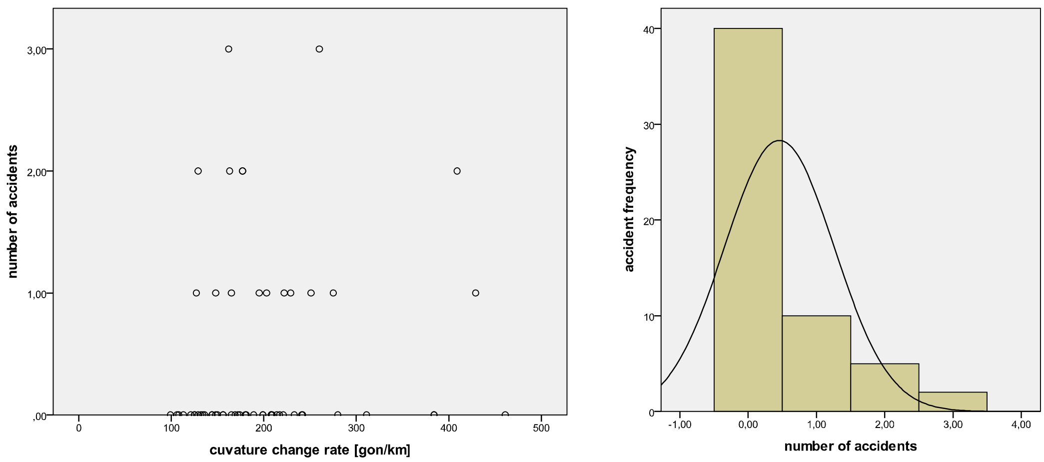


Figure 25: Distribution of number of accidents for curved sequence and curvature change rate

Figure 25 shows the distribution of the number of accidents with injuries. Again at most sites no accidents happened within the investigation time period. All in all there were only a small number of samples to be investigated (N=57) so that it can be assumed that the model will be weak. However, in order to test the results a model has been computed based on:

$$AF_{SES,CCR} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0+\beta_1 CCR}$$

parameter	regression coefficient	standard error	95% Wald-confidence interval: lower value	95% Wald-confidence interval: upper value	hypothesis testing: Wald-Chi-quadrat	hypothesis testing: df	hypothesis testing: sig.
(Konstanter Term)	-11.398	7.5700	-26.235	3.439	2.267	1	0.132
ccr	0.002	0.0028	-0.004	0.007	0.337	1	0.562
ln_traffic	1.146	0.4259	0.312	1.981	7.245	1	0.007
ln_length	0.182	1.0412	-1.859	2.223	0.031	1	0.861
(Skala)	0.880[a]						
(Negativ binomial)	1						

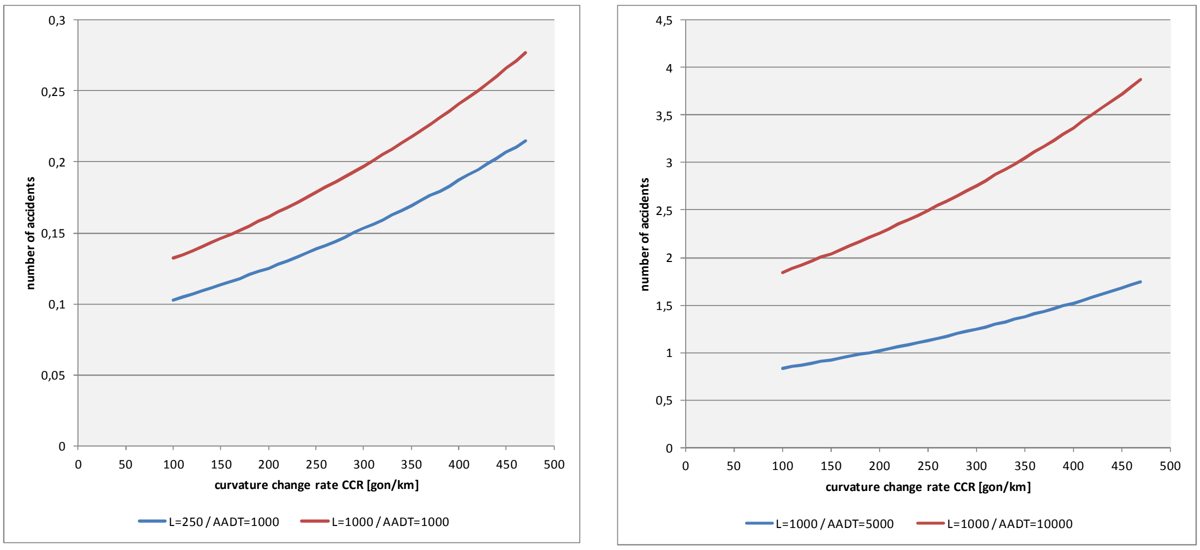
$$AF_{SES,CCR} = V_i^{1.146} L_i^{0.182} e^{-11.398+0.002CCR}$$

(150 gon/ km ≤ CCR ≤ 461 gon/km, 257 m ≤ L ≤ 1,028 m, 751 ≤ AADT ≤ 10,375)

CCR…curvature change rate, V…AADT, L…length of curved sequence

n=57

Table 11: Results of model development for curvature change rate of curved sequences



impact of length of curved sequence impact of AADT

Figure 26: Model AF ~ curvature change rate for curved sequences

Figure 26 and Table 11 includes the results of the model development. The assumed relations are evident although the results are not statistically significant due to the small sample size:

1. With increasing curvature change rate the number of accidents increases. It is known

that curved sequences with a high curvature change rate are not necessarily unsafe. It also depends on the relation between adjacent radii. Because of the small number of such cases in the samples this effect could not be shown here.

2. The longer the curvy stretch the higher the number of accidents.
3. Higher traffic volumes result in a higher accident frequency.

6.3.2 Model for Accident Cost Rate

Figure 27 shows the results for L-roads and the correlation of accident severity and curvature change rate. As expected, the accident cost rate increases with increasing CCR. However, from other studies, it is known that above a certain CCR-value, the accident cost rate decreases again. Above 400 gon/km the road is too curvy to drive fast, so speeds go down and therefore also the severity of accidents decreases. However, this effect could not be shown by the results (Dietze et al. 2007).

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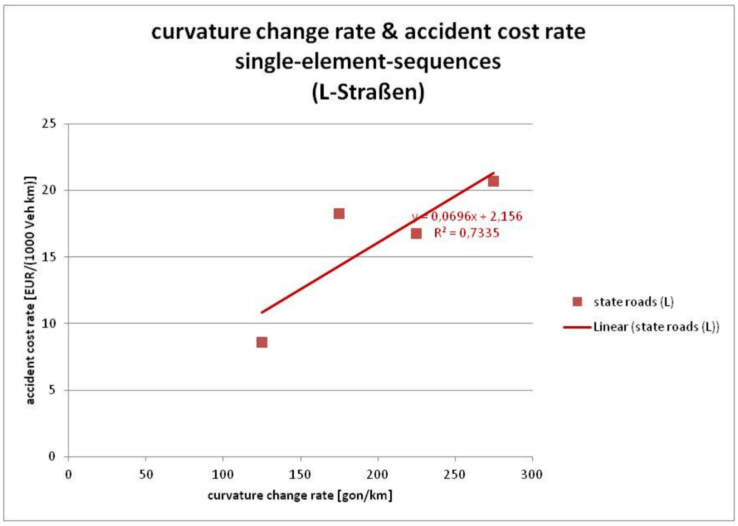


L-roads

class value	min	max	m	value	number of samples	
ccr	100	150	125	8,5936	7	ACR = 0.0696 * CCR + 2.156
ccr	150	200	175	18,2689	11	n = 32
ccr	200	250	225	16,776	11	R^2 = 0.73
ccr	250	300	275	20,698	2	

Figure 27: Model ACR ~ curvature change rate for state roads (Landstraßen)

6.4 Straight Sections

Straight sections with respect to the definition in chapter 4 are straight or almost straight road stretches. All in all 92 % of the detected straight sections are characterised by a curvature change rate of less or equal than 100 gon/km. At this level, the CCR has no impact on speed (FGSV 1995), thus drivers travel at high speeds. Furthermore, such geometric parts of the alignment are often used to overtake slower road users.

In order to analyse this effect the available samples have been limited to a maximum of 150 gon/km.

It is assumed that overtaking accidents are more important and frequent on (almost) straight road sections than on the other investigated sequence types where driving accidents dominate. Normally, on long straight road sections drivers overtake slower traffic and depending on the geometric configuration it might be safety critical.

The assumed difference regarding accident type one and six seems to be confirmed by the scatter plots shown in Figure 28. Obviously, accident type six (overtaking accident) is more likely especially in low ranges of curvature change rate.

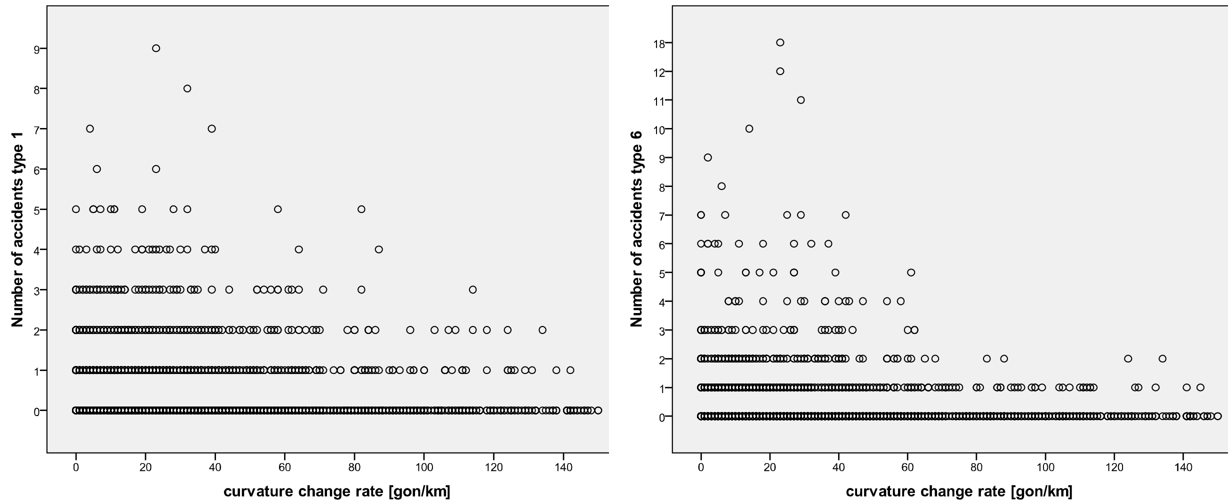


Figure 28: Distribution of number of accidents concerning accident type 1 (left) and 6 (right)

6.4.1 Model for Number of Accidents with injuries

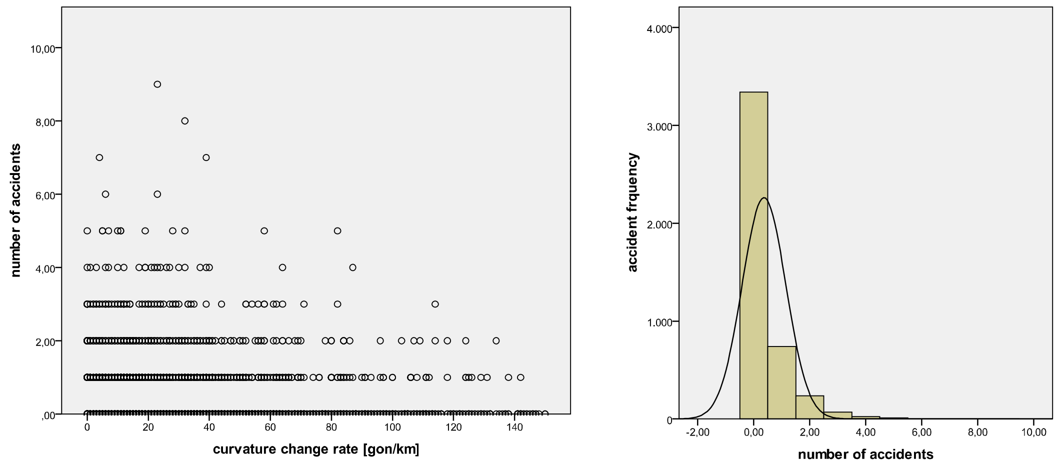


Figure 29: Distribution of number of accidents with injuries concerning CCR for straight sections

Figure 29 shows the distribution of the number of accidents with injuries. The majority of these locations revealed that there were no accidents registered during the three year period. The following model was developed:

$$AF_{ES,CCR} = V_i^{\alpha_{V_k}} L_i^{\alpha_{L_k}} e^{\beta_0 + \beta_1 CCR}$$

parameter	regression coeeficient	standard error	95% Wald-confidence interval lower value	95% Wald-confidence interval upper value	hypothesis testing Wald-Chi-quadrat	hypothesis testing df	hypothesis testing sig.
(Konstanter Term)	-11.308	0.4577	-12.205	-10.411	610.359	1	0,000
ccr	-0.004	0.0012	-0.003	-0.005	3.928	1	0,047
ln_traffic	0.480	0.0427	.396	0.564	126.206	1	0,000
ln_length	0.890	0.0397	.812	0.968	501.030	1	0,000
(skala)	0.925[a]						
(negativ binomial)	1						

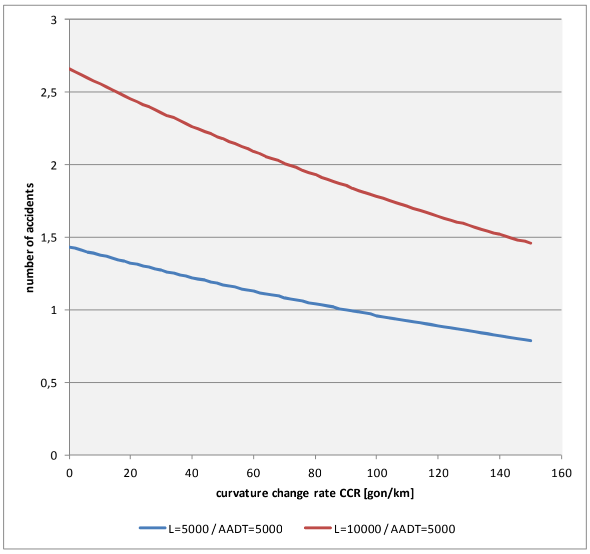
$$AF_{ES,CCR} = V_i^{0.480} L_i^{0.890} e^{-11.308-0.004CCR}$$

(0 gon/ km ≤ CCR ≤ 150 gon/km, 200 m ≤ L ≤ 12,130 m, 377 ≤ AADT ≤ 45,008)

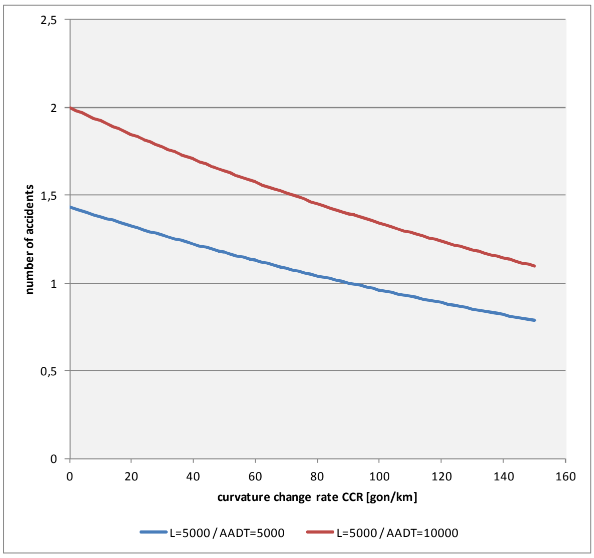
CCR…curvature change rate, V…AADT, L…length of straight section

n=4,020

Table 12: Results of model development for curvature change rate of straight sections



impact of length of straight section



impact of AADT

Figure 30: Model AF ~ curvature change rate for straight sections

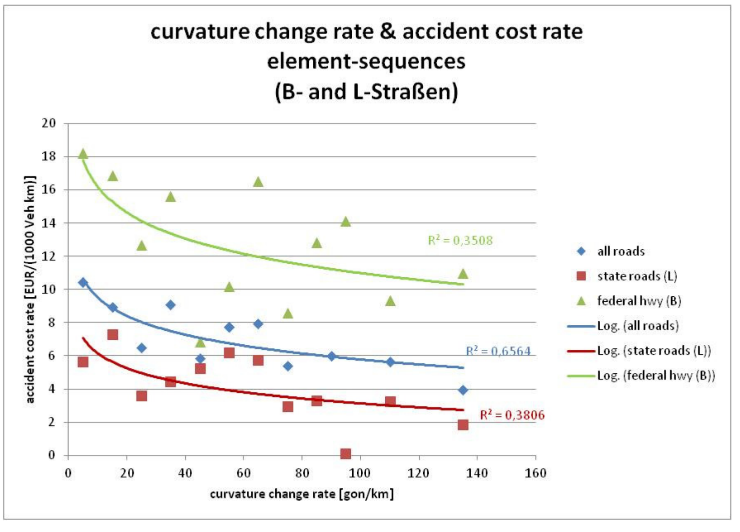
The applied regression coefficients are significant. The model graph shows a general decline of the number of injury accidents with increasing curvature change rate that might indicate the effect of a reduction of type six accidents (see Figure 28). Furthermore the lengths of straight section as well as the traffic volume have an impact. Summarised the following effects have been found:

1. With increasing curvature change rate the expected number of accidents with injuries declines as well. This is due the reduction of accidents of type six (overtaking accidents) which become unlikely if roads are more curvy.
2. The longer the straight section the higher the number of accidents. This shows mainly that on longer stretches overtaking manoeuvre are more likely. Furthermore, there might be the impact of higher speed levels that often are measured on such sections. Also, on long straight sections drivers do pay less attention or become fatigue.

3. Traffic volume has also an important impact. The higher the traffic volume the higher the expected number of accidents with injuries.

6.4.2 Model for Accident Cost Rate

The results are shown in Figure 31. The correlation models for both road categories show a decreasing relation between curvature change rate and accident cost rate: the higher the CCR the lower the severity of accidents. At first this seems to be in contrast to the results for the curved sequences. There, the accident severity increases with higher curvature change rate. But as discussed previously, the analysed curved sequences are curvy above 150 gon/km and geometric alignment influences driving behaviour; on the other hand, straight sections are straight or rather less curvy road stretches. As already discussed the driving behaviour is different and the probability of passing manoeuvres increases. Considering the distribution of accident types (Table 6) overtaking accidents are dominant.



B- and L-roads

class value	min	max	acr	number of samples	
ccr	0	10	10,4585	523	ACR = -1.633 * ln(CCR) + 13.293
ccr	10	20	8,9309	497	n = 2772
ccr	20	30	6,4792	404	R^2 = 0.66
ccr	30	40	9,0782	317	
ccr	40	50	5,8343	246	
ccr	50	60	7,7508	165	
ccr	50	60	7,7508	165	
ccr	60	70	7,9259	109	
ccr	70	80	5,3749	65	
ccr	80	100	5,9728	122	
ccr	100	120	5,6442	89	
ccr	120	150	3,9698	70	

L-roads

class value	min	max	acr	number of samples	
ccr	0	10	5,6535	289	ACR = -1.321 * ln(CCR) + 9.2068
ccr	10	20	7,3057	318	n = 1568
ccr	20	30	3,6185	254	R^2 = 0.38

ccr	30	40	4,4439	167
ccr	40	50	5,241	151
ccr	50	60	6,2093	101
ccr	60	70	5,7548	57
ccr	70	80	2,9577	33
ccr	80	90	3,3247	53
ccr	90	100	0,1	36
ccr	100	120	3,2426	58
ccr	120	150	1,8759	51

B-roads

class value	min	max	acr	number of samples	
ccr	0	10	18,2037	238	ACR = -2.274 * ln(CCR) + 21.451
ccr	10	20	16,8894	181	n = 1034
ccr	20	30	12,6804	148	R^2 = 0.35
ccr	30	40	15,6349	147	
ccr	40	50	6,8451	95	
ccr	50	60	10,1968	63	
ccr	60	70	16,5103	54	
ccr	70	80	8,5663	32	
ccr	80	90	12,8475	14	
ccr	90	100	14,1449	16	
ccr	100	120	9,3316	28	
ccr	120	150	10,9813	18	

Figure 31: Model ACR ~ curvature change rate separated for state roads (Landstraßen) and federal highways (Bundesstraßen)

This impact of overtaking accidents is reflected by the models. With increasing curvature change rates the probability of overtaking decreases. Most overtaking manoeuvres are carried out on straight sections which explains the higher accident cost rate in lower CCR-ranges as well as the decreasing accident cost rate in higher CCR-ranges. Generally speaking, the results are characterised by a high variation that might show the impact of single vehicle accidents that also happen on straight road parts (e. g. run-off-the-road accidents as single vehicle accidents).

It can be concluded that the effect of overtaking accidents is indicated by the developed models. They seem to be the significant safety problem on less curvy road parts.

7 Application and Test

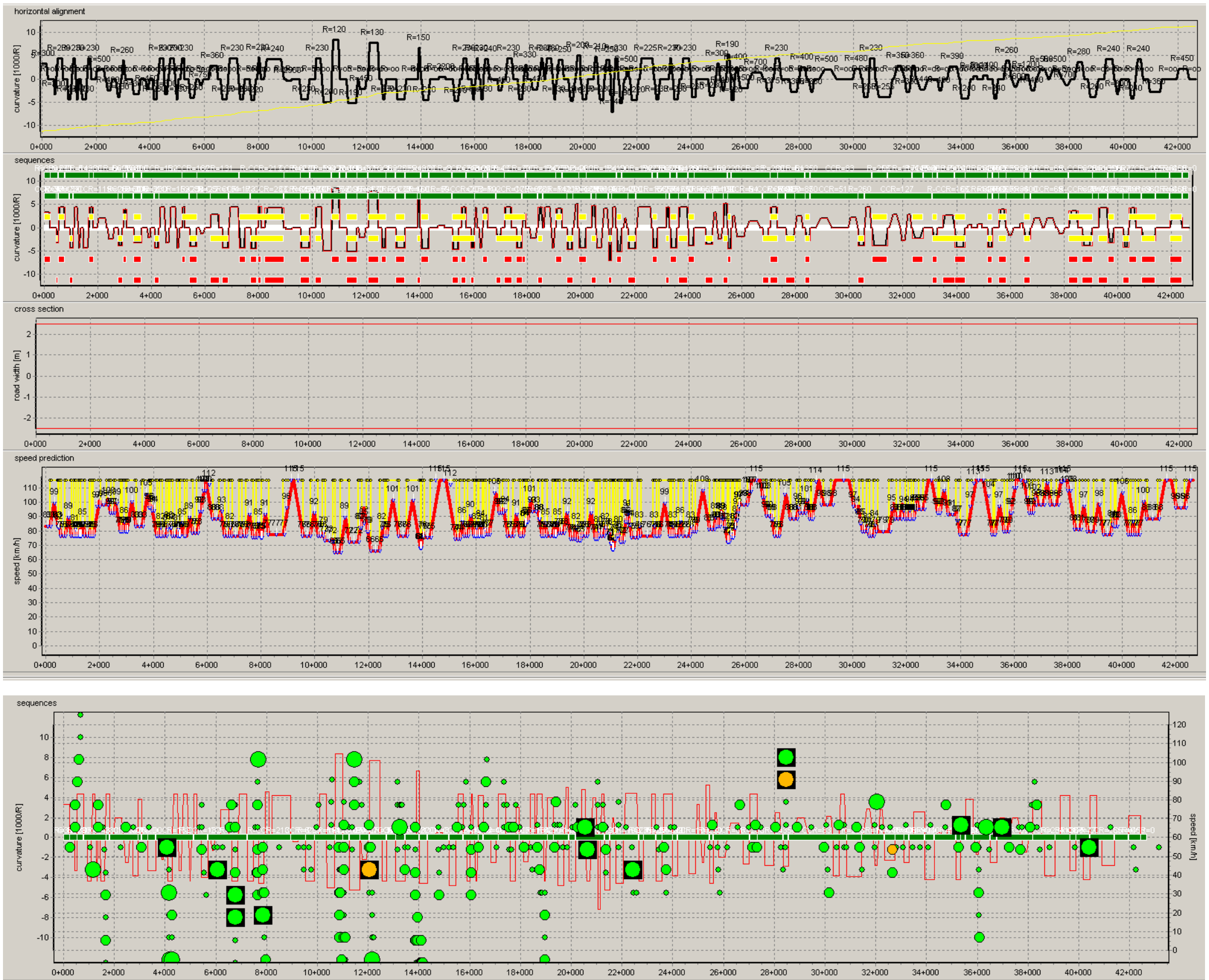
7.1 Introduction of Portuguese road

A 42 km stretch of the Portuguese road IP 04 (*Itinerários Principais*, Principal Routes) was investigated. However, the accident structure is different to the German structure of accident types. An attempt was made to match the data as far as possible to the German data structure.

IP 04 belongs to the main National Road Network and is characterised by a curvy horizontal alignment and a hilly longitudinal profile. The minimum horizontal radius is 120 metres; the maximum radius is about 2,500 metres. The curvature change rate is about 282 gon/km for the total road stretch.

A total of 665 accidents (accident type 1: 658, accident type 6: 7 according to the German accident types) occurred in the years 2003, 2004, and 2005. In these accidents 33 persons were killed (AT1 29/ AT6 4), 51 persons were seriously injured (AT1 43/ AT6 8) and 360 persons were slightly injured (AT1 356/ AT6 4). That means that almost one person per month was killed in an accident on this road stretch. The AADT was 13,401 vehicles per day (year 2004).

As for the development of the analysis, in a first step the sequence detection was applied. 60 single curves, 14 curved sequences and 75 straight sequences have been detected. This result shows the curvy character of the road again. Furthermore, the real accidents were mapped to the detected sequences in order to allow a comparison between real and predicted accident occurrence.



top to bottom: horizontal alignment, sequence detection, road width, dynamic speed profile, mapped accidents

Figure 32: Screenshots of analysis of IP04

7.2 Results for the application

To evaluate the predicted results a reference value is needed to make it possible to decide whether the predicted result is safety critical or not.

In Germany, such reference values are the so called basic accident cost rates. These were used to evaluate calculated accident cost rates based on the real accident occurrence for specific road stretches. Since these basic accident cost rates are only available for certain road classes (rural roads, motorways etc.) and do not consider further properties like geometric alignment, they are inappropriate for this project. Regarding the Poisson based analyses with the number of personal damage accidents they cannot be applied here, anyway.

Therefore, the reference values were derived in a different way separated for both prediction model types. The reference values were calculated as 95th quantile (95%) of all available data with respect to model definitions. These calculated reference values are given in Table 13 and Table 14.

sequence type	model		number of accidents with injuries
single curves	speed difference	L_{prior} ≤ 600 m	1,00
	speed difference	L_{prior} > 600 m	1,00
curved sequences	CCR		2,95
straight sections	CCR		2,00

Table 13: Reference value for number of accidents with injuries separated for each model

sequence type	model		accident cost rate reference value [€/(1000*Veh*km)]
single curves	speed difference	L, Length-prior<500	4,2375
	speed difference	L, Length-prior>500	5,8759
	speed difference	B, Length-prior<500	2,7258
	speed difference	B, Length-prior>500	4,9909
curved sequences	CCR	L	18,2689
	CCR	B	n/a
straight sections	CCR	L	5,2087
	CCR	B	14,5467

Table 14: Reference value for accident cost rate separated for each model

To evaluate predicted values they were compared to these separately derived reference values. A negative result means that the predicted value is lower than the reference value, in which case the sequence under consideration is not seen as critical. In contrast, if a predicted value is higher than the reference value it is seen as safety critical. Two levels have been set up:

- a ≤10% higher predicted value results in the yellow level.
- If it is higher, it will be a red level.

For the application of models for number of accidents with injuries the following prediction models were applied:

Single curves
L_{prior}≤600

$$AF_{SE,dV,L_{prior}} = V_i^{0.716} L_i^{0.018} e^{-7.936+0.022dV+0.001L_{prior}}$$

(10 km/h ≤ dV ≤ 73 km/h, 40 m ≤ L ≤ 471 m, 511 ≤ AADT ≤15,031, 100 m ≤ L_{prior} ≤ 600 m)

dV…speed reduction, V…AADT, L…length of single curve, L_{prior} …length of prior sequence

Single curves L_{prior}>600

$$AF_{SE,dV} = V_i^{0.585} L_i^{0,216} e^{-7.713+0.033dV}$$

(10 km/h ≤ dV ≤ 73 km/h, 40 m ≤ L ≤ 559 m, 511 ≤ AADT ≤ 20,750)
dV…speed reduction, V…AADT, L…length of single curve

Curved sequences

$$AF_{SES,CCR} = V_i^{1.146} L_i^{0.182} e^{-11.398+0.002CCR}$$

(150 gon/ km ≤ CCR ≤ 461 gon/km, 257 m ≤ L ≤ 1,028 m, 751 ≤ AADT ≤ 10,375)

CCR…curvature change rate, V…AADT, L…length of curved sequence

Straight sections

$$AF_{ES,CCR} = V_i^{0.480} L_i^{0.890} e^{-11.308-0.004CCR}$$

(0 gon/ km ≤ CCR ≤ 150 gon/km, 200 m ≤ L ≤ 12,130 m, 377 ≤ AADT ≤ 45,008)

CCR…curvature change rate, V…AADT, L…length of straight section

There is a difference concerning the speed models for single curves since the length of the prior sequence has an impact at lengths up to 600 m. Above this value, the general speed reduction model must be applied.

The results of sequence detection and prediction are given in Appendix 1. Table 15 shows the summarised results.

Sequence type	total	not critical	semi critical	critical
Single curve	60	52	2	6
Curved sequence	14	11	2	1
Straight section	75	71	0	4

Table 15: Number of detected and evaluated sample for number of accidents with injuries model separated by sequence types

Analogues, for the application of models for accident cost rates the following predictions models were applied:

- Single curve:
  - ACR = 0.007*dV²-0.1379*dV+2.8302 (L_{prior} < 500 m)
  - ACR = 0.0129*dV²-0.3521*dV+6.5203 (L_{prior} ≥ 500 m)
- Curved sequence
  - ACR = 0.0696*CCR+2.156
- Straight section
  - ACR = -1.321*ln(CCR)+9.2068

The results of sequence detection and prediction are given in Appendix 2. Table 16 shows the summarised results.

Sequence type	total	not critical	semi critical	critical
Single curve	60	47	2	11
Curved sequence	14	11	3	1
Straight section	75	51	5	22

Table 16: Number of detected and evaluated sample for accident cost rate model separated by sequence types

The results are different regarding both developed model types. About 10 percent (model number of accidents with injuries) and about 30 percent (model for accident cost rate) of all detected sequences are safety critical. This is not surprising since both models predicted a different value. The model for the number of injury accidents does not distinguish between different levels of accident severity. Fatalities, seriously and slightly injured persons are considered in the same way. In contrast, the model for the accident cost rate takes into account the distribution of the degree of injury. It makes an important difference whether an accident happens with fatalities or with slightly injured persons only.

These results show the importance of what has to be predicted. In order to focus on the statistical potential of geometric configurations that cause accidents the model for number of accidents with injuries seems to be appropriate. If the consequences of accidents are in the focus of the research, a weighted value such as the accident cost rate should be applied.

Compared to the real accident occurrence the predicted accident numbers seem to be too low. But this shows the significant difference between investigations of real accident data and safety prediction. The developed models indicate elements or element combinations that might be safety critical (according to the criteria represented by the model used). Real accident data analysis shows the current safety critical spots. That both are almost the same cannot be expected as is shown by many accident studies: a single curve with small radius is definitely safety critical but it is necessary that accidents happen within the investigated time period. Prediction computes potential safety problems whereas real accident analysis shows current safety problems.

In the case of the analysed stretch of IP04 road, longitudinal profile characteristics, with steep (6%) and long grades (over 1 km), are believed to influence driver speed choice in a way that is not very well represented by traditional speed profile models, degrading the accuracy of speed difference prediction and, thus, the safety prediction.

Another reason for the shown differences is that obviously the investigated stretch of IP 04 road is characterised by an exceptionally high accident occurrence in accordance with a high accident severity. This is significantly higher than the ‘normal safety situation’ in Portuguese IP roads and for that matter, also German roads on which these models are based. In fact, the reference values were calculated on the basis of this IP stretch alone; lower reference values would be obtained if all IP stretches of the Portuguese National Road Network had been used. Also, the models are based on the analysis of German accident data. Calibrating the models in order to take into account local (national) conditions in terms of accident structure, driving behaviour and standard of design, is considered essential.

8 Conclusions

The objective of this study was to develop accident prediction models that take driving behaviour into account. Existing models often include correlations between road geometry and accident parameters but data have not been analysed with regard to known effects from driving behaviour studies.

To improve accident prediction with a clear focus on severe accidents caused by inappropriate driving behaviour the developed approaches consider it in two different ways.

Since driver and driving behaviour is based on complex relations between the driver, the car and the environment within this study driving behaviour is reduced to speed behaviour. Even though this is a simplification, speed is definitely one of the most relevant and important parameters and is appropriate to be considered in such models (Ebersbach 2006).

8.1 Sequence definition

First elements and element combinations must be detected which have a verifiable significant impact on speed. For that reason three different sequence types have been defined based on experiences of driving behaviour investigations:

- Single curves that have a significant impact on speed and cause speed differences that might be dangerous. Their position within in the alignment allows no influence of other single curves. Mostly single curves with small radii belong to this type.
- Curved sequences are generally similar to single curves concerning their geometric parameters. But their distance to other single curves is very low so that they do affect driving behaviour not as a single but rather as a combination of several curves.
- Straight sections include geometric elements which have only a minor or no impact on speed. Such elements can be combined to less curvy stretches or are straight lines.

This differentiation covers a wide range of known effects of road geometry on driving behaviour. Besides the effect on speed behaviour their impact on road safety is also taken into account.

8.2 Sequence detection

To detect the defined sequences an algorithm has been developed which is based on a speed prediction model. The literature includes numerous research studies about speed prediction. Often they predict speed for certain elements and calculate a possible maximum speed. But they do not take into consideration the effect of geometric conditions on adjoining road sections. To detect the elements or element combinations with significant impact on driving behaviour, dynamic speed prediction is essential in order to simulate speed profiles over entire road stretches.

To do so, a curve speed prediction model in combination with a driving dynamic model has been applied. The curve speed model was developed by analysing real measured speed data and predicts speed for curves based on curve radius. The speeds that are predicted are possible maximum curve speeds. To link the predicted single curve speeds and simulate the speed profile it was combined with a dynamic speed model that has been derived from the classical physical constant motion. This simplified approach works with a de- and acceleration of 0.8 m/s² as a constant value. The advantage of this approach is its easy handling and that it allows analysing how speed changes with respect to alignment. Even though the assumption that drivers de- or accelerate constantly and on the same level does not meet the reality the speed influencing elements can nevertheless be detected.

For further investigations it seems promising to improve the dynamic speed model. It should consider the difference between acceleration and deceleration. Furthermore, the value of both should depend on the expected speed difference. This is because it is known from driving behaviour studies that drivers brake harder if they must slow down by 30 km/h instead of 5 km/h (Ebersbach 2006). Another improvement might be the consideration of the vertical alignment.

8.3 Results for Single Curves

The investigation of single curves has shown their significant impact on road safety. Based on the definition that single curves cause a high speed reduction independent from other elements, the combination of their impact on driving behaviour and negative effects on road safety was confirmed.

Generally, the results can be summarised as:

1. Single curves have a significant effect on driving behaviour by reducing speed and consequently have also an effect on road safety.
2. There is a clear relation between the radius of single curves and accident parameters. The smaller the curve
    a. the higher the number of accidents with injuries and
    b. the more severe are the accident consequences.
3. Based on the results of the dynamic speed model and analyses of real speed profiles the radius of curves is not the most appropriate parameter to describe the impact of single curves on road safety. This is because the effect on driving behaviour is mainly caused by the speed reduction. But the level of speed reduction caused by a single curve depends primarily on its configuration to other design elements. Therefore, it is more appropriate to investigate the influence of speed differences.
4. Speed differences correlate significantly with the accident parameters. The higher the speed differences
    a. the higher the number of accidents with injuries and
    b. the worse the accident consequences.

    It is assumed that the models for speed differences indicate the influence in a better way. Here, driving behaviour is directly considered in terms of speed reduction.
5. As already mentioned, the preceding sequence has an impact on the road safety level of subsequent single curves. In the case of the investigation shown here, and based on the sequence definition, a prior sequence is (almost) straight. It is known that with increasing length of a prior straight sequence, the more time is available to the driver to adapt the speed to a possible maximum. Also, it may change the expectations of the driver regarding the subsequent road stretch. If drivers have to negotiate single small curves (or curved stretches) over short distances they may expect the next stretches to have a similar alignment as well. But if the alignment is changing to longer straight sequences the driver might assume the alignment has generally been changed to being less curvy. When a single small element appears after a longer distance again then it does not meet driver's expectation and consequently the error rate is higher. For that reason also the impact of the prior sequence in terms of length has been considered. The results show a clear impact. The longer the length of the preceding sequence,
    a. the higher the number of accidents with injuries and
    b. the more severe the accident consequences.
6. Furthermore, the model for number of accidents with injuries shows the impact of further parameters:
    a. the longer the curve, the higher the number of accidents,
    b. the higher the traffic volume, the more accidents happen.

8.4 Results for Curved Sequences

With respect to the geographical situation in Brandenburg (prevailing flat territory with little or no effect from the topography on road design) the curved sequence on Federal roads could not be analysed due to the small sample size.

The results show the relation between the number of accidents with injuries/ accident cost rate and curvature change rate which is in accordance with results from the literature:

1. With increasing curvature change rate the number of accidents increases as well.
2. The longer the curvy stretch the higher the number of accidents.
3. Higher traffic volumes result in higher accident frequency

However, it has to be concluded that this study could not deliver robust results for this sequence type.

To improve the model a road network of a southern federal state should be analysed. In these states, this sequence type is common because the road alignment is closely adapted to the existing hilly terrain.

8.5 Results for Straight Sections

Straight sections represent straight or less curvy road stretches where drivers do not have to adapt their driving speed to the requirements of road geometry but approach maximum permissible speeds.

To separate this kind of geometric configuration into a special sequence type does make sense not only because of its specific impact on speed but also because safety problems on straights and less curvy road parts differ from that in single curves or curved sequences. For that reason it is essential to investigate such geometric element combinations using a separate approach.

Both models show different results when compared to curved sequence because

- the number of accidents with injuries as well as the accident severity decreases with higher CCR.

Obviously, this is the impact of a changing safety situation: overtaking manoeuvres are common on these road parts and become more important. This is confirmed by the shown scatter-plots of accident types one and six.

Generally, the results can be summarised as follows:

1. Overtaking accidents occur more often on this sequence type than on other sequence types.
2. It is assumed that with increasing curvature overtaking accidents become less likely, and so single vehicle accidents are more important. The models show
    a. a decreasing number of accidents with injuries and
    b. a decreasing accident severity with higher curvature change rates
3. The model for accident cost rate show differences between the two investigated road categories. On federal highways (Bundesstraßen) the impact is considerable higher than on state roads (Landstraßen). This can be explained with the larger design parameters (radii, cross section) which make passing more likely than on lower classified roads.
4. The model for the number of accidents with injuries shows furthermore the impact of sequence-length and traffic volume:
    a. the longer the sequence the higher the number of expected accidents,
    b. the higher the traffic volume the more accidents happen
    c. a difference between the investigated accident types was shown and it is assumed that this difference is also an effect of traffic volume: On straights the number of overtaking accidents increases with increasing traffic volume and respectively on less curvy sections the number of single accidents increases with increasing traffic volume.

5. The data are characterised by a higher variation than for other models. A reason for that might be the impact of single vehicle accidents that happen also on straight road sections (e. g. run-off the road accidents).

8.6 Application and Evaluation

The developed models have shown that the consideration of driving behaviour is useful and leads to good results. These results are appropriate to be used for accident predictions within road networks. To apply the algorithm, data of good quality are needed. This is especially the case regarding design elements of the horizontal alignment. Based on these data an analysis that uses the developed models can be realised.

When the prediction is applied the results (predicted accident cost rates) must be evaluated. But an evaluation requires a benchmark which makes it possible to decide whether the predicted result is acceptable or not. In Germany, the guideline for network analysis suggests a simple method. Calculated accident costs are compared to so-called basic accident cost rates. Basic accident cost rates are derived from network wide analysis of accident occurrence separated by road categories. In Germany basic accident rates are distinguished for

- Motorways (autobahn),
- rural roads, and
- urban roads.

This basic accident cost rate is compared to calculated accident cost rates. The difference between both is a resulting safety potential:

- safety potential > 0: there is a potential to improve road safety
- safety potential < 0: the investigated stretch is not critical.

Such an approach is relatively simple and would also be appropriate to evaluate predicted accident cost rates in terms of this study.

In Germany, on rural roads the basic accident cost rate is about 28 €/(1000*Veh.*km). Compared to the developed models this number is much higher. The models developed above, did in no case result in numbers higher than this basic accident cost rate. This would consequently mean there were no safety critical road stretches.

This result is not surprising given the approach developed here, which focuses on driving behaviour and for which only German accident types 1 and 6 were taken into account. In contrast to this approach, the German basic accident cost rate considers all accident types and does not make differences regarding road geometry. It is an averaged value that is expected on a certain road category. No further distinctions are considered. Therefore, it is not appropriate to be used in this case although it can be concluded that both considered accident types cause roughly half of the basic accident cost rate and clearly show their importance and significance for the total accidence occurrence.

In that case a special basic accident cost rate must be derived that considers the same specifications as the approach developed above does. That means that for each defined sequence type basic accident cost rates must be computed separately. With these different values an evaluation can be done.

A first test of developed models has been conducted for a 42 km long stretch of the Portuguese road IP 04. The investigated road stretch is characterised by a severe accident occurrence. Within the investigated time (2003 – 2005) the considered accidents caused 33 fatalities, at least one per month. However, the application of the models and methodology detected the defined sequence types and predicted model based accident cost rates. To evaluate them, the reference accident cost rates were used and finally the safety critical stretches were indicated. The applicability of the sequence as well as of the developed prediction models was adequately shown. However, the comparison of predicted results to real accident occurrence shows marked differences. There might be numerous reasons for that : the entire road stretch is disproportionally unsafe, the longitudinal profile of this hilly road affects speed choice (a condition which is not frequent in normal roads and also not considered by the speed prediction model) and, the prediction is based on German data which means that a calibration must be done in order to consider national circumstances. Moreover, an accident prediction cannot be equalled to real accident occurrence. A prediction model is rather appropriate to indicate potential safety problems in road design based on the experiences and results of statistical analysis of driving behaviour and road safety. This makes it a tool especially suited to the design or redesign stage of new or existing roads.

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Appendix 1: Evaluation results for model for number of accidents with injuries

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalities	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	0	432	432				42	97	107	3		0	0	0	0	0	0	0			0,61			-69,52%	-69,52%
1	432	530	98	L	R	300	20		83	1	16	432	3	0	0	0	5	3	0,7			-29,49%			-29,49%
1	530	932	402				55	136	101	3		98	22	0	0	0	12	22			0,49			-75,54%	-75,54%
1	932	1094	162	L	R	230	44		76	1	13	402	0	0	0	0	0	0	0,6			-35,36%			-35,36%
1	1094	2736	1642				195	118	104	3		162	5	0	0	0	4	5			1,84			-8,02%	-8,02%
1	2736	2919	183	L	R	260	44		79	1	20	1642	1	0	0	0	0	1	0,6			-35,42%			-35,42%
1	2919	3323	404				20	49	115	3		183	0	0	0	0	0	0			0,70			-65,20%	-65,20%
1	3323	3641	318	L	R	300	67		83	1	17	404	1	0	0	0	0	1	0,7			-28,41%			-28,41%
1	3641	4097	456				14	31	115	3		318	0	0	0	0	0	0			0,83			-58,37%	-58,37%
1	4097	4271	174	L	R	230	48		76	1	20	456	4	0	0	0	2	4	0,8			-20,31%			-20,31%
1	4271	5415	1144				174	152	98	3		174	14	0	5	4	10	14			1,16			-41,80%	-41,80%
1	5415	5691	276	L	R	250	70		78	1	11	1144	3	0	0	0	0	3	0,5			-47,56%			-47,56%
1	5691	6173	482				12	24	115	3		276	1	0	0	0	0	1			0,90			-55,00%	-55,00%
1	6173	6870	697				128	183	93	2		482	10	0	0	0	7	10		2,50			-15,33%		-15,33%
1	6870	7673	803				139	173	95	3		697	13	1	0	0	4	14			0,78			-60,95%	-60,95%
1	7673	8933	1260				293	232	85	2		803	14	0	0	3	10	14		3,07			4,01%		4,01%
1	8933	9532	599				5	8	115	3		1260	0	0	0	0	0	0			1,16			-41,79%	-41,79%
1	9532	9890	358	L	R	230	99		76	1	39	599	0	0	0	0	0	0	1,4			41,47%			41,47%
1	9890	10097	207				0	1	115	3		358	2	0	0	0	0	2			0,46			-76,76%	-76,76%
1	10097	10342	245	R	R	230	67		76	1	16	207	1	0	0	0	0	1	0,6			-42,76%			-42,76%

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	10342	11260	918				231	251	82	3		245	41	0	0	1	32	41			0,64			-67,80%	-67,80%
1	11260	11662	402	L	R	190	134		72	1	17	918	7	0	0	2	0	7	0,7			-30,66%			-30,66%
1	11662	12054	392				34	86	109	3		402	1	0	0	0	0	1			0,58			-70,78%	-70,78%
1	12054	12460	406	R	R	130	198		66	1	19	392	21	1	1	1	6	22	0,7			-25,76%			-25,76%
1	12460	13091	631				32	51	114	3		406	6	0	0	0	6	6			1,03			-48,69%	-48,69%
1	13091	13465	374	L	R	230	103		76	1	25	631	8	0	0	0	0	8	0,9			-11,11%			-11,11%
1	13465	13896	431				0	1	115	3		374	4	0	0	0	1	4			0,89			-55,36%	-55,36%
1	13896	14003	107	R	R	150	45		68	1	33	431	7	0	0	0	3	7	1,0			2,55%			2,55%
1	14003	15202	1199				83	69	111	3		107	22	0	1	2	15	22			1,69			-15,42%	-15,42%
1	15202	16024	822				167	203	90	2		1199	6	0	0	0	1	6		2,68			-9,19%		-9,19%
1	16024	16835	811				83	11	106	3		822	5	0	0	0	3	5			1,51			-24,71%	-24,71%
1	16835	17800	965				169	175	94	2		811	6	0	0	0	1	6		2,61			-11,59%		-11,59%
1	17800	18379	579				50	86	109	3		965	2	0	0	0	0	2			0,83			-58,66%	-58,66%
1	18379	18577	198	R	R	230	54		76	1	17	579	1	0	0	0	0	1	0,8			-15,44%			-15,44%
1	18577	19472	895				132	147	99	3		198	6	0	0	0	1	6			0,95			-52,27%	-52,27%
1	19472	19703	231	L	R	210	70		74	1	18	895	1	0	0	0	0	1	0,6			-36,42%			-36,42%
1	19703	20402	699				97	138	100	3		231	2	0	0	0	0	2			0,79			-60,29%	-60,29%
1	20402	20549	147	R	R	210	44		74	1	18	699	1	0	1	1	0	1	0,6			-42,33%			-42,33%
1	20549	21041	492				95	193	91	3		147	1	0	1	1	0	1			0,47			-76,69%	-76,69%
1	21041	21138	97	L	R	140	44		67	1	11	492	3	0	0	0	0	3	0,7			-32,94%			-32,94%
1	21138	21758	620				87	141	100	3		97	3	0	0	0	1	3			0,70			-64,76%	-64,76%
1	21758	22048	290	L	R	220	83		75	1	16	620	2	0	0	0	0	2	0,6			-37,48%			-37,48%

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	22048	23168	1120				174	155	98	3		290	3	0	0	0	1	3			1,13			-43,57%	-43,57%
1	23168	23313	145	R	R	230	40		76	1	23	1120	0	0	0	0	0	0	0,7			-32,19%			-32,19%
1	23313	23642	329				51	155	98	3		145	1	0	0	0	0	1			0,38			-81,03%	-81,03%
1	23642	23992	350	R	R	230	96		76	1	10	329	1	0	0	0	0	1	0,6			-42,96%			-42,96%
1	23992	24636	644				42	65	112	3		350	1	0	0	0	0	1			0,99			-50,57%	-50,57%
1	24636	24899	263	L	R	280	59		81	1	27	644	0	0	0	0	0	0	0,9			-12,00%			-12,00%
1	24899	25310	411				45	11	105	3		263	0	0	0	0	0	0			0,82			-58,88%	-58,88%
1	25310	25460	150	R	R	190	50		72	1	17	411	0	0	0	0	0	0	0,7			-28,88%			-28,88%
1	25460	26761	1301				122	93	108	3		150	3	0	0	0	5	3			1,65			-17,37%	-17,37%
1	26761	27326	565				118	208	89	2		1301	2	0	0	0	1	2		2,53			-14,33%		-14,33%
1	27326	27633	307				0	1	115	3		565	1	0	0	0	0	1			0,66			-66,99%	-66,99%
1	27633	27976	343	L	R	360	60		88	1	17	307	0	0	0	0	0	0	0,7			-34,94%			-34,94%
1	27976	28365	389				34	87	109	3		343	1	0	0	0	1	1			0,58			-71,10%	-71,10%
1	28365	28558	193	L	R	350	35		88	1	13	389	4	1	4	5	3	5	0,6			-36,00%			-36,00%
1	28558	30324	1766				90	51	114	3		193	3	0	0	0	3	3			2,56			28,24%	28,24%
1	30324	30570	246	L	R	260	60		79	1	36	1766	1	0	0	0	1	1	1,2			16,73%			16,73%
1	30570	33105	2535				323	127	102	3		246	6	0	0	1	2	6			2,61			30,59%	30,59%
1	33105	34313	1208				200	165	96	2		2535	2	0	0	0	0	2		2,66			-9,73%		-9,73%
1	34313	35150	837				12	14	115	3		1208	2	0	0	0	2	2			1,53			-23,46%	-23,46%
1	35150	35345	195	L	R	240	51		77	1	38	837	1	0	1	1	0	1	1,2			18,59%			18,59%
1	35345	35555	210				0	1	115	3		195	1	0	1	1	0	1			0,47			-76,46%	-76,46%
1	35555	35842	287	R	R	260	70		79	1	18	210	0	0	0	0	0	0	0,6			-39,83%			-39,83%

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	35842	36512	670				24	35	115	3		287	2	0	0	2	5	2			1,15			-42,27%	-42,27%
1	36512	36762	250	L	R	400	39		92	1	23	670	0	0	0	0	0	0	0,8			-23,72%			-23,72%
1	36762	38185	1423				98	68	112	3		250	5	0	1	0	5	5			1,98			-1,09%	-1,09%
1	38185	39057	872				178	204	90	2		1423	2	0	0	0	0	2		2,71			-8,03%		-8,03%
1	39057	39281	224				0	1	115	3		872	0	0	0	0	0	0			0,50			-75,07%	-75,07%
1	39281	39646	365	R	R	240	96		77	1	21	224	0	0	0	0	0	0	0,7			-34,54%			-34,54%
1	39646	40189	543				28	51	114	3		365	0	0	0	0	0	0			0,90			-55,09%	-55,09%
1	40189	40432	243	L	R	240	64		77	1	29	543	0	0	0	0	0	0	1,1			6,60%			6,60%
1	40432	40902	470				51	11	105	3		243	0	0	0	0	0	0			0,93			-53,67%	-53,67%
1	40902	41413	511	L	R	360	90		88	1	12	470	1	0	0	0	0	1	0,7			-30,91%			-30,91%
1	41413	41951	538				0	1	115	3		511	0	0	0	0	0	0			1,09			-45,62%	-45,62%
1	41951	42429	478	R	R	450	67		96	1	19	538	0	0	0	0	0	0	0,9			-13,83%			-13,83%
1	42429	42667	238				0	1	115	3		478	0	0	0	0	0	0			0,53			-73,68%	-73,68%
2	0	222	222	R	R	300	47		83	1	16	0	1	0	0	0	5	1	0,5			-53,55%			-53,55%
2	222	530	308				12	38	115	3		222	1	0	0	0	5	1			0,57			-71,44%	-71,44%
2	530	784	254	R	R	230	70		76	1	13	308	12	0	0	0	10	12	0,6			-40,68%			-40,68%
2	784	1664	880				130	147	99	3		254	5	0	0	1	0	5			0,94			-52,99%	-52,99%
2	1664	1826	162	R	R	230	44		76	1	22	880	16	0	0	1	12	16	0,7			-32,80%			-32,80%
2	1826	2933	1107				95	85	109	3		162	6	0	0	0	0	6			1,48			-26,10%	-26,10%
2	2933	3076	143	R	R	260	35		79	1	21	1107	1	0	0	0	1	1	0,6			-36,71%			-36,71%
2	3076	3323	247				0	1	115	3		143	0	0	0	0	0	0			0,54			-72,80%	-72,80%
2	3323	3641	318	L	R	300	67		83	1	22	247	0	0	0	0	0	0	0,7			-31,70%			-31,70%

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	3641	5130	1489				197	132	101	3		318	47	0	1	9	22	47			1,59			-20,28%	-20,28%
2	5130	5691	561				102	181	93	2		1489	5	0	0	0	1	5		2,39			-18,94%		-18,94%
2	5691	7258	1567				206	131	101	3		561	33	1	5	8	15	34			1,68			-16,24%	-16,24%
2	7258	8933	1675				357	213	88	2		1567	23	0	2	1	15	23		3,11			5,46%		5,46%
2	8933	9532	599				5	8	115	3		1675	3	0	0	0	0	3			1,16			-41,79%	-41,79%
2	9532	9890	358	L	R	230	99		76	1	16	599	2	0	0	0	0	2	0,9			-14,71%			-14,71%
2	9890	10708	818				159	194	91	3		358	1	0	0	0	0	1			0,73			-63,50%	-63,50%
2	10708	11011	303	R	R	120	160		65	1	24	818	29	0	0	1	20	29	0,8			-17,82%			-17,82%
2	11011	11260	249				0	1	115	3		303	17	1	0	0	13	18			0,55			-72,60%	-72,60%
2	11260	11662	402	L	R	190	134		72	1	13	249	4	0	0	0	2	4	0,6			-43,62%			-43,62%
2	11662	12054	392				34	86	109	3		402	1	0	0	0	0	1			0,58			-70,78%	-70,78%
2	12054	12729	675				245	362	64	2		392	43	0	1	3	16	43		3,55			20,41%		20,41%
2	12729	13091	362				0	1	115	3		675	4	0	0	0	2	4			0,76			-61,78%	-61,78%
2	13091	13465	374	L	R	230	103		76	1	25	362	8	0	0	1	3	8	0,8			-17,91%			-17,91%
2	13465	14031	566				27	47	115	3		374	14	0	0	0	8	14			0,95			-52,65%	-52,65%
2	14031	14349	318	L	R	220	92		75	1	40	566	32	0	0	0	20	32	1,4			39,62%			39,62%
2	14349	15202	853				7	8	115	3		318	6	1	0	3	1	7			1,59			-20,27%	-20,27%
2	15202	15736	534				130	243	83	2		853	3	0	0	0	0	3		2,68			-9,06%		-9,06%
2	15736	16330	594				63	11	105	3		534	3	0	0	0	3	3			1,14			-42,94%	-42,94%
2	16330	16536	206	R	R	240	54		77	1	29	594	1	0	0	0	1	1	1,1			11,85%			11,85%
2	16536	17137	601				24	39	115	3		206	1	0	0	0	0	1			1,03			-48,42%	-48,42%
2	17137	17944	807				161	199	90	2		601	4	0	0	0	2	4		2,65			-10,22%		-10,22%

sequence detection												real accident occurrence						results of prediction							
											prior sequence		number of						model		percentage to reference value				
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	17944	19059	1115				149	133	101	3		807	12	0	0	0	13	12			1,23			-38,62%	-38,62%
2	19059	19306	247	R	R	250	62		78	1	14	1115	0	0	0	0	0	0	0,6			-43,47%			-43,47%
2	19306	19919	613				88	143	99	3		247	5	0	0	0	1	5			0,69			-65,37%	-65,37%
2	19919	20184	265	L	R	230	73		76	1	16	613	0	0	0	0	0	0	0,6			-38,69%			-38,69%
2	20184	21327	1143				187	163	96	3		265	3	0	5	0	2	3			1,11			-44,35%	-44,35%
2	21327	21526	199	L	R	190	66		72	1	19	1143	3	0	0	0	1	3	0,6			-36,37%			-36,37%
2	21526	22657	1131				217	191	92	3		199	7	0	1	0	1	7			0,99			-50,71%	-50,71%
2	22657	22854	197	L	R	230	54		76	1	23	1131	0	0	0	0	0	0	0,7			-27,55%			-27,55%
2	22854	23331	477				25	52	114	3		197	0	0	0	0	0	0			0,80			-60,14%	-60,14%
2	23331	23569	238	L	R	230	65		76	1	10	477	1	0	0	0	0	1	0,7			-34,32%			-34,32%
2	23569	23992	423				80	189	92	3		238	3	0	0	0	7	3			0,41			-79,29%	-79,29%
2	23992	24206	214	L	R	260	52		79	1	29	423	0	0	0	0	0	0	0,9			-5,67%			-5,67%
2	24206	25462	1256				126	11	106	3		214	0	0	0	0	0	0			2,22			11,12%	11,12%
2	25462	25597	135	L	R	220	39		75	1	23	1256	1	0	0	0	0	1	0,7			-33,23%			-33,23%
2	25597	27047	1450				128	88	108	3		135	4	0	0	0	0	4			1,86			-7,16%	-7,16%
2	27047	27326	279	R	R	230	77		76	1	29	1450	2	0	0	0	2	2	1,0			-4,79%			-4,79%
2	27326	28365	1039				84	81	110	3		279	2	0	0	0	1	2			1,42			-29,06%	-29,06%
2	28365	28558	193	L	R	350	35		88	1	26	1039	1	0	0	0	0	1	0,8			-20,36%			-20,36%
2	28558	30837	2279				190	83	109	3		193	6	0	0	0	5	6			2,83			41,64%	41,64%
2	30837	31442	605	L	R	256	150		79	1	16	2279	3	0	0	0	2	3	0,7			-26,72%			-26,72%
2	31442	32338	896				105	117	104	3		605	2	0	0	0	0	2			1,08			-46,14%	-46,14%
2	32338	32753	415	L	R	440	60		95	1	20	896	1	1	0	0	2	2	0,8			-22,92%			-22,92%

road ERA net

sequence detection													real accident occurrence						results of prediction						
											prior sequence		number of						model			percentage to reference value			
driving direction	stat1	stat2	length	direction	typ	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	fatalitiers	seriously injured	slightly injured	accidents with injuries	Single Curves	Curved Sequence	Straight section	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	32753	33105	352				0	1	115	3		415	2	0	0	0	0	2			0,75			-62,72%	-62,72%
2	33105	33304	199	L	R	400	31		92	1	16	352	1	0	0	0	0	1	0,7			-34,08%			-34,08%
2	33304	33938	634				57	89	108	3		199	2	0	0	0	0	2			0,89			-55,72%	-55,72%
2	33938	34313	375	L	R	240	99		77	1	38	634	1	0	0	0	0	1	1,4			36,58%			36,58%
2	34313	35150	837				12	14	115	3		375	0	0	0	0	0	0			1,53			-23,46%	-23,46%
2	35150	35345	195	L	R	240	51		77	1	20	837	1	0	0	0	2	1	0,7			-34,52%			-34,52%
2	35345	35555	210				0	1	115	3		195	0	0	0	0	0	0			0,47			-76,46%	-76,46%
2	35555	35842	287	R	R	260	70		79	1	36	210	0	0	0	0	0	0	0,9			-10,60%			-10,60%
2	35842	36512	670				24	35	115	3		287	7	0	0	0	4	7			1,15			-42,27%	-42,27%
2	36512	36762	250	L	R	400	39		92	1	10	670	1	0	0	0	0	1	0,5			-50,33%			-50,33%
2	36762	38185	1423				98	68	112	3		250	2	0	0	0	2	2			1,98			-1,09%	-1,09%
2	38185	39057	872				178	204	90	2		1423	4	0	0	0	3	4		2,71			-8,03%		-8,03%
2	39057	39654	597				81	135	101	3		872	0	0	0	0	0	0			0,70			-65,08%	-65,08%
2	39654	39874	220	L	R	300	46		83	1	23	597	1	0	0	0	0	1	1,0			-1,57%			-1,57%
2	39874	40433	559				43	76	110	3		220	2	0	4	0	1	2			0,83			-58,30%	-58,30%
2	40433	41413	980				162	165	96	2		559	1	0	4	0	1	1		2,56			-13,10%		-13,10%
2	41413	41951	538				0	1	115	3		980	0	0	0	0	0	0			1,09			-45,62%	-45,62%
2	41951	42429	478	R	R	450	67		96	1	19	538	2	0	0	0	0	2	0,9			-13,83%			-13,83%
2	42429	42667	238				0	1	115	3		478	0	0	0	0	0	0			0,53			-73,68%	-73,68%

Appendix 2: Evaluation results for model for accident cost rates

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	0	432	432				42	97	107	3		0	0	0	0	0	0	-		3,16			-39,26%	-39,26%
1	432	530	98	L	R	300	20		83	1	16	432	3	0	0	0	5	4,10	2,42		-42,99%			-42,99%
1	530	932	402				55	136	101	3		98	22	0	0	0	12	63,91		2,72			-47,83%	-47,83%
1	932	1094	162	L	R	230	44		76	1	13	402	0	0	0	0	0	-	2,22		-47,60%			-47,60%
1	1094	2736	1642				195	118	104	3		162	5	0	0	0	4	3,73		2,90			-44,23%	-44,23%
1	2736	2919	183	L	R	260	44		79	1	20	1642	1	0	0	0	0	0,99	4,64		-21,06%			-21,06%
1	2919	3323	404				20	49	115	3		183	0	0	0	0	0	-		4,07			-21,94%	-21,94%
1	3323	3641	318	L	R	300	67		83	1	17	404	1	0	0	0	0	0,99	2,51		-40,79%			-40,79%
1	3641	4097	456				14	31	115	3		318	0	0	0	0	0	-		4,67			-10,42%	-10,42%
1	4097	4271	174	L	R	230	48		76	1	20	456	4	0	0	0	2	4,34	2,87		-32,22%			-32,22%
1	4271	5415	1144				174	152	98	3		174	14	0	5	4	10	82,34		2,57			-50,65%	-50,65%
1	5415	5691	276	L	R	250	70		78	1	11	1144	3	0	0	0	0	2,98	4,21		-28,38%			-28,38%
1	5691	6173	482				12	24	115	3		276	1	0	0	0	0	2,06		5,01			-3,84%	-3,84%
1	6173	6870	697				128	183	93	2		482	10	0	0	0	7	15,92		14,89		-18,48%		-18,48%
1	6870	7673	803				139	173	95	3		697	13	1	0	0	4	19,26		2,40			-53,94%	-53,94%
1	7673	8933	1260				293	232	85	2		803	14	0	0	3	10	28,81		18,30		0,19%		0,19%
1	8933	9532	599				5	8	115	3		1260	0	0	0	0	0	-		6,46			24,02%	24,02%
1	9532	9890	358	L	R	230	99		76	1	39	599	0	0	0	0	0	-	12,41		111,19%			111,19%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	9890	10097	207				0	1,1	115	3		358	2	0	0	0	0	9,58		9,07			74,09%	74,09%
1	10097	10342	245	R	R	230	67		76	1	16	207	1	0	0	0	0	0,99	2,42		-42,99%			-42,99%
1	10342	11260	918				231	251	82	3		245	41	0	0	1	32	72,98		1,91			-63,38%	-63,38%
1	11260	11662	402	L	R	190	134		72	1	17	918	7	0	0	2	0	26,61	4,26		-27,45%			-27,45%
1	11662	12054	392				34	86	109	3		402	1	0	0	0	0	2,54		3,32			-36,21%	-36,21%
1	12054	12460	406	R	R	130	198		66	1	19	392	21	1	1	1	6	43,05	2,74		-35,41%			-35,41%
1	12460	13091	631				32	51	114	3		406	6	0	0	0	6	10,67		4,01			-23,01%	-23,01%
1	13091	13465	374	L	R	230	103		76	1	25	631	8	0	0	0	0	7,95	5,78		-1,63%			-1,63%
1	13465	13896	431				0	1,1	115	3		374	4	0	0	0	1	10,11		9,07			74,09%	74,09%
1	13896	14003	107	R	R	150	45		68	1	33	431	7	0	0	0	3	7,67	5,90		39,29%			39,29%
1	14003	15202	1199				83	69	111	3		107	22	0	1	2	15	53,34		3,61			-30,62%	-30,62%
1	15202	16024	822				167	203	90	2		1199	6	0	0	0	1	7,73		16,28		-10,86%		-10,86%
1	16024	16835	811				83	11	106	3		822	5	0	0	0	3	7,08		6,03			15,69%	15,69%
1	16835	17800	965				169	175	94	2		811	6	0	0	0	1	6,59		14,34		-21,53%		-21,53%
1	17800	18379	579				50	86	109	3		965	2	0	0	0	0	3,44		3,32			-36,21%	-36,21%
1	18379	18577	198	R	R	230	54		76	1	17	579	1	0	0	0	0	0,99	4,26		-27,45%			-27,45%
1	18577	19472	895				132	147	99	3		198	6	0	0	0	1	7,10		2,61			-49,81%	-49,81%
1	19472	19703	231	L	R	210	70		74	1	18	895	1	0	0	0	0	0,99	4,36		-25,76%			-25,76%
1	19703	20402	699				97	138	100	3		231	2	0	0	0	0	2,85		2,70			-48,20%	-48,20%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	20402	20549	147	R	R	210	44		74	1	18	699	1	0	1	1	0	20,55	4,36		-25,76%			-25,76%
1	20549	21041	492				95	193	91	3		147	1	0	1	1	0	41,98		2,25			-56,71%	-56,71%
1	21041	21138	97	L	R	140	44		67	1	11	492	3	0	0	0	0	2,96	2,16		-49,02%			-49,02%
1	21138	21758	620				87	141	100	3		97	3	0	0	0	1	5,43		2,67			-48,77%	-48,77%
1	21758	22048	290	L	R	220	83		75	1	16	620	2	0	0	0	0	1,99	4,19		-28,71%			-28,71%
1	22048	23168	1120				174	155	98	3		290	3	0	0	0	1	3,01		2,54			-51,15%	-51,15%
1	23168	23313	145	R	R	230	40		76	1	23	1120	0	0	0	0	0	-	5,25		-10,72%			-10,72%
1	23313	23642	329				51	155	98	3		145	1	0	0	0	0	3,02		2,54			-51,15%	-51,15%
1	23642	23992	350	R	R	230	96		76	1	10	329	1	0	0	0	0	0,99	2,15		-49,23%			-49,23%
1	23992	24636	644				42	65	112	3		350	1	0	0	0	0	1,54		3,69			-29,11%	-29,11%
1	24636	24899	263	L	R	280	59		81	1	27	644	0	0	0	0	0	-	6,42		9,22%			9,22%
1	24899	25310	411				45	11	105	3		263	0	0	0	0	0	-		6,03			15,69%	15,69%
1	25310	25460	150	R	R	190	50		72	1	17	411	0	0	0	0	0	-	2,51		-40,79%			-40,79%
1	25460	26761	1301				122	93	108	3		150	3	0	0	0	5	2,88		3,22			-38,20%	-38,20%
1	26761	27326	565				118	208	89	2		1301	2	0	0	0	1	4,20		16,63		-8,96%		-8,96%
1	27326	27633	307				0	1,1	115	3		565	1	0	0	0	0	3,24		9,07			74,09%	74,09%
1	27633	27976	343	L	R	360	60		88	1	17	307	0	0	0	0	0	-	2,51		-40,79%			-40,79%
1	27976	28365	389				34	87	109	3		343	1	0	0	0	1	3,54		3,31			-36,50%	-36,50%
1	28365	28558	193	L	R	350	35		88	1	13	389	4	1	4	5	3	44,15	2,22		-47,60%			-47,60%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	28558	30324	1766				90	51	114	3		193	3	0	0	0	3	1,91		4,01			-23,01%	-23,01%
1	30324	30570	246	L	R	260	60		79	1	36	1766	1	0	0	0	1	1,37	10,56		79,77%			79,77%
1	30570	33105	2535				323	127	102	3		246	6	0	0	1	2	10,28		2,81			-46,10%	-46,10%
1	33105	34313	1208				200	165	96	2		2535	2	0	0	0	0	1,65		13,64		-25,34%		-25,34%
1	34313	35150	837				12	14	115	3		1208	2	0	0	0	2	2,84		5,72			9,83%	9,83%
1	35150	35345	195	L	R	240	51		77	1	38	837	1	0	1	1	0	20,59	11,77		100,28%			100,28%
1	35345	35555	210				0	1,1	115	3		195	1	0	1	1	0	98,08		9,07			74,09%	74,09%
1	35555	35842	287	R	R	260	70		79	1	18	210	0	0	0	0	0	-	2,62		-38,27%			-38,27%
1	35842	36512	670				24	35	115	3		287	2	0	0	2	5	32,33		4,51			-13,41%	-13,41%
1	36512	36762	250	L	R	400	39		92	1	23	670	0	0	0	0	0	-	5,25		-10,72%			-10,72%
1	36762	38185	1423				98	68	112	3		250	5	0	1	0	5	17,60		3,63			-30,25%	-30,25%
1	38185	39057	872				178	204	90	2		1423	2	0	0	0	0	2,28		16,35		-10,48%		-10,48%
1	39057	39281	224				0	1,1	115	3		872	0	0	0	0	0	-		9,07			74,09%	74,09%
1	39281	39646	365	R	R	240	96		77	1	21	224	0	0	0	0	0	-	3,02		-28,70%			-28,70%
1	39646	40189	543				28	51	114	3		365	0	0	0	0	0	-		4,01			-22,96%	-22,96%
1	40189	40432	243	L	R	240	64		77	1	29	543	0	0	0	0	0	-	7,16		21,82%			21,82%
1	40432	40902	470				51	11	105	3		243	0	0	0	0	0	-		6,03			15,69%	15,69%
1	40902	41413	511	L	R	360	90		88	1	12	470	1	0	0	0	0	0,99	2,18		-48,47%			-48,47%
1	41413	41951	538				0	1,1	115	3		511	0	0	0	0	0	-		9,07			74,09%	74,09%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
1	41951	42429	478	R	R	450	67		96	1	19	538	0	0	0	0	0	-	4,49		-23,63%			-23,63%
1	42429	42667	238				0	1,1	115	3		478	0	0	0	0	0	-		9,07			74,09%	74,09%
2	0	222	222	R	R	300	47		83	1	16	0	1	0	0	0	5	1,37	2,42		-42,99%			-42,99%
2	222	530	308				12	38	115	3		222	1	0	0	0	5	4,47		4,40			-15,50%	-15,50%
2	530	784	254	R	R	230	70		76	1	13	308	12	0	0	0	10	14,58	2,22		-47,60%			-47,60%
2	784	1664	880				130	147	99	3		254	5	0	0	1	0	28,02		2,61			-49,81%	-49,81%
2	1664	1826	162	R	R	230	44		76	1	22	880	16	0	0	1	12	36,57	5,02		-14,61%			-14,61%
2	1826	2933	1107				95	85	109	3		162	6	0	0	0	0	5,40		3,34			-35,91%	-35,91%
2	2933	3076	143	R	R	260	35		79	1	21	1107	1	0	0	0	1	1,37	4,82		-18,05%			-18,05%
2	3076	3323	247				0	1,1	115	3		143	0	0	0	0	0	-		9,07			74,09%	74,09%
2	3323	3641	318	L	R	300	67		83	1	22	247	0	0	0	0	0	-	3,18		-24,85%			-24,85%
2	3641	5130	1489				197	132	101	3		318	47	0	1	9	22	113,84		2,76			-47,08%	-47,08%
2	5130	5691	561				102	181	93	2		1489	5	0	0	0	1	9,55		14,75		-19,24%		-19,24%
2	5691	7258	1567				206	131	101	3		561	33	1	5	8	15	74,06		2,77			-46,88%	-46,88%
2	7258	8933	1675				357	213	88	2		1567	23	0	2	1	15	39,01		16,98		-7,05%		-7,05%
2	8933	9532	599				5	8	115	3		1675	3	0	0	0	0	4,98		6,46			24,02%	24,02%
2	9532	9890	358	L	R	230	99		76	1	16	599	2	0	0	0	0	1,99	4,19		-28,71%			-28,71%
2	9890	10708	818				159	194	91	3		358	1	0	0	0	0	1,22		2,25			-56,84%	-56,84%
2	10708	11011	303	R	R	120	160		65	1	24	818	29	0	0	1	20	52,64	5,50		-6,39%			-6,39%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	11011	11260	249				0	1,1	115	3		303	17	1	0	0	13	82,48		9,07			74,09%	74,09%
2	11260	11662	402	L	R	190	134		72	1	13	249	4	0	0	0	2	4,74	2,22		-47,60%			-47,60%
2	11662	12054	392				34	86	109	3		402	1	0	0	0	0	2,54		3,32			-36,21%	-36,21%
2	12054	12729	675				245	362	64	2		392	43	0	1	3	16	154,78		27,35		49,71%		49,71%
2	12729	13091	362				0	1,1	115	3		675	4	0	0	0	2	13,09		9,07			74,09%	74,09%
2	13091	13465	374	L	R	230	103		76	1	25	362	8	0	0	1	3	27,98	3,76		-11,32%			-11,32%
2	13465	14031	566				27	47	115	3		374	14	0	0	0	8	28,66		4,12			-20,89%	-20,89%
2	14031	14349	318	L	R	220	92		75	1	40	566	32	0	0	0	20	35,61	13,08		122,54%			122,54%
2	14349	15202	853				7	8	115	3		318	6	1	0	3	1	31,68		6,46			24,02%	24,02%
2	15202	15736	534				130	243	83	2		853	3	0	0	0	0	5,59		19,07		4,38%		4,38%
2	15736	16330	594				63	11	105	3		534	3	0	0	0	3	6,96		6,03			15,69%	15,69%
2	16330	16536	206	R	R	240	54		77	1	29	594	1	0	0	0	1	1,37	7,16		21,82%			21,82%
2	16536	17137	601				24	39	115	3		206	1	0	0	0	0	1,66		4,37			-16,15%	-16,15%
2	17137	17944	807				161	199	90	2		601	4	0	0	0	2	5,41		16,01		-12,38%		-12,38%
2	17944	19059	1115				149	133	101	3		807	12	0	0	0	13	12,43		2,75			-47,27%	-47,27%
2	19059	19306	247	R	R	250	62		78	1	14	1115	0	0	0	0	0	-	4,12		-29,89%			-29,89%
2	19306	19919	613				88	143	99	3		247	5	0	0	0	1	8,74		2,65			-49,11%	-49,11%
2	19919	20184	265	L	R	230	73		76	1	16	613	0	0	0	0	0	-	4,19		-28,71%			-28,71%
2	20184	21327	1143				187	163	96	3		265	3	0	5	0	2	20,17		2,48			-52,43%	-52,43%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	21327	21526	199	L	R	190	66		72	1	19	1143	3	0	0	0	1	3,36	4,49		-23,63%			-23,63%
2	21526	22657	1131				217	191	92	3		199	7	0	1	0	1	23,56		2,27			-56,45%	-56,45%
2	22657	22854	197	L	R	230	54		76	1	23	1131	0	0	0	0	0	-	5,25		-10,72%			-10,72%
2	22854	23331	477				25	52	114	3		197	0	0	0	0	0	-		3,99			-23,45%	-23,45%
2	23331	23569	238	L	R	230	65		76	1	10	477	1	0	0	0	0	0,99	2,15		-49,23%			-49,23%
2	23569	23992	423				80	189	92	3		238	3	0	0	0	7	8,86		2,28			-56,18%	-56,18%
2	23992	24206	214	L	R	260	52		79	1	29	423	0	0	0	0	0	-	4,72		11,34%			11,34%
2	24206	25462	1256				126	11	106	3		214	0	0	0	0	0	-		6,03			15,69%	15,69%
2	25462	25597	135	L	R	220	39		75	1	23	1256	1	0	0	0	0	0,99	5,25		-10,72%			-10,72%
2	25597	27047	1450				128	88	108	3		135	4	0	0	0	0	2,75		3,29			-36,79%	-36,79%
2	27047	27326	279	R	R	230	77		76	1	29	1450	2	0	0	0	2	2,75	7,16		21,82%			21,82%
2	27326	28365	1039				84	81	110	3		279	2	0	0	0	1	2,28		3,40			-34,73%	-34,73%
2	28365	28558	193	L	R	350	35		88	1	26	1039	1	0	0	0	0	0,99	6,09		3,58%			3,58%
2	28558	30837	2279				190	83	109	3		193	6	0	0	0	5	2,96		3,37			-35,31%	-35,31%
2	30837	31442	605	L	R	256	150		79	1	16	2279	3	0	0	0	2	3,37	4,19		-28,71%			-28,71%
2	31442	32338	896				105	117	104	3		605	2	0	0	0	0	2,22		2,92			-44,02%	-44,02%
2	32338	32753	415	L	R	440	60		95	1	20	896	1	1	0	0	2	2,75	4,64		-21,06%			-21,06%
2	32753	33105	352				0	1,1	115	3		415	2	0	0	0	0	5,65		9,07			74,09%	74,09%
2	33105	33304	199	L	R	400	31		92	1	16	352	1	0	0	0	0	0,99	2,42		-42,99%			-42,99%

sequence detection													real accident occurrence						results of prediction					
											prior element		number of						model		percentage to reference value			
driving direction	stat1	stat2	length	direction	type	parameter	deviation	ccr	speed	sequence type	speed difference	length	single accidents	overtaking accidents	Fatalities	Seriously injured	Slightly injured	Accident cost rate	sequence type 1 (speed diff.)	sequence type 2 / 3 (CCR)	sequence type 1 (speed diff.)	sequence type 2 (CCR)	sequence type 3 (CCR)	total
2	33304	33938	634				57	89	108	3		199	2	0	0	0	0	3,14		3,28			-37,08%	-37,08%
2	33938	34313	375	L	R	240	99		77	1	38	634	1	0	0	0	0	0,99	11,77		100,28%			100,28%
2	34313	35150	837				12	14	115	3		375	0	0	0	0	0	-		5,72			9,83%	9,83%
2	35150	35345	195	L	R	240	51		77	1	20	837	1	0	0	0	2	1,37	4,64		-21,06%			-21,06%
2	35345	35555	210				0	1,1	115	3		195	0	0	0	0	0	-		9,07			74,09%	74,09%
2	35555	35842	287	R	R	260	70		79	1	36	210	0	0	0	0	0	-	6,94		63,72%			63,72%
2	35842	36512	670				24	35	115	3		287	7	0	0	0	4	12,11		4,51			-13,41%	-13,41%
2	36512	36762	250	L	R	400	39		92	1	10	670	1	0	0	0	0	0,99	4,29		-27,00%			-27,00%
2	36762	38185	1423				98	68	112	3		250	2	0	0	0	2	1,94		3,63			-30,25%	-30,25%
2	38185	39057	872				178	204	90	2		1423	4	0	0	0	3	5,00		16,35		-10,48%		-10,48%
2	39057	39654	597				81	135	101	3		872	0	0	0	0	0	-		2,73			-47,65%	-47,65%
2	39654	39874	220	L	R	300	46		83	1	23	597	1	0	0	0	0	0,99	5,25		-10,72%			-10,72%
2	39874	40433	559				43	76	110	3		220	2	0	4	0	1	38,73		3,49			-33,08%	-33,08%
2	40433	41413	980				162	165	96	2		559	1	0	4	0	1	21,10		13,64		-25,34%		-25,34%
2	41413	41951	538				0	1,1	115	3		980	0	0	0	0	0	-		9,07			74,09%	74,09%
2	41951	42429	478	R	R	450	67		96	1	19	538	2	0	0	0	0	1,99	4,49		-23,63%			-23,63%
2	42429	42667	238				0	1,1	115	3		478	0	0	0	0	0	-		9,07			74,09%	74,09%

Results for Portuguese road link of IP04 (length 42km, both driving directions)