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Detection of Traffic Conflicts in Single Vehicle Accident Situations

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DANKSAGUNG

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KURZFASSUNG

Zwischen 2002 und 2011 ereigneten sich auf Österreichs Straßen 49.423 Alleinunfälle, wovon 1.692 tödlich verletzte Personen und 14.789 schwer verletzte Personen die Folge waren. Ständig weiterentwickelte Fahrassistenzsysteme sollen das Unfallgeschehen in Zukunft vermindern. Ziel dieser Arbeit war es Konzepte für eine frühzeitige Erkennung von Konflikten im Straßenverkehr zu erarbeiten. Gefährliche Situationen sollen erkannt werden bevor sie überhaupt entstehen. Die Tiefenanalyse von Unfallstatistiken hat ergeben, dass die häufigsten Unfalltypen bei Alleinunfällen ein Verlassen der Fahrbahn auf einer Geraden oder in einer Kurve sind. Die anschließend analysierten, rekonstruierten und simulierten Realunfälle haben gezeigt, dass die häufigste bekannte Unfallursache erhöhte Geschwindigkeit war (fast 25%). Aufgrund dessen wurde der Schwerpunkt dieser Arbeit auf das Fahrzeug gelegt und die Konflikterkennung abhängig von der Geschwindigkeit gemacht. Durch die Simulation von Realunfällen konnten wichtige Einflussfaktoren und entscheidende Parameter ausgeforscht werden. Großen Einfluss haben Parameter wie Reaktionsgeschwindigkeit des Fahrers, die Straßenbeschaffenheit, der Fahrzeugwinkel beim Abkommen der Fahrbahn, der Radius der Kurve und die Breite der Fahrbahn. All diese Parameter wurden anschließend in generische Simulationen eingearbeitet, entsprechend variiert und evaluiert. Auf dieser Basis wurden Konzepte erarbeitet, welche Alleinunfälle durch Abkommen in Zukunft verringern sollen. Somit war es möglich den Zeitpunkt zu ermitteln an dem ein Konflikt auftritt. Wenn dieser Zeitpunkt erkannt wurde, kann der Lenker/Lenkerin des Fahrzeuges frühzeitig gewarnt werden um einen möglichen Unfall zu verhindern. Diese Konzepte wurden auf deren Potential analysiert und festgestellt, dass knapp 25% der untersuchten Realunfälle Potential für eine Vermeidung gehabt hätten.

ABSTRACT

Between 2002 and 2011 a total amount of 49,423 single vehicle accidents occurred on Austrian roads. 1,692 of them resulted in fatalities and 14,789 in severe injuries. Continuous improvements in driver assistant systems are intended to reduce the accident occurrence in the future. The goal of the thesis was to explore concepts for early identification and detection of traffic conflicts. That is, so that potentially dangerous situations can be detected before they even appear. In-depth analysis of accident statistics showed that most single vehicle accidents occurred due to a running off the road on a straight section of a road or in a bend. By analysing, reconstructing and simulating real accidents it turned out that the most common known cause for those accidents was exceeded velocity (almost 25%). This is the reason why the focus of this work was on the vehicle and depending on the velocity of the vehicle. Important factors and key parameters for the accidents and thus also for the detection of traffic conflicts could be investigated. Big influences have parameters such as the reaction time of a driver, the radii of the bends, the conditions of the road, the vehicle angle while leaving the road and the width of a lane. These were used, varied and evaluated during the generic accidents. On this basis, concepts to reduce departing accidents in the future have been developed. It was possible to detect the moment when a vehicle drives into a traffic conflict. If this moment is defined then the driver can be warned early enough to avoid this conflict. These concepts were analysed and it turned out that almost 25% of the examined real accidents had potential for avoidance.

TABLE OF CONTENT

1 INTRODUCTION

Between 2002 and 2011 a total amount of 324,151 accidents and 5,078 fatalities occurred on Austrian roads. Single vehicle accidents have a total share of 15.3% and the highest share of fatalities (33.3%).

The goal of this thesis was to develop concepts which shall be able to reduce this number of single vehicle accidents. Specifically it is about detecting traffic conflicts in an early stage in order to avoid them. An accident can be avoided if a conflict is detected early enough. The potential to reduce the accident occurrence in the future is given through the clear correlation between traffic conflict and accident.

Chapter 2 explains firstly the term traffic conflict and then the correlation to an accident. Furthermore the reaction time of a driver and its influencing factors are explained through different studies and reports. The reaction time has a significant influence on the detection of traffic conflicts in single vehicle accidents. This can vary widely and thus affecting the moment of the detection of a conflict significantly.

Chapter 3 provides an overview of the accident occurrence in Austria and the further focus on single vehicle accidents. Single vehicle accidents have the highest share of fatalities. All different single vehicle accident types are shown and compared at rural and urban sites. Also the distributions over the different road types were determined to show the frequency of occurrence between country roads, federal roads, motorways, expressways and other roads. Over 68% of all single vehicle accidents occurred on state roads (country roads and federal roads). Therefore the thesis focuses on accidents on these roads. Also different factors such as lighting or road conditions were determined.

The procedural method is explained step by step in chapter 4. A big part of this work was the reconstruction and simulation of real single vehicle accidents on state roads by using the software PC-Crash. Firstly, the basics for a reconstruction using PC-Crash and the needed data for it are presented. Then it is shown an example of such a reconstruction, the importance of different parameters and how a complete simulation runs. Furthermore it is explained which different evaluations are possible within this software. Also the concepts for an early detection of a conflict are shown in this chapter. This includes a concept for detection of a conflict on a straight section of a road as well as in a bend. The feasibility of these conflicts was verified through generic accidents situations within PC-Crash. This is necessary because the moment of conflict detection is greatly affected by the velocity of a vehicle, the radii of a bend, the road conditions and the reaction time of a driver. All those variations parameters have been considered during the generic simulations.

Chapter 5 describes and discusses the simulation results of the real accidents and the generic accidents. These results provide the basics for further development of the concepts and a possible implementation into new driving assistant systems in the future.

Finally, a summary of the work and the outlook have been made during the last chapter.

2 ANALYSIS OF TRAFFIC CONFLICTS AND THEIR INFLUENCING FACTORS

2.1 Traffic conflicts and the correlation to traffic accidents

“Traffic Conflict” is a term which cannot be easily defined with one word. Referring to the following books, more than just one definition has been found. The books were from Perkins and Harris in “Criteria for traffic conflicts characteristics” (1967), Baker in “An evaluation of traffic conflicts technique” (1972) and Amundsen and Hyden in “Proceeding of first workshop on traffic conflicts” (1977). In the following pages, different definitions of “Traffic Conflict” and the relation to “Accident” are listed.

Definition 1

-*“A traffic conflict is any potential accident situation leading to the occurrence of evasive actions such as braking and swerving.”*[42, 1967]

Karim El-Basyouny and Tarek Sayed pointed out that this was the first proposal of a definition of traffic conflict. [33, 2012]

Definition 2

-*“A traffic conflict is the situation, in which a driver tries to avoid a potential crash, or a dangerous situation, applying some evasive action (braking, accelerating or changing lanes).”* [9, 1972]

Authors like Giuseppe Guido and Alessandro Vitale referred as well to this definition in their research study.*[25, 2012]*

Definition 3

-*“A traffic conflict is an observable situation in which one or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.”* [6, 1977]

Also the authors Gary A. Davis, John Hourdos, V. Guttinger and Hoong-Chor Chin referred to this definition of traffic conflict. [24, 2011][27, 1984][30, 1997]

According to Karim El-Basyouny and Tarek Sayed, this definition became internationally accepted in 1977 and is still used nowadays. [33, 2012]

There are three components in this definition: the initial condition, the action of the road users and the collision related outcome. The initial condition appears as a conflict only if it satisfies a counterfactual test. If the road users didn´t change their movements, a collision would probably result. The main question to be answered is: Does a conflict lead automatically to a crash, or does a conflict also exist if there is no crash? In other words, according to Guttinger [27, 1984], it is not obvious to understand the term traffic conflict in just one way. For theoretical work it can be useful to treat conflicts as potential crashes. On the other hand, for empirical work, it is necessary to recognize that only potential crashes, which did not result in a crash, are observed in a conflict study.

Hauer noted that traffic conflicts can be seen as crash opportunities. That means there is a relation between the number of conflicts and the expected number of crashes, which is shown in formula 1 below. The crash-to-conflict ratio reflects the probability that a crash opportunity results in a crash. It should be stable across the entities being compared and is estimated for different traffic situations.[28, 1982]

$$Expected\ number\ of\ crashes = (number\ of\ conflicts) * (crash - to - conflict\ ratio)$$

Formula 1 Expected number of crashes[28, 1982]

A relevant parameter in accident analysis is the Time To Collision (TTC).The TTC is an effective measure for rating the severity of a traffic conflict.

Hayward defined TTC in 1972 as:

-*“The time required for two vehicles to collide if they continue at their present speed and on the same path.” [46, 1972]*

Van der Horst has considered different points, at which the beginning of TTC should be measured. The TTC at the onset of braking (also called “time to accident”) and the minimum registered value of TTC in an interaction process are two of the most commonly used quantitative measures in conflict analysis. [31, 1990]

According to Van der Horst, two vehicles are assumed to be in a traffic conflict or in an unavoidable collision path, when the minimum value of TTC is lower than 1.5 seconds. [32, 1991]

In order to understand the correlation between TTC and traffic conflict, Chin and Quek [30, 1997] defined it as followed:

"The greater the difference in speeds or the smaller the spacing between the vehicles, the shorter will be the time to collision and hence the more serious the conflict. Since time to collision decreases with increasing severity, it would be better to represent the conflict measure in terms of the reciprocal of time to collision, which increases with increasing conflict severity."

If the reciprocal of time to collision becomes zero, than the conflict ceases and there is no longer a dangerous situation for the people involved. Chin conducted an experiment of traffic movements and Figure 1 illustrates the results. On the x-axis the reciprocal of time-to-collision is indicated (s^{-1}) and on the y-axis the relative frequency when the drivers were able to avoid an accident.

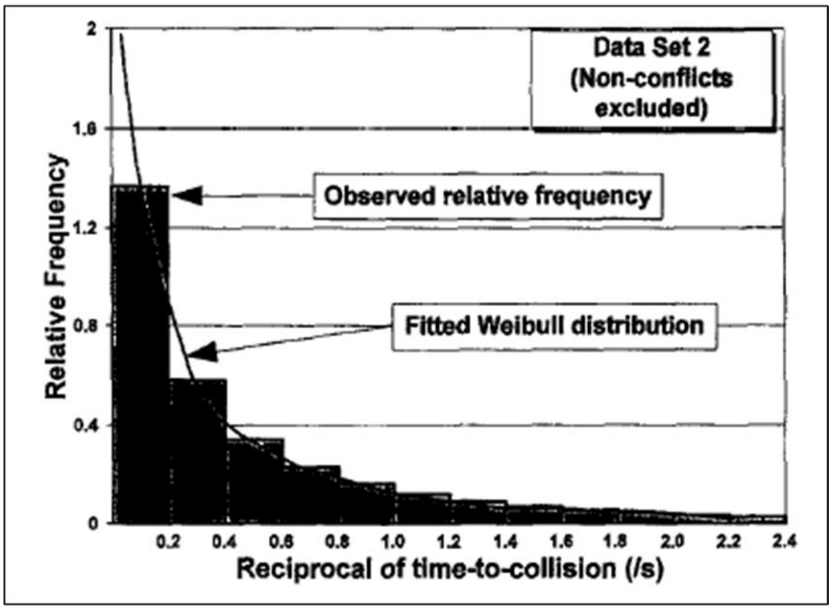


Figure 1 Frequency distribution of time-to-collision values [12, 1992]

Safety performance indicators can also have an influence on potential traffic conflicts. Actually, safety performance indicators highlight potentially unsafe conditions in a traffic stream. Those indicators can influence the reaction time of a driver, the friction value of a road, the braking capability of a vehicle or even the visibility of a driver. [36, 2001]

Evans et al. mentioned some of the safety performance indicators: driver feature and conditions (experience, drowsiness, etc.), road characteristics (surface, geometric features, etc.), traffic conditions (volume, speed, etc.), vehicle attributes (braking capability, stability, etc.) and environmental conditions (weather, lighting conditions, etc.) [22, 1991]

Tiwari et al. [23, 2013], defined the parties which can be involved in a traffic conflict or in an accident in two major groups:

a) Non-motorized-vehicles or entities:

   These are all kinds of entities and means of transportation without an engine to boost the vehicle.

   Examples: pedestrians, bicycles, e-bikes, skates, pedaled cycle rickshaws, animal-drawn carts and human-drawn push/pull carts.

b) Motorized vehicles:

   These are all kinds of vehicles which are propelled by an engine (internal combustion engine or electric motor).

   Example: automobiles, buses, trucks, motorcycles, motor scooter, auto rickshaws or off-highway vehicles.

For evaluation it is necessary to capture traffic conflicts in real situations. The three most common ways to capture traffic conflicts are:[23, 2013]

- Manual observation with trained field observers.
- Automated video cameras and evaluation of the captured data.
- Simulation models for different possible scenarios. Therefore the program needs detailed information about the environmental conditions and the vehicles.

Those three ways to capture traffic conflicts were also used by Karim El-Basyouny, Tarek Sayed and Dagmar Kocárková in their studies.[33, 2012][34, 2012]

A further, not so commonly used method was presented in the paper from Giuseppe Guido. This method used three smartphones which were equipped with a GPS receiver and positioned in three different vehicles. The position measured obtained by the smartphones allowed the reconstruction of the individual vehicle paths, from which it was possible to identify all the interactions. [25, 2012]

2.2 The reaction time and different influencing factors

The reaction time can be crucial for a driver to avoid an accident. But the reaction time also has an influence on traffic conflicts. Van der Horst defined the TTC as the time interval between the onset of braking (or steering) and the collision. A driver will brake (or steer) earlier if the reaction time decreases. The early braking (or steering) will lead to a longer time to collision. A longer TTC means a decreasing risk of a traffic conflict.

Reaction time is most typically defined as the interval between the presentation of a stimulus to a subject and the subject´s response. The interval between the onset of the stimulus and the initiation of a response is not always a simple matter. Robert G. Pachella described the time interval as follows: The subjects in a reaction time experiment wait for the stimulus to be presented and respond immediately. In other words, the subjects are not rushing their response, nor wasting any time. Reaction time is taken to be the minimum amount of time needed in order to produce a correct response. [47, 1973]

2.2.1 Distraction and mental workload as an influencing factor

Dozza et al. published studies where they performed reaction time experiments. An influencing factor can be distraction while driving a car. The reaction time of a driver can be increased significantly by distraction. Operating a mobile phone or the car navigation system can be examples of this. [17, 2012]

It was demonstrated (Consiglio et al., 2003), that conversations, whether personal or via mobile phone, increase the reaction time. Difficult and complex conversations lead to distraction and thus to an increasing reaction time. Conversations while driving cannot be prohibited, but the driver must compensate for the increased risk, by changing the driving style. An example of this could be reducing the speed of the vehicle. But a driver does not realize the increasing reaction time during a conversation. [13, 2003]

The influences of such mental workload differ greatly among individuals. Examples of such influencing factors are age and the physical condition. They play an important role regarding the reaction time. [40, 1985]

Hiroshi Makishita examined the influence of age and mental workload on reaction time of drivers. In total 30 male drivers of three age groups were analyzed within this study. The first age group in this experiment was between 20-29 years old (young). The second age group was middle aged at 41-54 years old (middle) and the third group was between 61-64 years old (elderly group). All participants drove automobiles in daily life, but they were not occupational drivers. That means they are average car users.

The study was carried out on a simulated city street and a public road in Japan (Figure 2). Each lane is about 3m wide and the areas along the course are grass-covered. Point "A" was the starting point. It is a 12 km course, which includes a major road with two lanes in each direction and a minor road with one lane in each direction. The reaction time was measured while driving straight on the road. There was not much traffic.

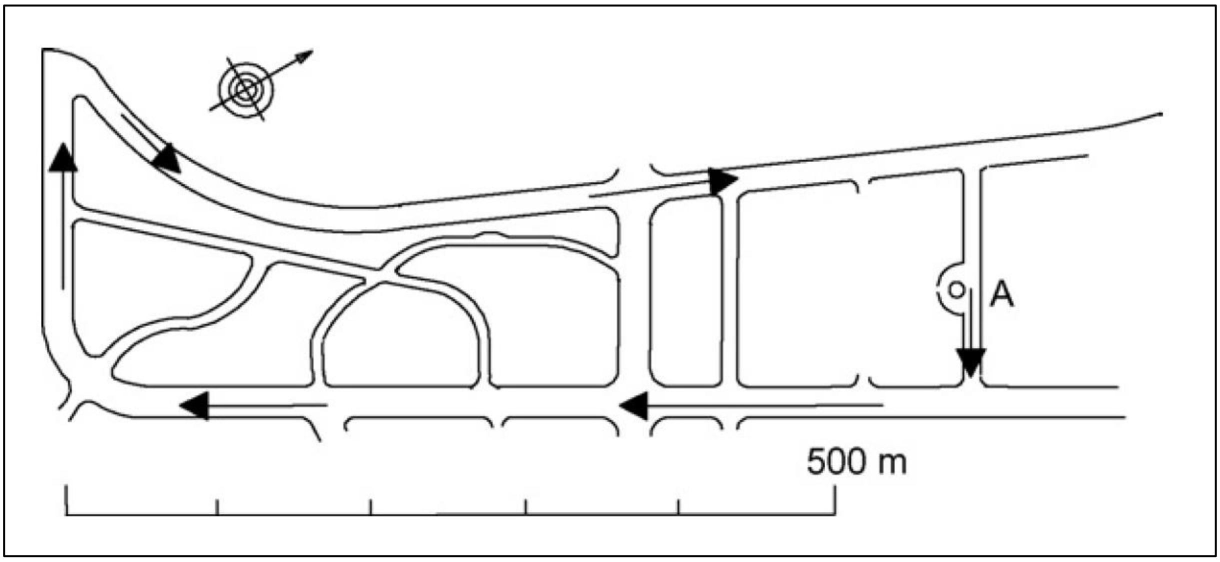


Figure 2 Simulated city street and public road used for the experiment[29, 2007]

Suddenly, during the drive, a buzzer sound appeared and the reaction time was measured under the following five conditions:

a) While merely sitting in a stationary car *(Stationary, no task)*
b) While sitting in a stationary car and making mental calculations *(Stationary, MC)*
c) During normal driving on a simulated city street at about 50 km/h *(Driving, no task)*
d) During driving on a simulated city street at about 50 km/h while performing mental calculations *(Driving, MC)*
e) During normal driving on a public road *(Public road)*

The equipment generated a 2200 Hz, 80 dB (A) buzzer sound. The subjects had to operate the switch immediately when they heard the buzzer sound. The switch was the blinker lever, which had to be moved to the front. The measurement precision of the reaction time to the buzzer sound was 1/100 seconds. Measurements for each subject were taken at least four times under each condition, 17 times at most. [29, 2007]

75% of the measured reaction times were 1 second or less for each age group under each condition, except for the subjects between 61 and 64 years.

Figure 3 shows the average reaction times from this experiment. Under condition 1 (Stationary, no task) the elderly group has the lowest reaction time (0.35 sec) and the young group has the highest value (0.42 sec). During condition 2 (Stationary, MC) the elderly group has the highest value with about one second. The young and middle groups have nearly the same value with about 0.6 seconds. The differences under condition 3 (Driving, no task) between the three groups is lower than 0.1 seconds. The elderly group reached the highest reaction time (0.6 sec). During condition 4 (Driving, MC) the elderly group has the highest reaction time (1.15 sec) and the young group has the lowest (0.65 sec). While driving on public road the middle group has the lowest value (0.7 sec). The young and elderly group achieved nearly the same reaction time with about 0.8 seconds.

As shown in this experiment, the average reaction time is different for every person and condition. It is between 0.35 seconds and 1.15 seconds. Single people from the elderly group reached a maximum reaction time of almost 1.8 seconds (Driving, MC).

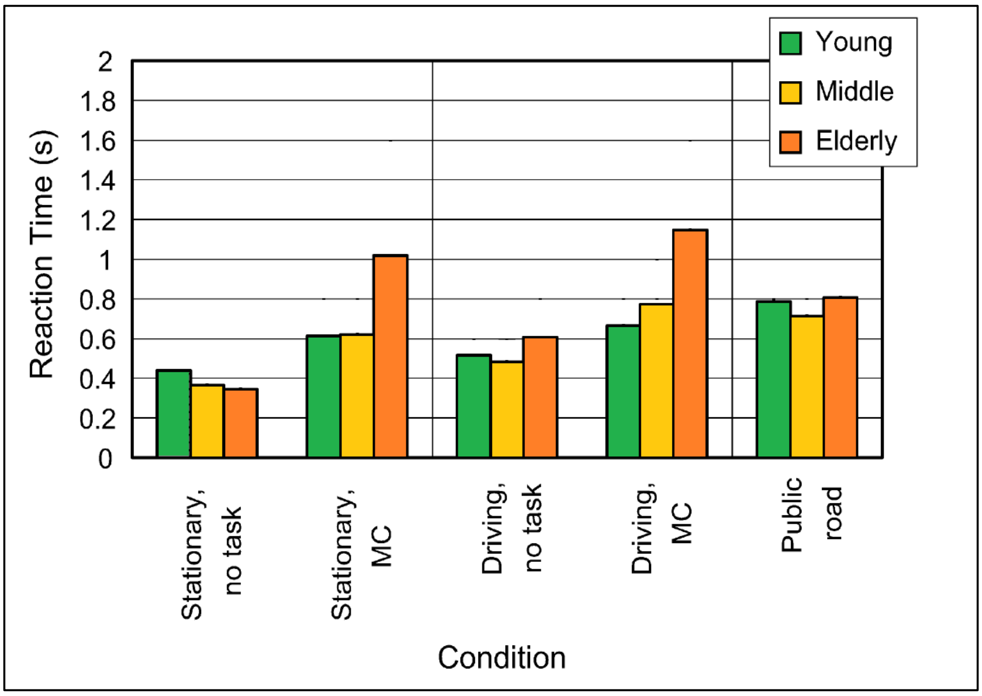


Figure 3 The average reaction times under five conditions for each group [29, 2007]

2.2.2 Driver-related and environment-related factors

A study from Dozza, Dingus et al. deals with 43,000 hours of data in 100 different cars in real traffic. Additionally data from 8 trucks with a total mileage of 735,000 miles was analyzed. The author considered different factors in the analysis, such as age, gender, type of distracted gaze (eyes off/on the road), reaction of the drivers (braking, braking and steering, steering), hands on/off the steering wheel and other factors considering the road conditions.

A total amount of 820 near crashes and 88 crashes were registered. 38 female drivers and 56 male drivers of three age groups caused these crashes and near crashes. Out of the total number of 908 events, 493 (472 car and 21 truck) of them had sufficient data to determine the reaction time (response time). [14, 2006]

Figure 4 illustrates the response time for driver related factors. The central mark in each box (red line) is the median. The edges of the boxes indicate the 25th and 75th percentiles. The dashed lines show the most extreme data points (outliners not considered). Single outliers are indicated as red plus signs in the figure. Notches indicate 95% confidence interval for the medians.

Eyes off road delayed the drivers´ average response time from 1 second (eyes on road) to 1.6 seconds. The difference between not distracted (1 second) and distracted (1.2 seconds) is lower. An increase in the response time considering the evasive maneuver can be seen in Figure 4C. The response time for braking (1 second) is shorter than the response time for steering (1.6 seconds). Also a difference between female (1.2 seconds) and male drivers (1 second) can be seen.

Drivers in the 51-68 years age class have the highest response time (1.2 sec), followed by drivers in the 18-20 years age class (1.1 sec) and the 21-51 years age class have the lowest value (1 sec). The influence of the position of the drivers´ hands while driving is shown in Figure 4F. With both hands on the steering wheel has the lowest response time (1 sec). The highest values have drivers who had none of the hands on the steering wheel (1.8 sec). Single drivers have a response time of over five seconds, while single truck drivers have a response time of less than 0.3 seconds.

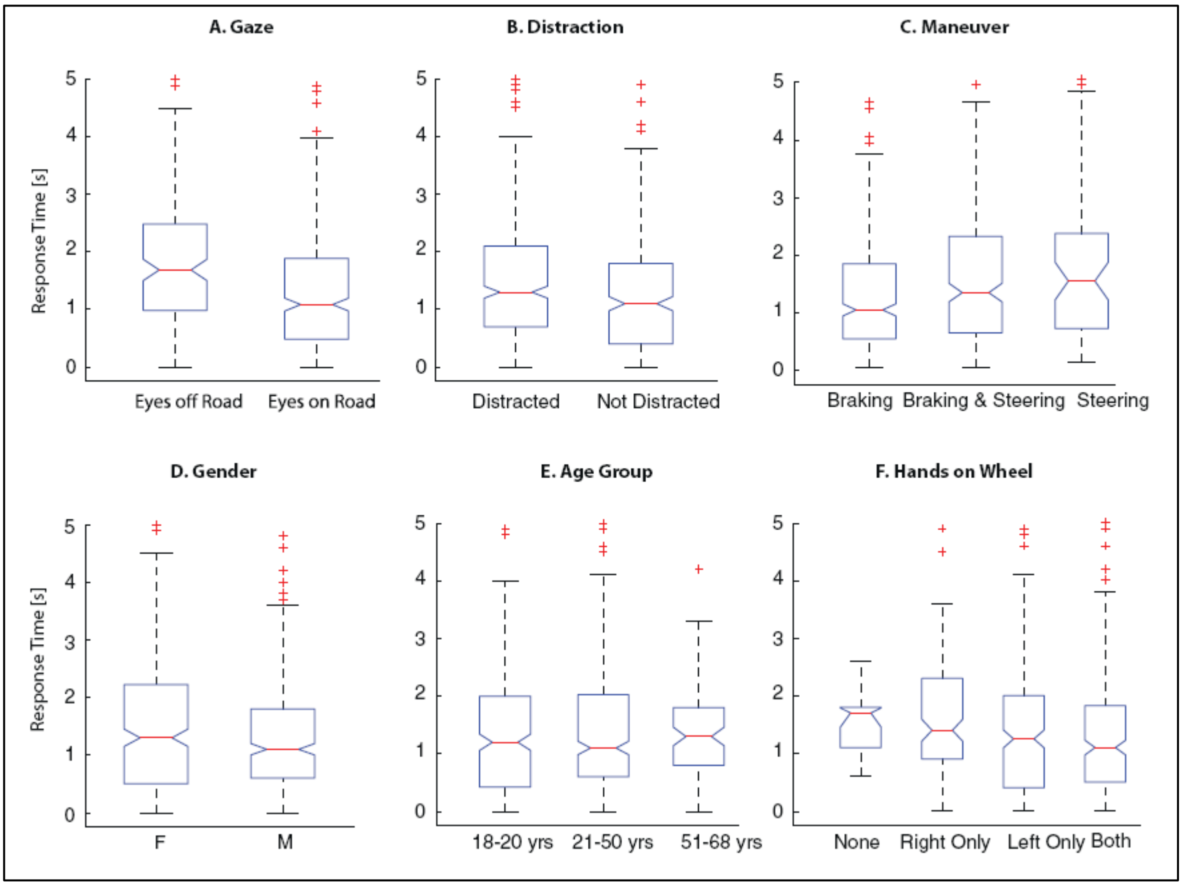


Figure 4 Response time for driver-related factors [17, 2012]

The response time for environment-related factors is shown in Figure 5. A longitudinal incident required an average response time of about one second. The value for a lateral incident was higher (1.6 sec). Lighting conditions also have an influence on the response time. The lowest average value is during darkness (lit) with less than one second. The highest value is during darkness (not lit) with about 1.7 seconds. Also the average response time during dusk (1.5 sec), dawn (1.3 sec) and during daylight (1.1 sec) were determined. Regarding the surface of a road, the response time differentiates between a dry road (1.1 sec) and a wet road (1.3 sec).

Different weather conditions also have an influence on the average response time. The lowest value is during clear conditions (1.3 sec). The value for cloudy and raining conditions is nearly the same with about 1.5 seconds. A distinction in traffic density was also made and can be seen in Figure 5E. The distinctions were between flow with restriction (1.2 sec), stable flow (1.2 sec), free flow (1.1 sec), slow flow (1.1 sec) and slow flow with stoppage (1.9 sec).

The last factor was divided into different localities. The drivers in a residential area have the lowest average response time (1 sec). The highest value is reached in open country (1.4 sec). In a business area (industry area) a value of 1.1 seconds is reached and on an interstate a value of 1.2 seconds.

In total, an average response time of approximately 1.2 seconds was measured during these experiments. [17, 2012]

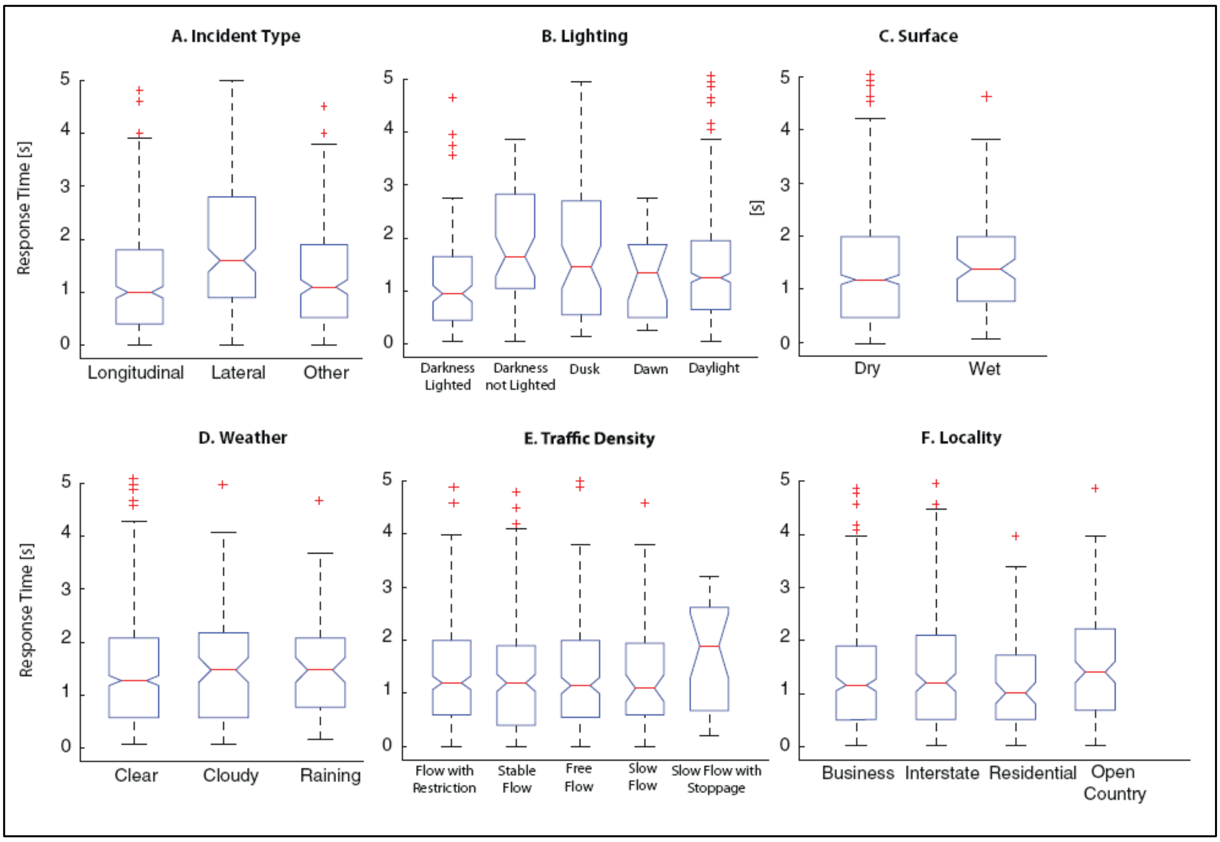


Figure 5 Response time for environment-related factors [17, 2012]

2.2.3 Influence of alcohol on the reaction time

Dietze, Lenné et al. conducted an experiment with 22 drivers between 18 and 21 years old and 25 drivers between 25 and 40 years old. The study was performed in a simulator which provided realistic traffic sound, road feel and vehicle dynamics. The participants were separated into two groups. Every person was provided with drinks, but only one group actually had alcohol in their drinks. The other group was provided with placebo drinks which consisted of orange juice. The alcohol used was ethanol (95%) mixed with orange juice. Low doses were used to produce BAC below 0.025% and high doses were used to produce a BAC of 0.05%.

One task for every group was to detect a sign while driving in the simulator. Several signs appeared suddenly on the screen and the driver had to push a button on the steering wheel in response. The vehicle drove at a speed of 70 km/h. Another task was to follow a leading car at a fixed distance, while the speed of the car in front varied from 60 km/h to 80 km/h.

The average reaction time of the placebo group was 1.07 seconds. The reaction time of the low dosage group was 1.06 seconds and of the high dosage group 1.08 seconds. The higher the BAC, the higher the reaction time will be. [35, 2009]

This study deals with a maximum BAC of 0.05%. Higher dosages of BAC were discussed by Movig, Drummer at al. According to Movig and Drummer there is an association between alcohol-impaired drivers and traffic crashes. The risk of causing an accident is 5.5 times higher with a blood alcohol concentration (BAC) greater than 0.08%, compared to a BAC of zero. The driver culpability increases exponentially, if the BAC is greater or equal to 0.1% BAC. [37, 2004]

3 ROAD ACCIDENTS IN AUSTRIA

Between 2002 and 2011 a total number of 324,151 traffic accidents occurred in Austria. 5,078 fatalities were the consequence. 49,423 of these accidents were single vehicle accidents, whereof 1,692 ended in fatalities. The evolution of accidents and several distinctions of locations, different roads and conditions were determined.

3.1 Comparison of Vehicle Accidents in European Countries

Several European countries and their number of accidents and fatalities per 100,000 inhabitants are shown in Figure 6. These numbers were published in 2011 from the International Traffic and Accident Database and from the International Transport Forum and refer to the year 2008 [48, 2013] [49, 2013]. Austria has a number of 471 accidents, 607 injured people and 8 fatally injured people per 100,000 inhabitants. The European average was 272 accidents, 362 injured people and 6 fatally injured people per 100,000 inhabitants in 2008.

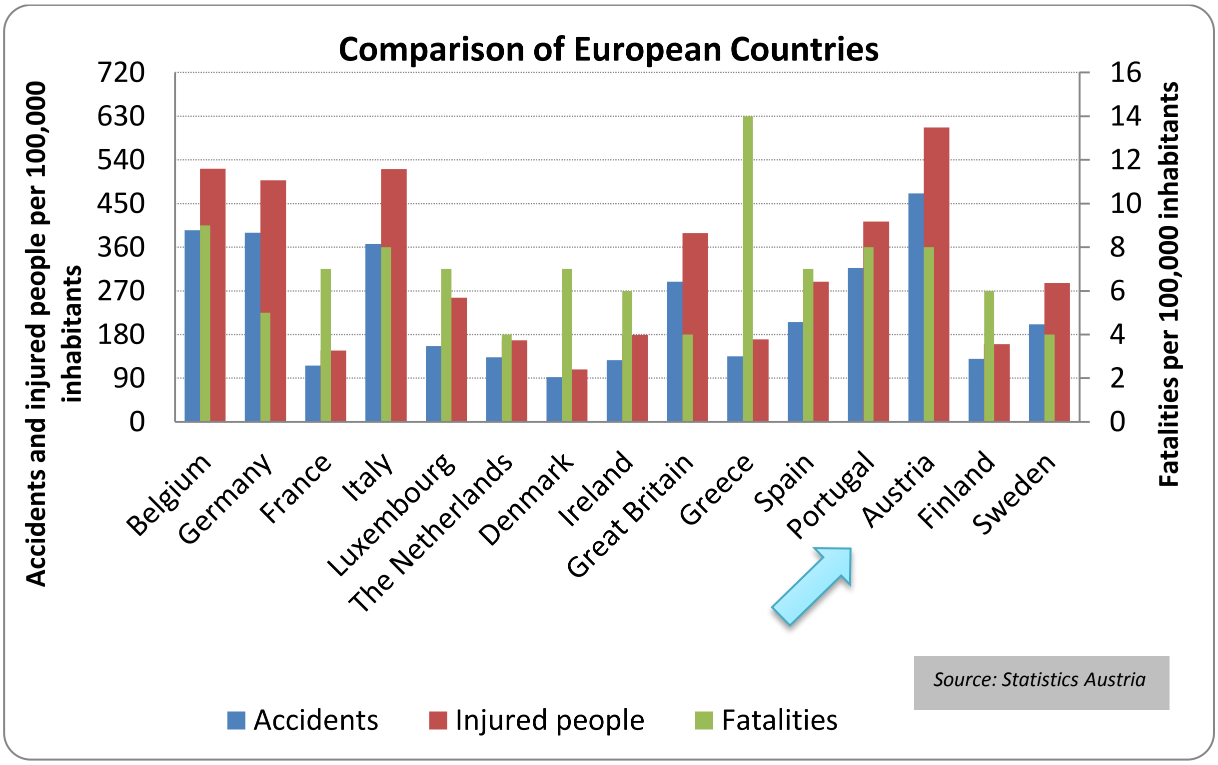


Figure 6 Injury severity in European countries in 2008 [11, 2011] [10]

3.2 Evolution of accidents and vehicle stock in Austria

Figure 7 shows the evolution of accidents in Austria from 1961-2009. The amount of accidents in 1961 is illustrated as 100%. The diagram shows a clear decrease in accidents with personal injuries since 1970. The number of fatally injured people has decreased even more, compared with the total amount of accidents. The number of accidents in 2010 has reduced by 17% (compared to 1961) and the number of fatally injured people has reduced by 66%. The total amount of 35,348 accidents (in 2010) and 42,653 accidents (in 1961) with personal injury was published by "Statistics Austria" in 2011. The number of fatalities was 552 (in 2010) and 1,640 (in 1961).

The number of power-driven vehicles has risen from 1.426 million in 1961 to 6.092 million in 2010 (Figure 7). Although the number of vehicles has increased by 430%, the number of accidents has a decreasing behavior (-17%).

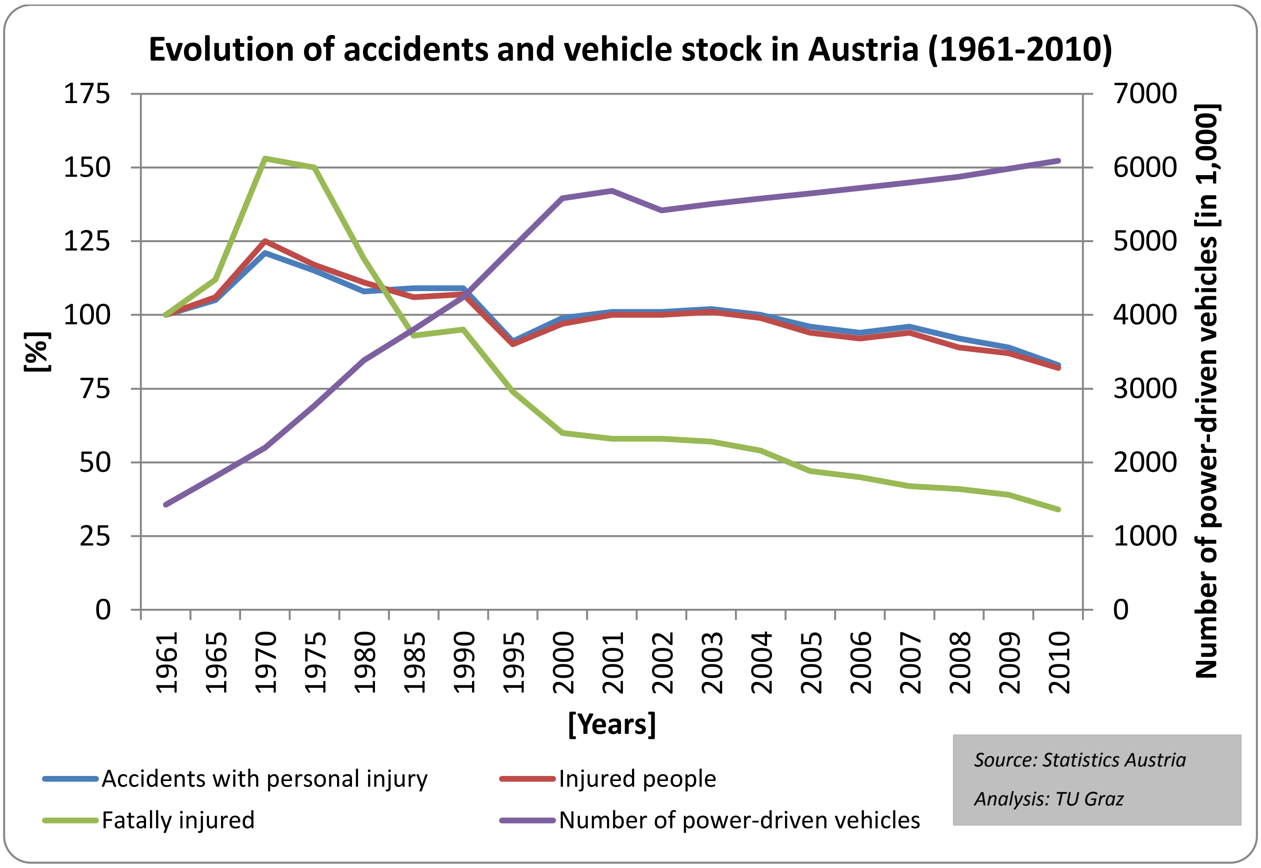


Figure 7 Evolution of accidents and vehicle stock in Austria from 1961-2010 [10] [11, 2011]

3.3 Injury severity of different accident types in Austria

Accidents at junctions have the highest share with about 36.3% (Figure 8). The number of fatal accidents at junctions is quite lower (12.45%). Second most important accident type are accidents with traffic in the same direction (25.56%). The number of fatalities for this accident type is about 7.7%. Pedestrian accidents have a frequency of 10.19% and a share of about 15% fatalities. Accidents with oncoming traffic have the second highest share of fatalities (28.61%) and a total frequency of 9.28%.

15.25% of all accidents in Austria are “Single Vehicle Accidents”. Single vehicle accidents have the highest share of fatalities (33.32%).

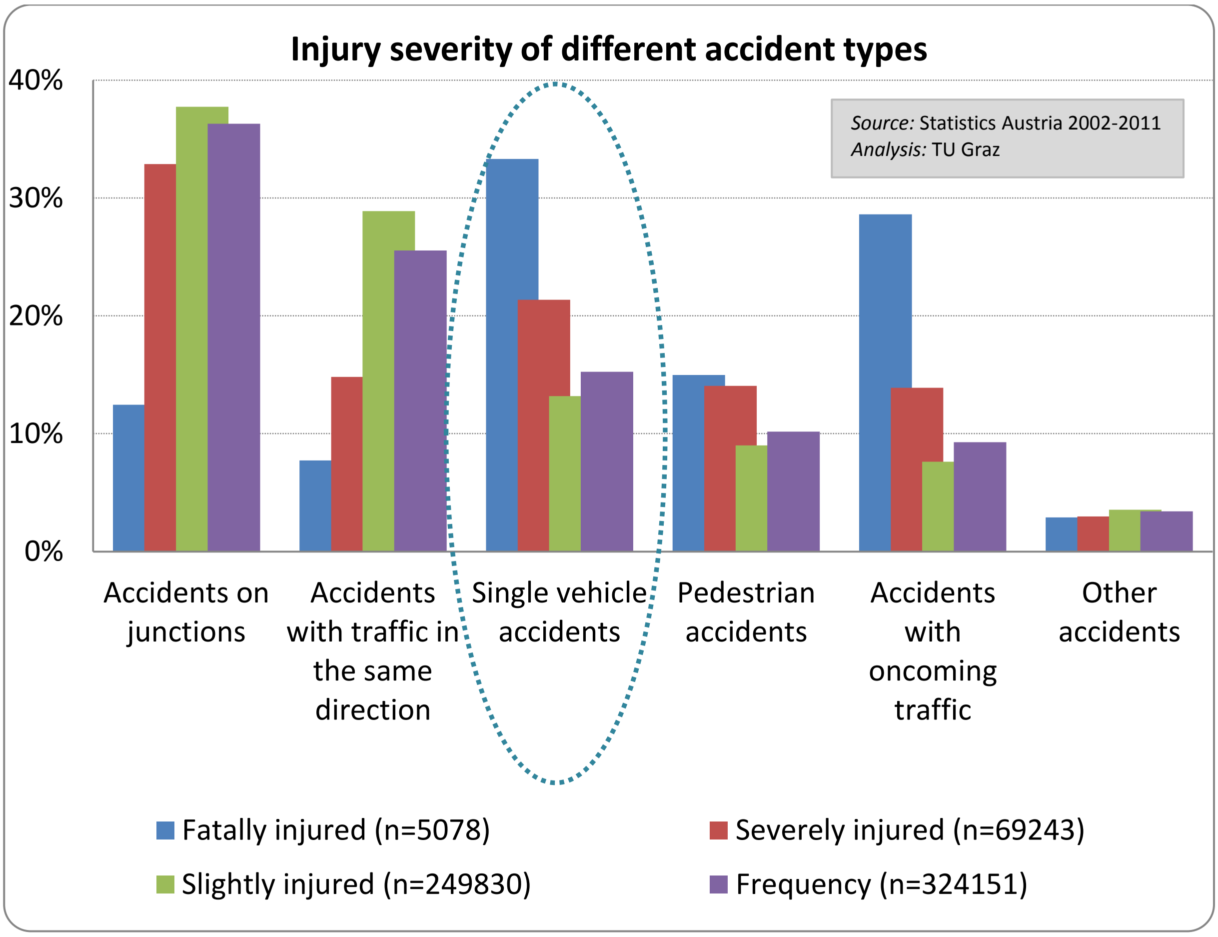


Figure 8 Injury severity of different accident types in Austria from 2002-2011 [10]

3.4 Injury severity at rural and urban sites

There is a clear difference between the degree of injury and the accident site (Figure 9). Looking at the overall frequency, there are more accidents at urban sites (37%). But looking at the injury severity of an accident, there are more fatal accidents at rural sites (77%).

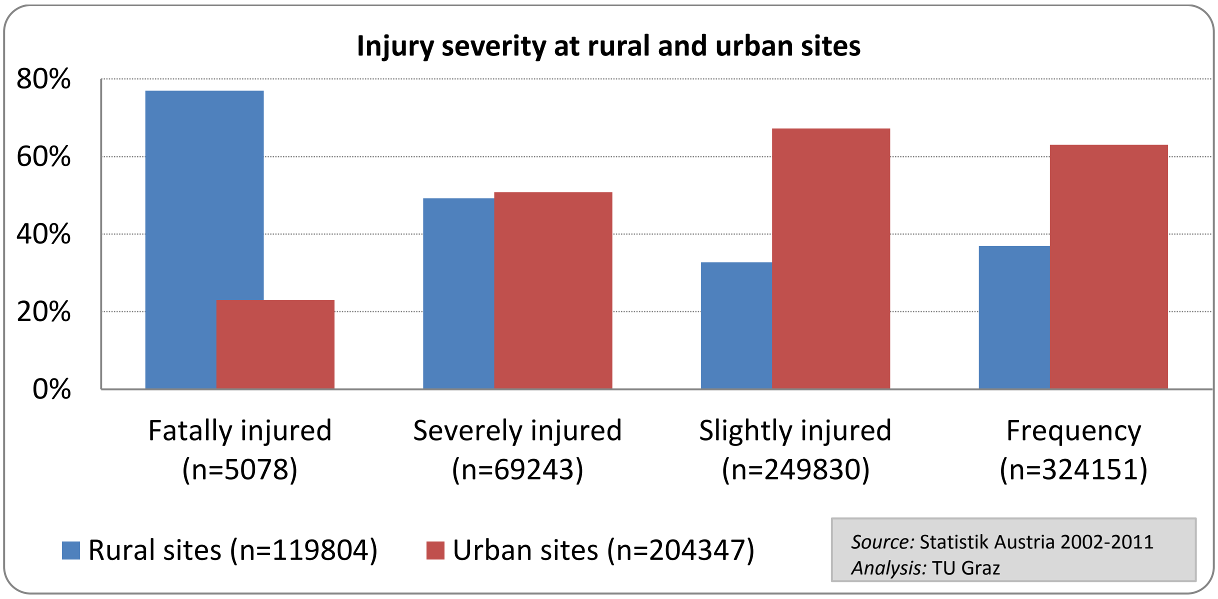


Figure 9 Accidents at rural and urban sites in Austria from 2002-2011 [10]

Most of the single vehicle accidents occurred at rural sites (Figure 10). Almost 80.9% of all single vehicle accidents are at rural sites. Fatalities have a share of 87.3%.

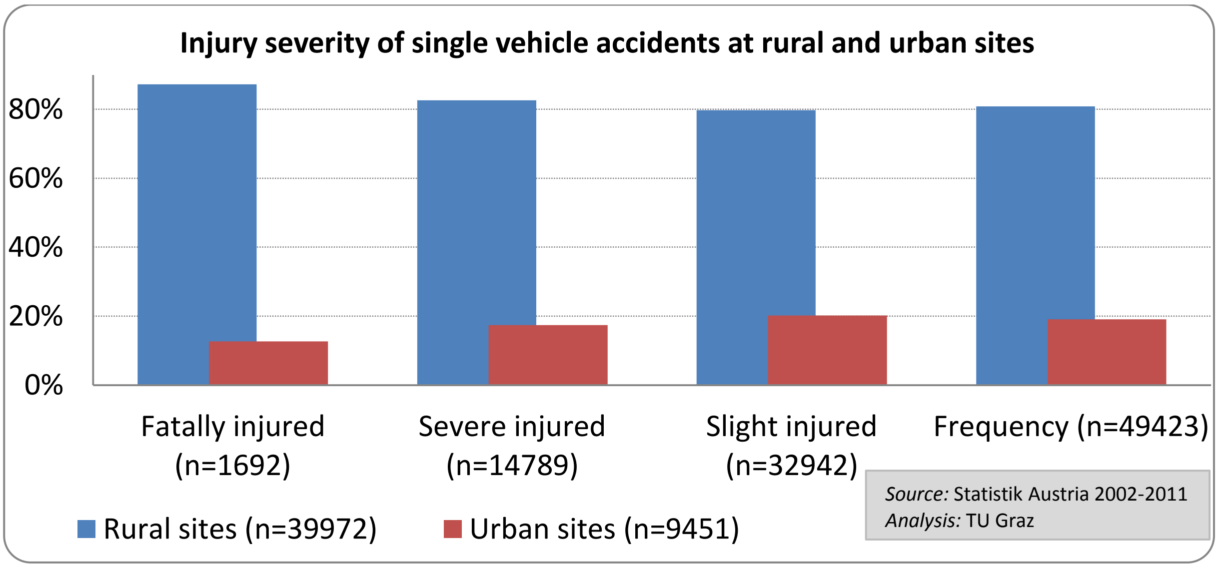


Figure 10 Single Vehicle Accidents at rural and urban sites in Austria from 2002-2011 [10]

3.5 Injury severity on different roads

High-ranking roads are motorways and expressways. State roads consist of country roads and federal roads. Figure 11 shows the distribution over different roads. State roads have the highest share (57.6%) and also the highest number of fatalities (72.7%). High-ranking roads have the lowest frequency with about 6.2%. The second highest share (36.2%) have other streets, such as mountain roads or private roads. The number of fatalities for high-ranking roads is 13.6% and for other roads 13.8%.

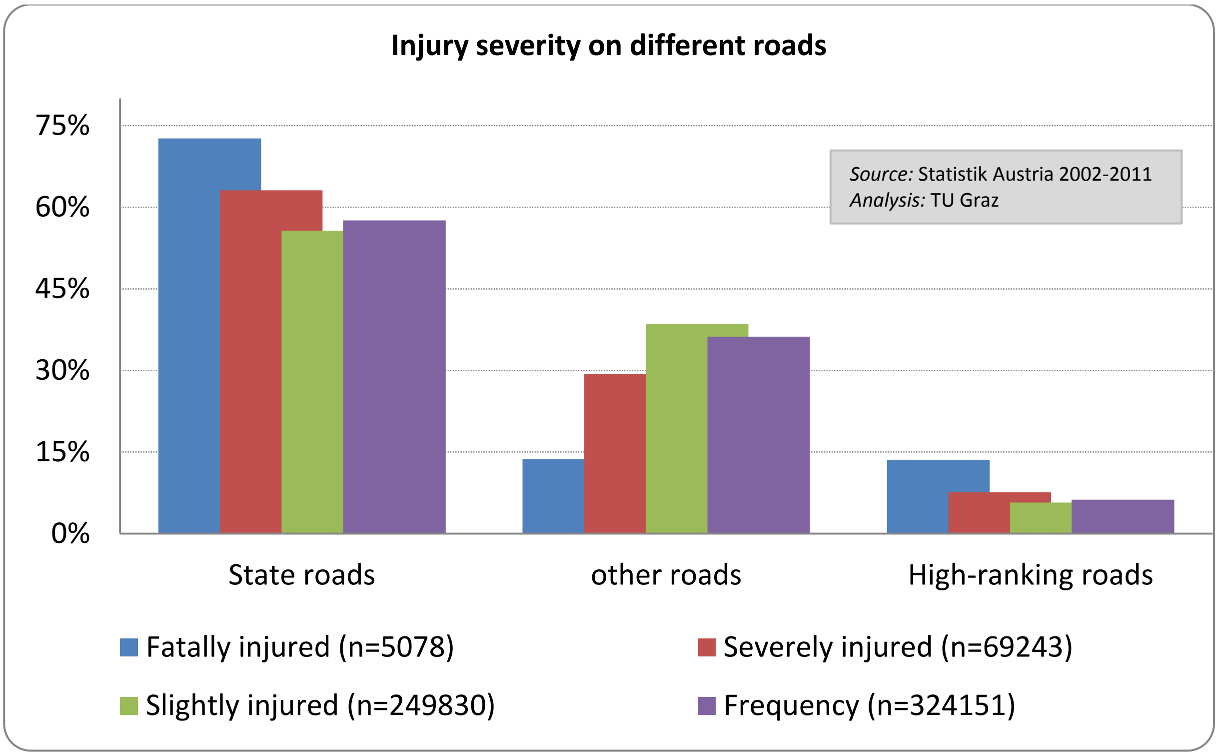


Figure 11 Injury severity on different roads in Austria from 2002-2011 [10]

Figure 12 illustrates the injury severity of single vehicle accidents. A share of 68.1% occurred on state roads. State roads have the highest number of fatalities (65.7%). High-ranking roads have the second highest number of fatalities (18.9%). 16.5% of the single vehicle accidents occurred on other roads, whereof 15.4% ended in fatalities.

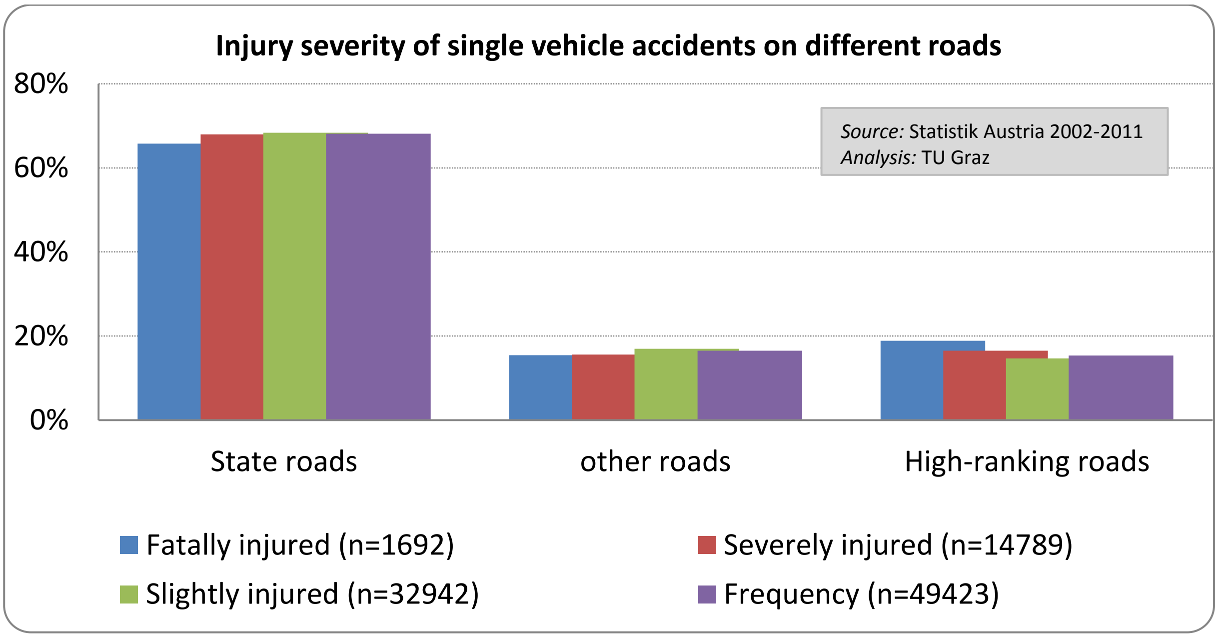


Figure 12 Injury severity of single vehicle accidents on different roads in Austria from 2002-2011 [10]

3.6 Injury severity of different single vehicle accidents in Austria

Figure 13 shows different accident types of single vehicle accidents. The accident type with the highest share is leaving the road on a straight section. At rural sites, leaving the road on a straight section to the right side has a frequency of 27.7% and the highest number of fatalities (34.2%). This accident type also has the highest share at urban sites (5.3%) and a number of 3.9% fatalities. Leaving the road on a straight section to the left side has the second highest share with 17.3% at rural sites and 3.6% at urban sites. Leaving the road in a turn is divided into four different accident types:

- driving straight ahead in a left turn
- driving straight ahead in a right turn
- leaving the road on the inner side of a right turn
- leaving the road on the inner side of a left turn

Figure 14 illustrates different accident types, regarding the place where single vehicle accidents occurred. Leaving the road on a straight section to the right side has the highest share on motorways (7.9%), on expressways (1.3%), on federal roads (9.9%), on country roads (9.8%) and on other roads as well (4.2%).

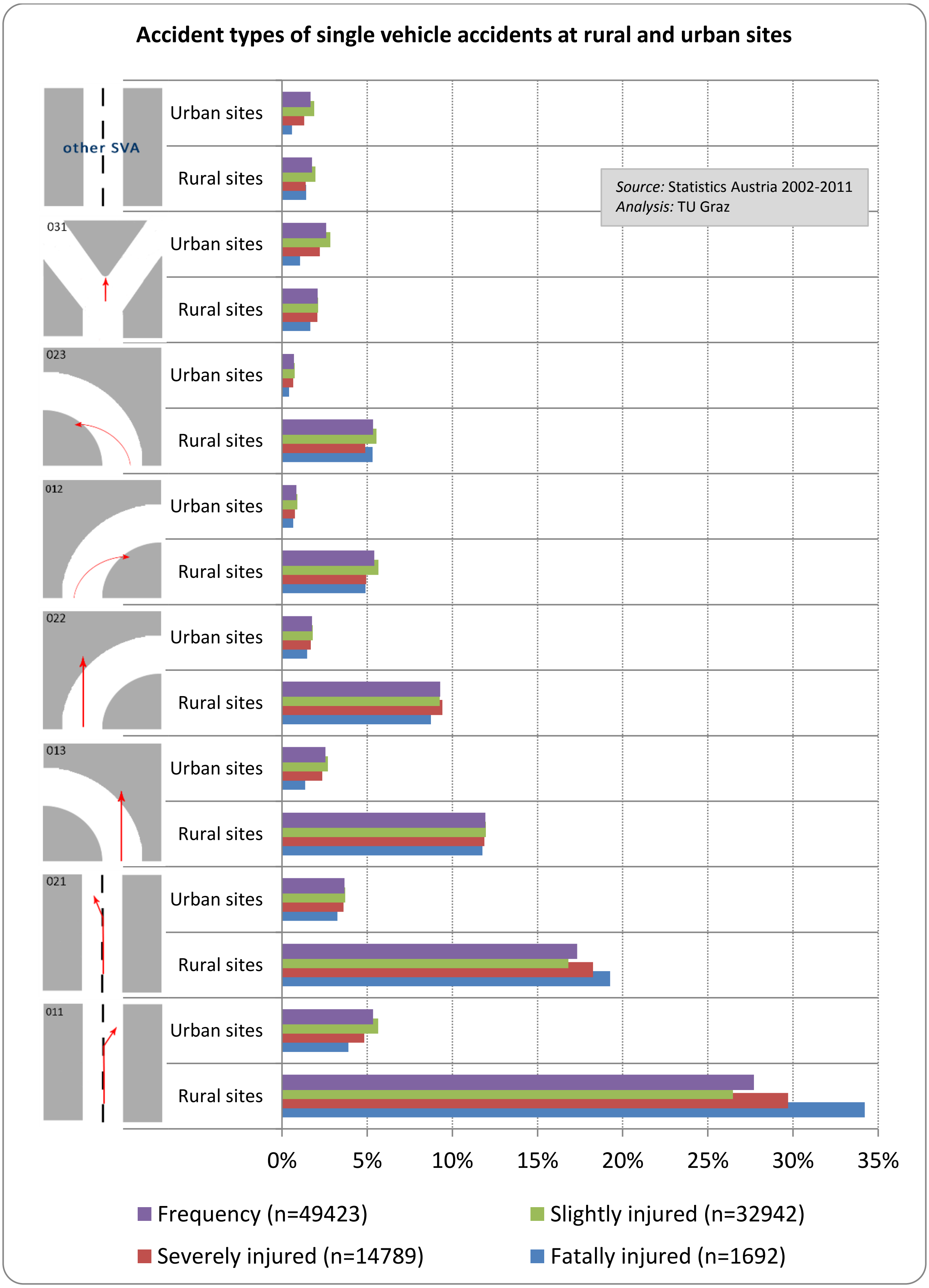


Figure 13 Accident types of single vehicle accidents at rural and urban sites in Austria from 2002-2011 [10]

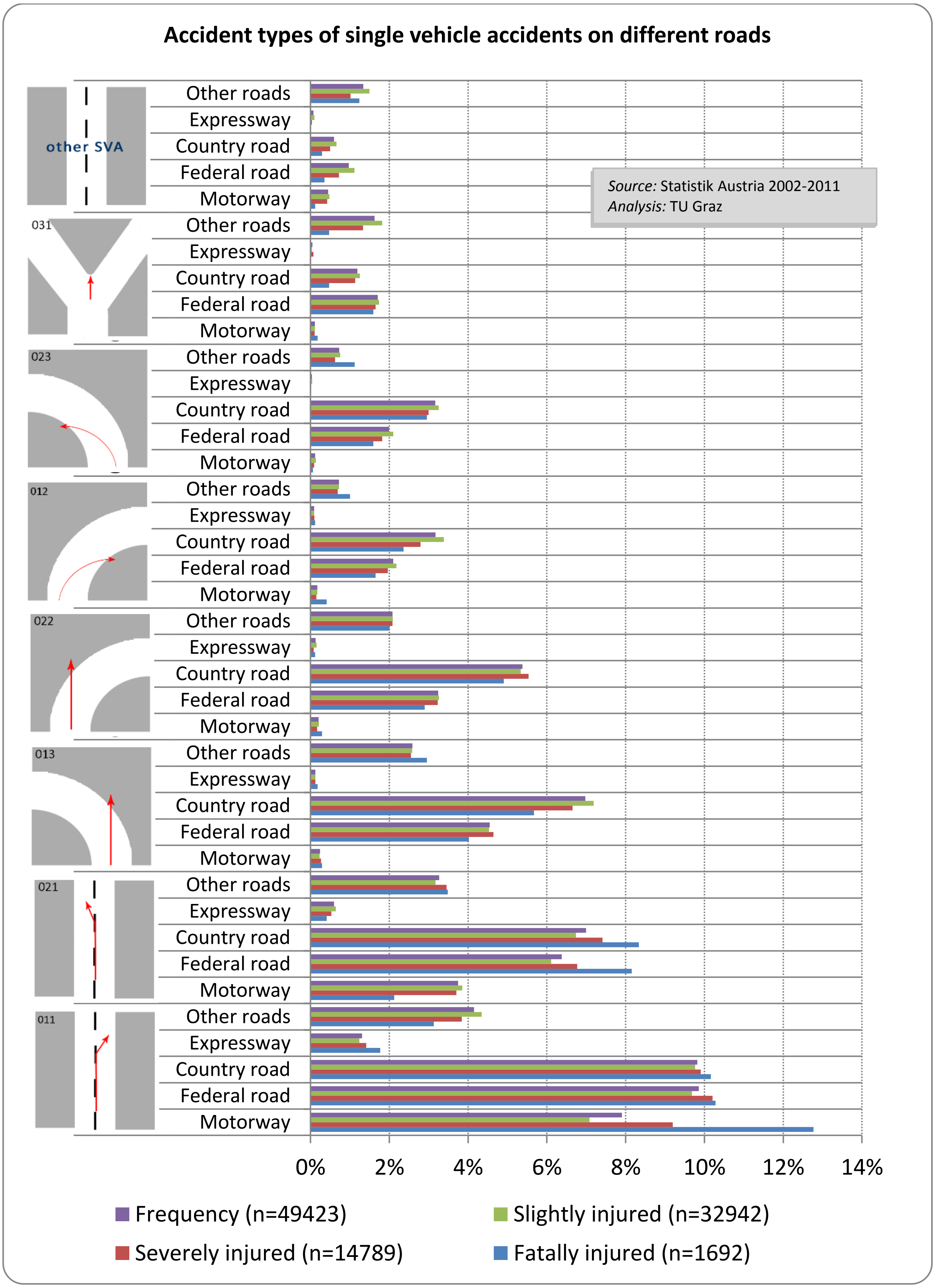


Figure 14 Accident types of single vehicle accidents on different roads in Austria from 2002-2011 [10]

3.7 Conditions during single vehicle accidents

The lighting, precipitation and road conditions during single vehicle accidents were determined and listed on the following pages.

3.7.1 Injury severity of single vehicle accidents according to lighting conditions

During daylight, most of the accidents occurred (48.3%). But during darkness and twilight, fatal accidents have the highest share (53.3%). Figure 15 illustrates the injury severity of single vehicle accidents for different lighting conditions.

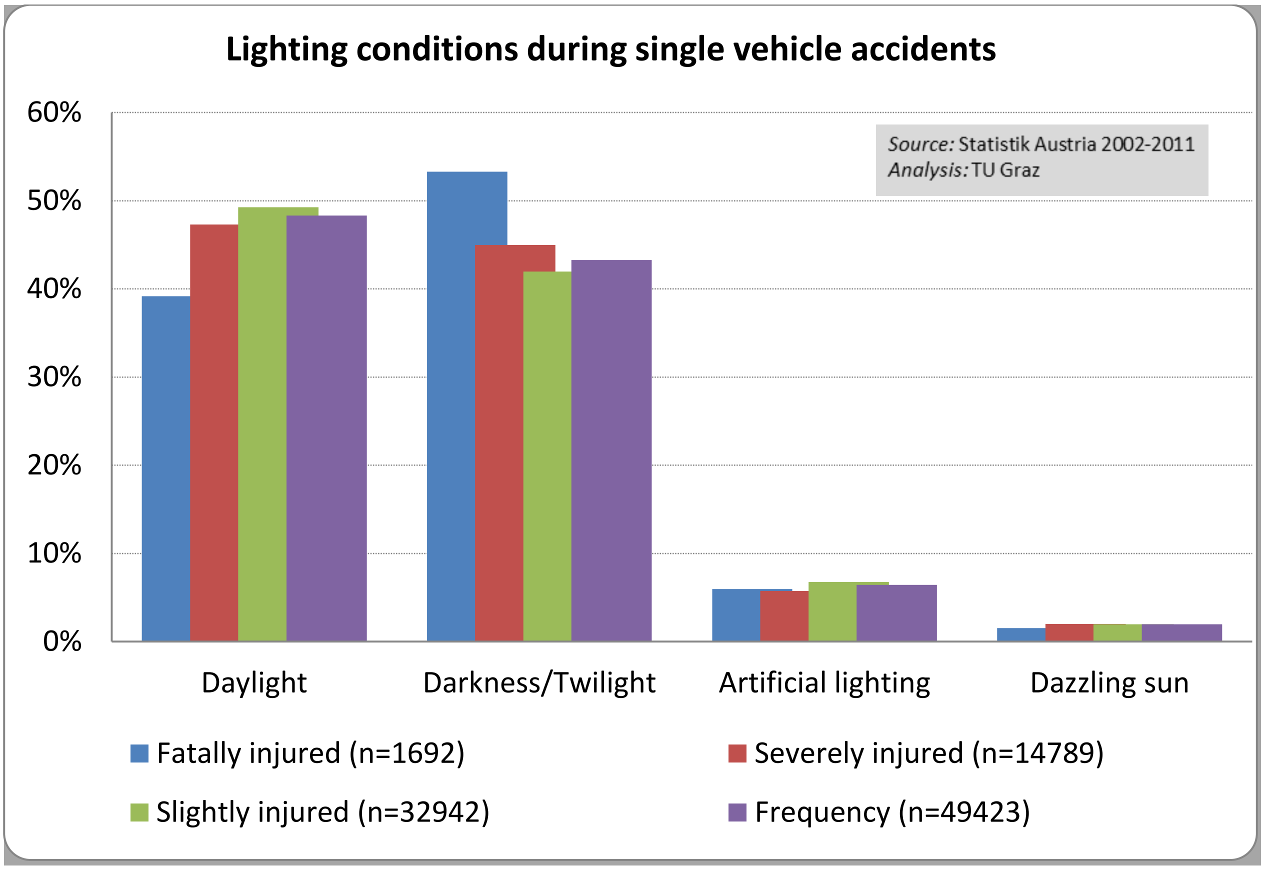


Figure 15 Lighting conditions during single vehicle accidents in Austria between 2002-2011 [10]

3.7.2 Injury severity according to precipitation conditions

Most of the accidents happened during conditions with no precipitation (Figure 16).

86% of all fatalities and 77% of all single vehicle accidents happened during rain free and snow free conditions.

During rain (drizzle) and snowfall, 22.3% of all single vehicle accidents and nearly 14% of all accidents with fatalities occurred. The number of other precipitation conditions (freezing rain or hail) together amounts to less than 1%.

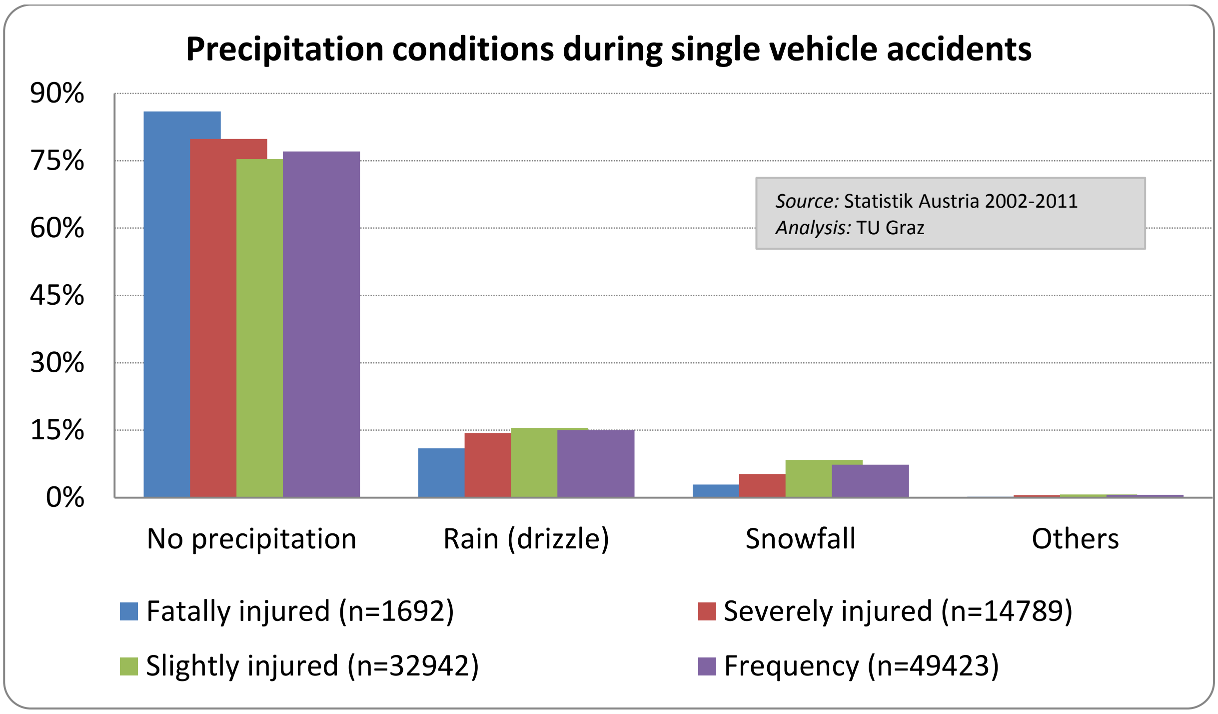


Figure 16 Precipitation conditions during single vehicle accidents in Austria from 2002-2011 [10]

3.7.3 Injury severity according to road conditions

The weather and precipitation conditions lead to certain road conditions. These road conditions have a big influence on the stability and maneuverability of a vehicle. Figure 17 represents the road conditions during all single vehicle accidents. More than half of all single vehicle accidents and 69% of all fatalities occurred on dry lanes.

The share of single vehicle accidents on a wet road is about 27.6%. The number of fatalities during wet conditions is 23.1%. Winter smoothness (scattered and not scattered) has a frequency of 10.5% and a number of 4.4% fatalities.

Snow, sand, grid, oil or soil on the road are other possible road conditions during single vehicle accidents.

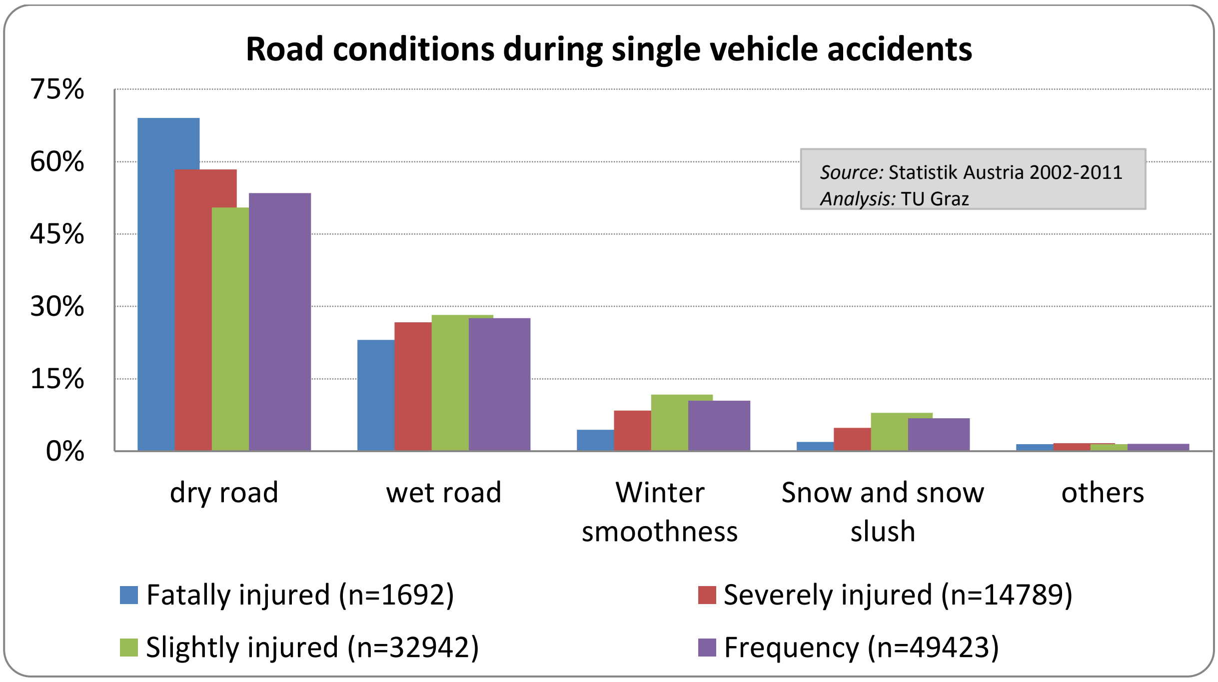


Figure 17 Road conditions during single vehicle accidents in Austria from 2002-2011 [10]

3.8 Conclusion

Between 2002 and 2011 a total number of 324,151 accidents occurred on Austrian roads, including 5,078 fatalities. Single vehicle accidents have a share of 15.3% and a number of 33.3% of all fatalities. Single vehicle accidents have the highest share of fatalities among all different accident types. Over 80% of all single vehicle accidents and over 87% of all fatalities occurred at rural sites.

Over 65% of single vehicle accidents took place on a state road, such as federal road or country road. High-ranking roads (motorways and expressways) have a share of almost 19%.

The most common accident type of single vehicle accidents is leaving the road on a straight section to the right side. It has the highest share on motorways, expressways, federal roads, country roads and other roads at rural and urban sites.

More than half of all fatalities occurred during darkness or twilight. Almost 86% of all single vehicle accidents happened during precipitation free conditions and more than half of them occurred on dry road.

4 PROCEDURAL METHOD

Real accidents have been reconstructed and simulated in order to collect as much information as possible about single vehicle accidents. Here are explained the procedure during a reconstruction, the available material, the concepts for detection of traffic conflicts and the development of generic accidents.

4.1 Reconstruction and simulation of real accidents

4.1.1 Data sources for accident analysis

In order to achieve the most realistic reconstruction of an accident occurrence, certain data was needed. Some of the documents which were used for the reconstruction are explained in the following lines.

- **Accident report:** it is written by the responsible police station and includes a short description of the accident occurrence. Furthermore it gives information about the time and location of the accident, speed limit of the road, traffic volume, lighting conditions, road conditions, precipitation conditions, evidence/marks (braking marks, skidding marks, abnormalities on the car, etc.), time of incoming emergency call, data of involved people (name, gender, date of birth, address, etc.) and other personal data of the victims.
- **Protocol:** it is the statement of a witness. In some cases there are witnesses of the accident who were either inside the car or outside the car. They give a detailed statement of their observations regarding the accident occurrence.
- **Alcohol test:** all examined accidents included one or more fatalities. If more than one person was in the car and one of them survived the accident, an alcohol test was made. It is carried out by the responsible police station.
- **Vehicle data:** it includes all important vehicle data such as year of construction, type, weight, power of the engine, tires, colour and the accident damage.

- **Photographic images:** different images from the accident places. These can be images of braking or skidding marks, the end position of the vehicle or other noticeable obstacles which were included in the accident.
- **Accident sketch:** the accident location and all its relevant places have been measured and are summarized in a sketch.
- **Medical reports:** it includes an injury report of the involved people (who were not fatally injured). A medical report can also be an autopsy of the person who was killed.

It has to be mentioned that not all this information was provided for every accident in its entirety or in the same quality.

To have appropriate environmental conditions and the right course of a road it is reasonable to use an aerial image of the accident location. The exact position of the accident location is given by the police through the kilometre and the name of the street. The sources for these images were geoland.at and maps.google.at.

4.1.2 Basics of the reconstruction using PC-Crash

PC-Crash is a numerical simulation method which is used for reconstructions of traffic accidents. It features a detailed data base of different vehicles and allows the user to adjust parameters regarding geometry, mass, tyres and many others. PC-Crash allows uploading bitmaps as JPEG files. This makes it possible to upload aerial images of the accident location in order to reconstruct the accident occurrence as realistically as possible.

Movements of the vehicle are controlled via different sequences, such as reacting, braking or accelerating. Steering manoeuvres can also be simulated. A second option for reconstructing the path of a vehicle is the tracking system. The user defines points and the vehicle follows these points.

4.1.3 Constraints regarding the examined accidents

Several constraints were applied to the single vehicle accident reconstructions.

Only accidents with passenger cars were considered. Accidents with trucks, buses, motorcycles or other vehicles were not considered. A second constraint was the injury severity of the accidents. Only accidents with fatalities were examined. Thus all other single vehicle accidents with severely or slightly injured people were not considered.

Only accidents on state roads (country roads and federal roads) at rural and urban sites were reconstructed. Accidents on motorways or expressways remained unconsidered. 72.6% of all single vehicle accidents occurred on state roads.

4.1.4 Possible scenarios for a vehicle after having left the road

Different scenarios can occur if a vehicle is running off the road. Several examples are shown in figure 18. A lateral collision with a tree and the end position of the accident vehicle is illustrated in figure 18a. The car started to skid on the road and collided in a lateral position into the tree. Figure 18b shows a frontal crash with a tree during snowfall. A collision with a house is shown in figure 18c. The vehicle skidded through a field and crashed into a house. In figure 18d can be seen a frontal collision of a vehicle and a bridge railing. Figure 18e shows the end position of a vehicle after leaving the road, hitting a tree and falling down the slope into a small river. The impact of the car and the wall inside the river was deadly for the driver. Figure 18f illustrates the course of an accident vehicle. The driver lost control and drove through a rail guard. The rail guard caused the vehicle to lift-off and the result was a roll-over accident. The end position is shown in figure 18g. Figure 18h shows the damage of another vehicle after a roll-over accident.

18a Lateral collision with a tree

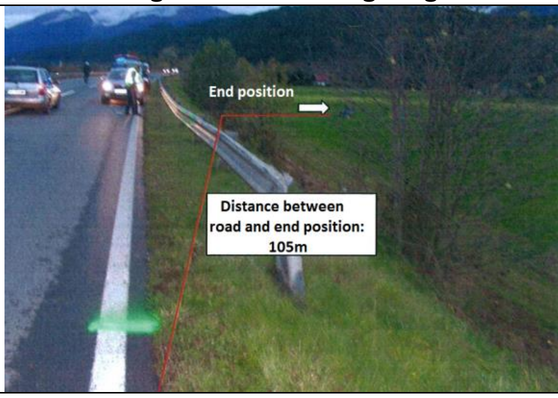
18b Frontal collision with a tree

18c Lateral collision with a house

18d Frontal collision with a bridge railing

18e End position in a river

18f Leaving the road through a guard rail



18g End position after a roll-over

18h Vehicle damage after a roll-over

Figure 18 Examples of different scenarios after a leaving of the road

4.2 **Procedure for a reconstruction of a real accident through an example**

All different steps to setup a reconstruction and run a simulation using PC-Crash are shown and explained on the next pages.

4.2.1 Introduction and facts of the single vehicle accident

The accident happened during daylight on a dry road. The driver was a 68 year old male and drove a Renault Clio. The speed limit for this road is 100km/h and the radius of the bend was 290 meters. Due to the strong collision the driver was jammed in the car and was presumably immediately dead. Figure 19 shows the aerial photograph of the bend where the accident occurred, the course of the road from the perspective of the driver, the car in its end position and the car during salvage work.

According to the accident report the following accident occurrence could be simulated. The driver lost control of the vehicle in a left-hand curve and steered the vehicle to the left side. Thereby it ran off the road and the car crashed laterally into a roadside tree.

Figure 19 Images of the location and the accident vehicle

4.2.2 Insert of an appropriate environmental surface

PC-Crash makes it possible to upload bitmaps. This function makes it possible to use aerial photographs of the accident location and to scale it in the right measure. Figure 20 shows the uploaded bitmap in PC-Crash.

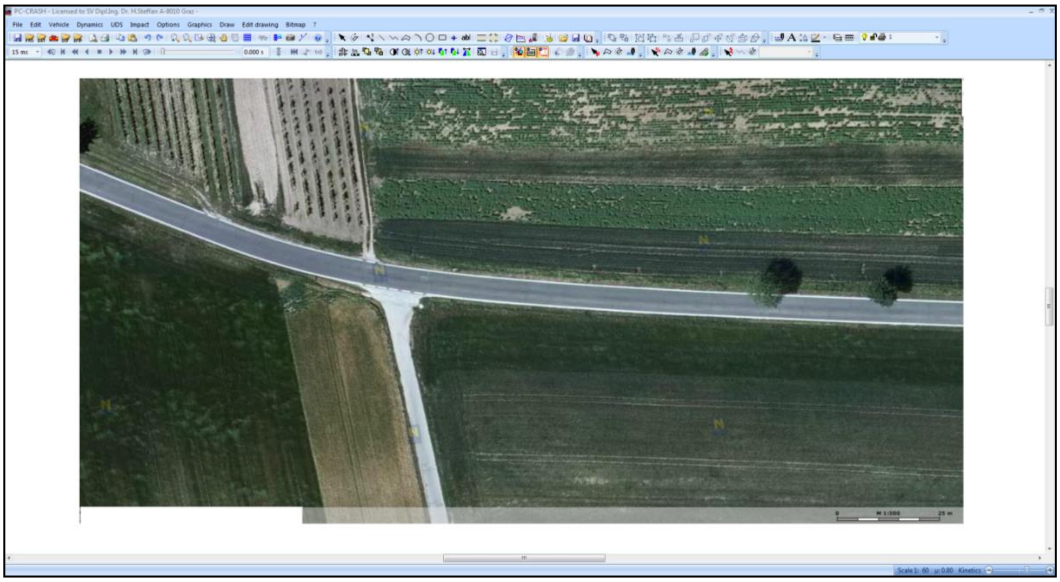


Figure 20 Uploaded bitmap in PC-Crash

Regarding the topography it does not correspond with the reality. Therefore the corresponding height of the road can be built up with slope polygons (figure 21). PC-Crash allows the reconstruction of any kind of landscape with the function of slope polygons. Gaps, hills and paths of nearly all different shapes are possible to setup.

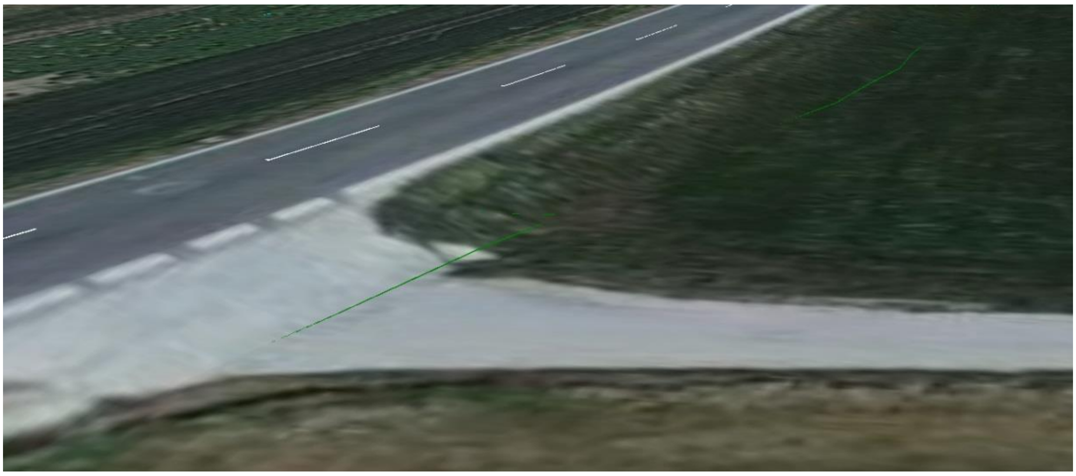


Figure 21 Slope polygons to reconstruct appropriate environmental conditions

The current accident involves a tree. If a vehicle collides with an obstacle on (or near) the road it is necessary to import the desired object. PC-Crash has a data base where different objects (trees, houses, walls, barns, etc.) can be imported to copy the real environment in the best possible way. Figure 22 shows the position of the tree. Several settings of the object can be selected (e.g. height, width, etc.).

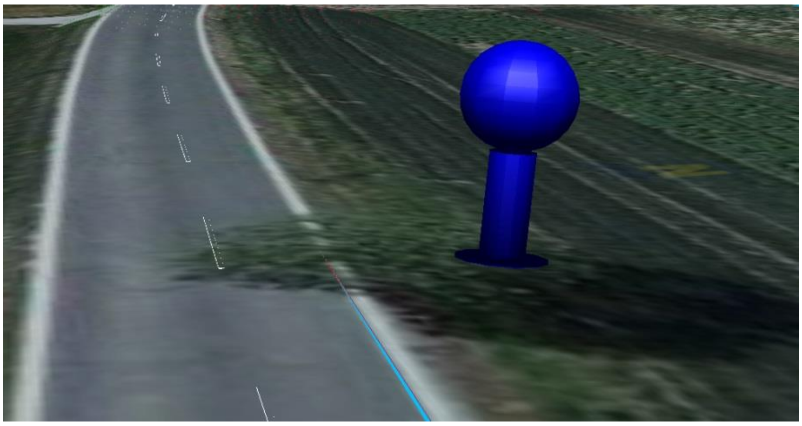


Figure 22 Inserted tree

4.2.3 Vehicle data

PC-Crash has an extensive data base of different vehicles. The accident reports give detailed information about the type of the car, the year of construction and the level of motorization. Those factors are sufficient to determine the appropriate vehicle in the data base. Figure 23 shows a detailed picture of the data base with important information about the vehicle.

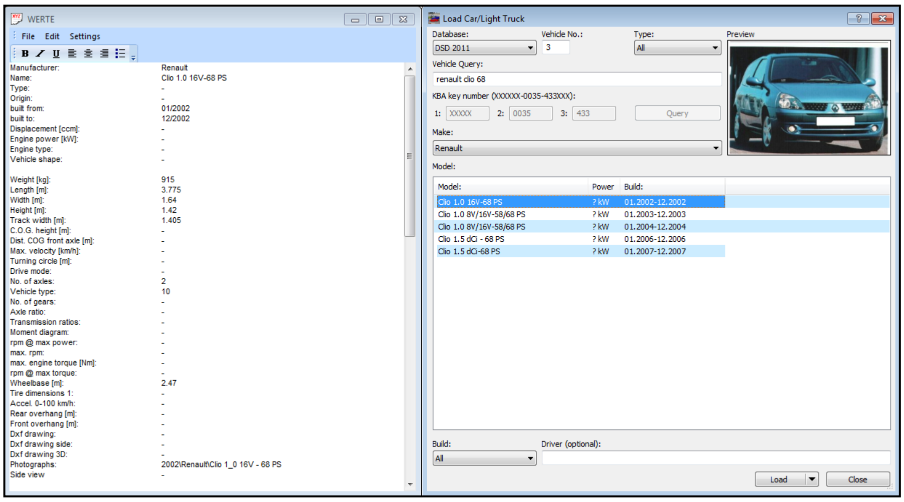


Figure 23 PC-Crashs vehicle data base

After the determination of the appropriate vehicle different settings can be selected. The vehicle geometry (e.g. length, width, height, etc…) and the vehicle shape are just two examples of many parameters (figure 24). If the vehicle involved was equipped with an anti-blocking system (ABS) or an electronic stability program (ESP), corresponding settings can also be selected.

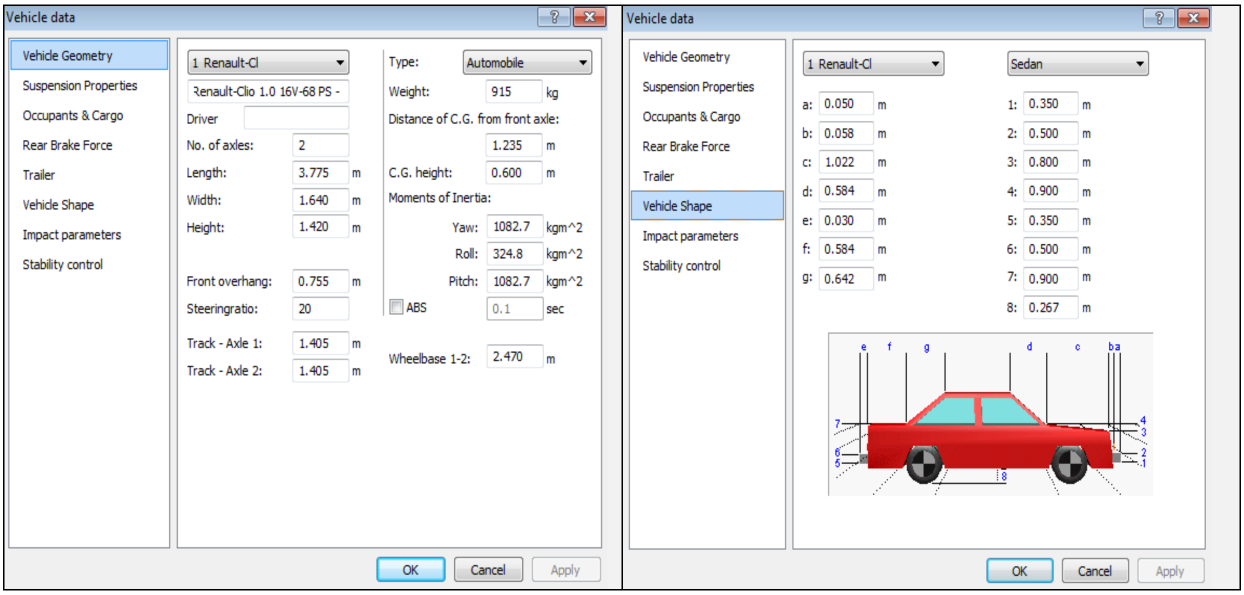


Figure 24 Examples for vehicle settings (vehicle geometry, vehicle shape)

4.2.4 Forward simulation of the collision path

After providing an appropriate environment and choosing the right vehicle it is necessary to find out the path which the car took before the accident. Pictures of the accident location and reports from surveyors and police make the path of the accident vehicle more or less clear.

In the current case the driver lost control in the bend and made a steering manoeuvre to the left side. Through the sudden steering manoeuvre the vehicle started to skid on the road. The driver was not capable of getting his vehicle under control and collided laterally into a tree without braking. Figure 25 shows the position of the car before it entered into the bend. This position is also the starting position of the simulation (t=0s).

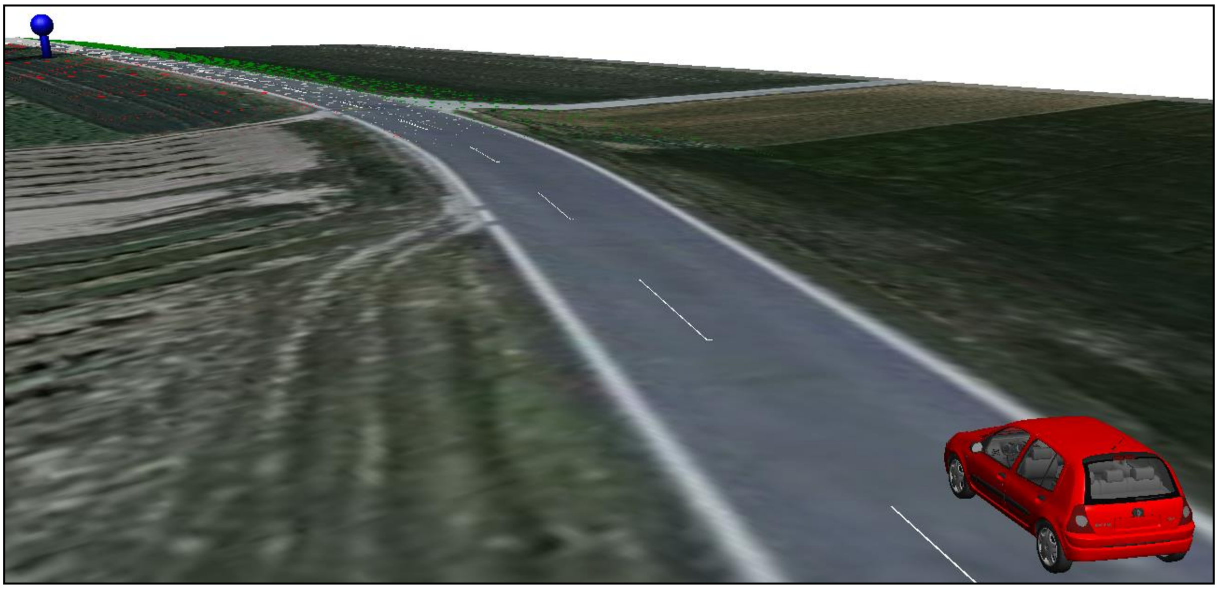


Figure 25 Starting position of the vehicle in the simulation

PC-Crash uses sequences to simulate different driving manoeuvres. Figure 26 illustrates an example of different sequences and their settings. Steering, braking, accelerating and reacting sequences can be setup. Different angles for every wheel during a steering manoeuvre, the time to achieve the full braking pressure (lag), the value of acceleration and the duration of it are just a few examples of the settings. These settings are used to simulate the path of the vehicle. The order of the sequences is from the top to the bottom.

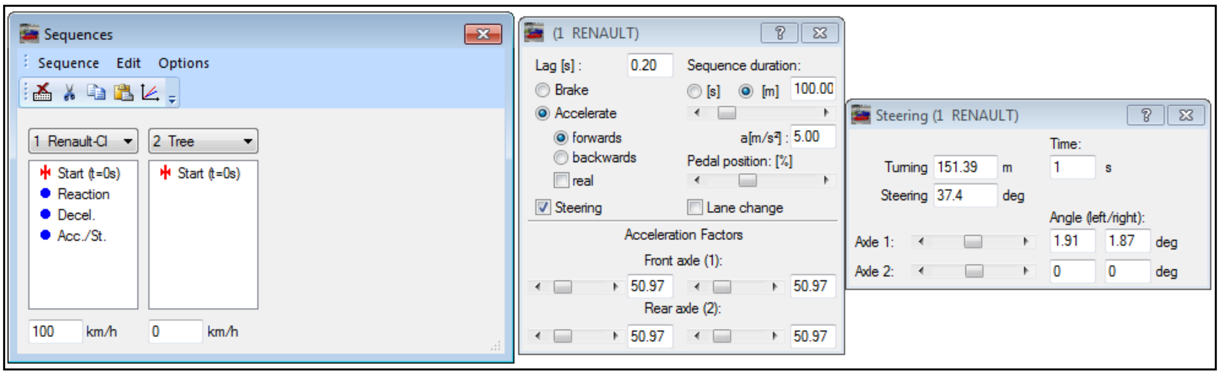


Figure 26 Example for different sequences and their settings

A second option for simulating the path of a vehicle is the tracking system of PC-Crash. This tracking system is a method where several following points are defined. They are illustrated in figure 27 as a red line. The number of the following points varies and can be adjusted. The vehicle follows these points and thus the path for the vehicle is defined. These following points have to be adjusted until the path of the car in the simulation is conforming to the accident reports. The end position of the vehicle in the simulation must correspond to the end position of the real accident. This method was used for the simulations.

Figure 27 Following points of the accident vehicle

An important factor for all simulations is the friction value of a road. It has an influence on the behaviour of the vehicle and depends on the road condition. PC-Crash is able to vary the friction value according to the road condition during the day of accident. Different friction values and their maximum deceleration values are shown in table 1.

Table 1 Friction value for different road conditions and their maximum deceleration

Road Condition	Friction Value	Maximum Deceleration [m/s^2]
dry	0.7 to 0.9	6.87 to 8.83
wet	0.5 to 0.7	4.91 to 6.87
very wet	0.4 to 0.5	3.92 to 4.91
snow	0.1 to 0.5	0.98 to 4.91
ice	0.05 to 0.25	0.49 to 2.45

4.2.5 Simulation result of the reconstruction

Figure 28-29 shows the complete simulation from the starting position until the collision with the tree. The simulation results were that the vehicle drove with a starting velocity of 100 km/h and collided into the tree with a velocity of 57 km/h.

Figure 28 Path of the accident vehicle and collision with a tree

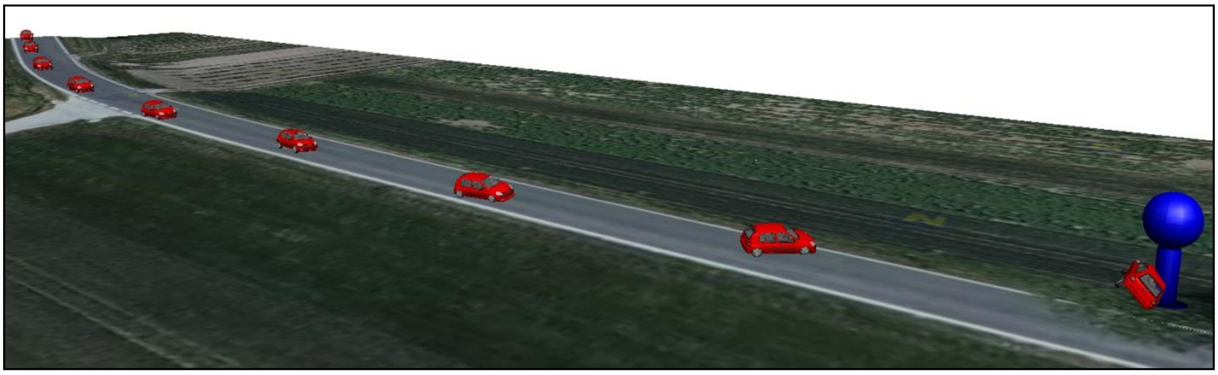


Figure 29 Path of the accident vehicle and collision with a tree

Requested data can be determined and evaluated now. Figure 30 shows a few parameters which can be examined in detail. On the left side of the figure there are examples for different parameters during the impact on the tree. On the right side of the figure different values are listed, which can be evaluated as a time-depending diagram. Furthermore skidding or braking marks, vehicle outline path and other settings can be included in the simulation for a better illustration.

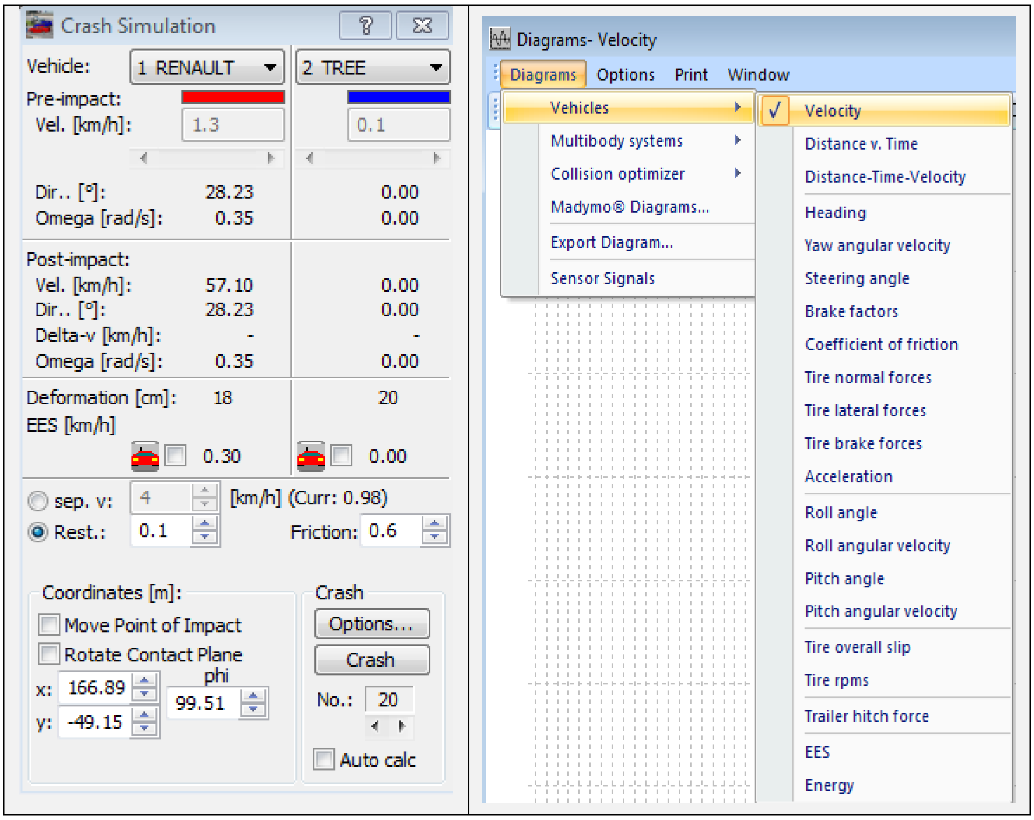


Figure 30 Impact data and different parameters for creating diagrams

4.3 **Simulated and investigated accident types**

Different accident types were reconstructed and simulated. The simulation results of the reconstructions are shown and explained on the following pages. Several real single vehicle accidents for every accident type have been reconstructed and simulated.

4.3.1 Example for leaving the road on a straight section to the right side

The simulation result of the reconstruction is shown in figure 31. The vehicle ran off the road to the right side and collided frontally with a tree. The driver didn´t use a seat belt and was fatally injured. The causes for this accident is not known.

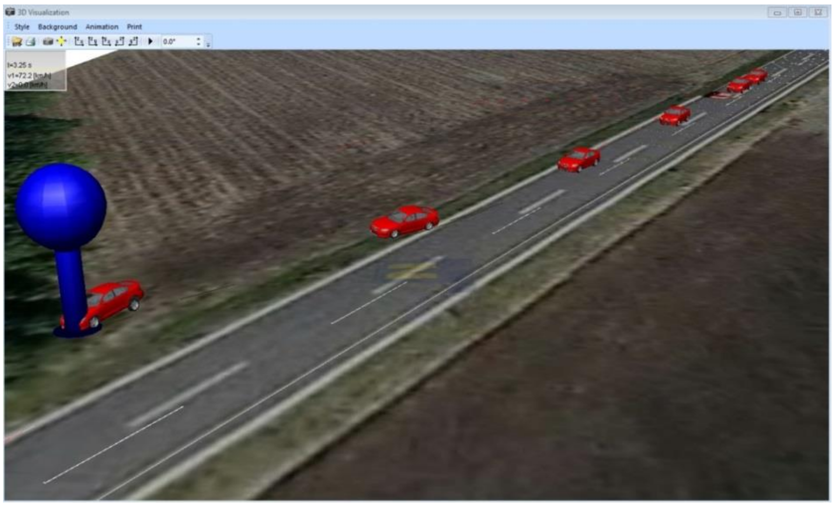


Figure 31 Leaving the road to the right side of a straight section

4.3.2 Example for leaving the road on a straight section to the left side

Figure 32 shows the simulation result of this accident scenario. The driver lost control of the vehicle on a straight section of the road probably due to high velocity. After a steering manoeuvre the vehicle started to skid on the road and the driver was not able to avoid leaving the road. A slope next to the road made the car jump into a field where it rolled over several times. The driver didn´t use the seat belt and was thrown from the vehicle.

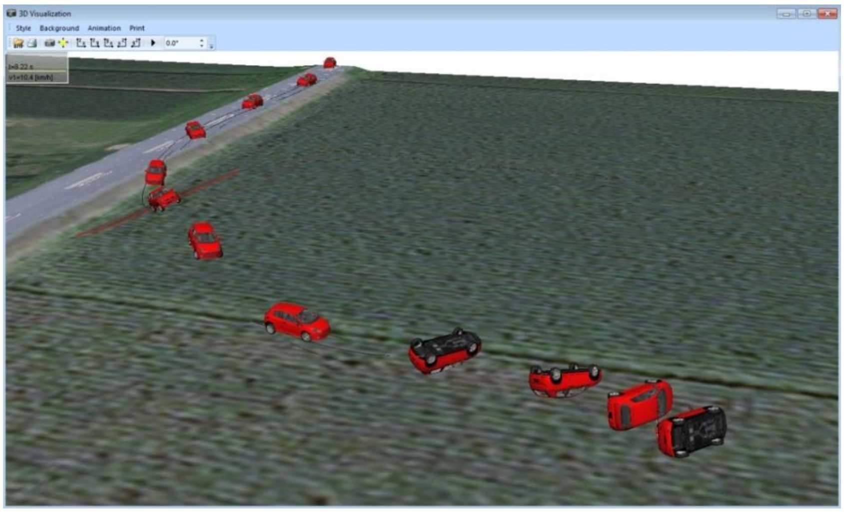


Figure 32 Leaving the road to the left side of a straight section

4.3.3 Example for leaving the road to the right side of a left-hand curve

Due to excessive velocity the vehicle started to skid in a left bend, entered the hard shoulder, drove back to the road again and left the road to the right side. The vehicle rolled over several times. The accident occurrence can be seen in figure 33.

Figure 33 Leaving the road to the right side of a left-hand curve

4.3.4 Example for leaving the road to the left side of a right-hand curve

The course of the accident vehicle is shown in figure 34. The driver lost control of the vehicle in a bend. The causes are not known and there were no witnesses. After leaving the road the vehicle had a frontal impact with a tree which was 5 meters next to the road. According to the accident reports no braking marks were noticeable at the scene of accident.

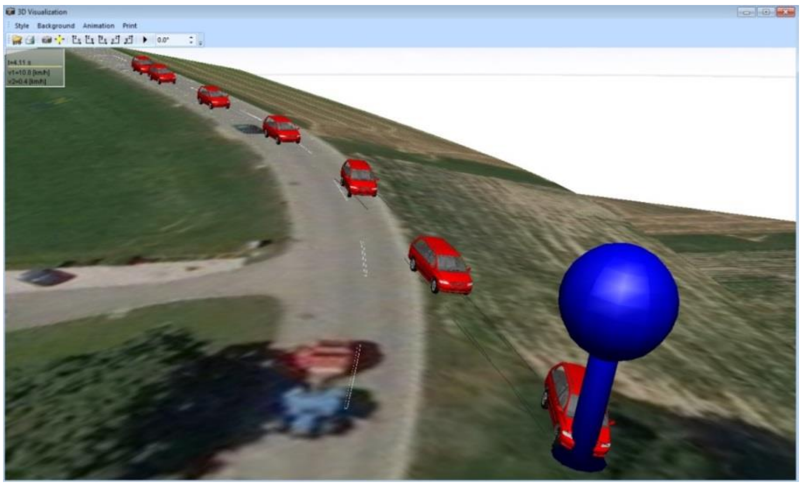


Figure 34 Leaving the road to the left side of a right-hand curve

4.3.5 Example for leaving the road to the right side of a right-hand curve

The driver of this single vehicle accident drove under the influence of alcohol. The vehicle ran off the road after a right turn and collided with a drain pipe. The simulation result of this accident occurrence can be seen in figure 35.

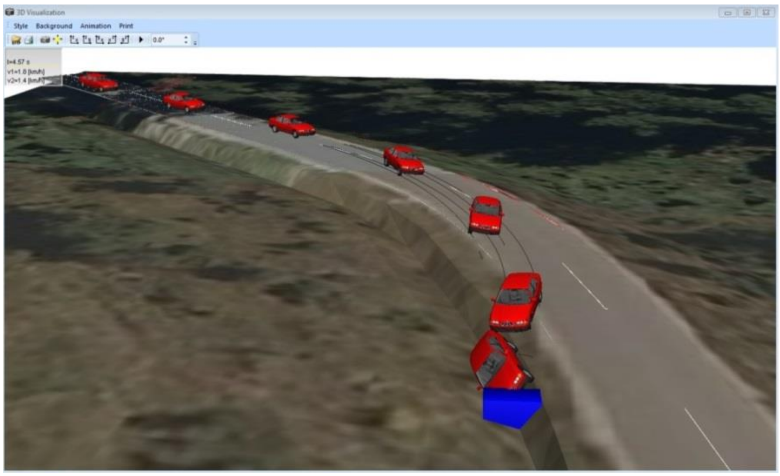


Figure 35 Leaving the road to the right side of a right-hand curve

4.3.6 Example for leaving the road to the left side of a left-hand-curve

The result of the simulation is illustrated in figure 36. It is assumed that the cause of the accident was a high speed and a wet road. The vehicle got too close to the right side of the road and tried to counter steer. Due to this manoeuvre the vehicle started to skid, left the road and rolled over several times. The driver didn´t use a seat belt.

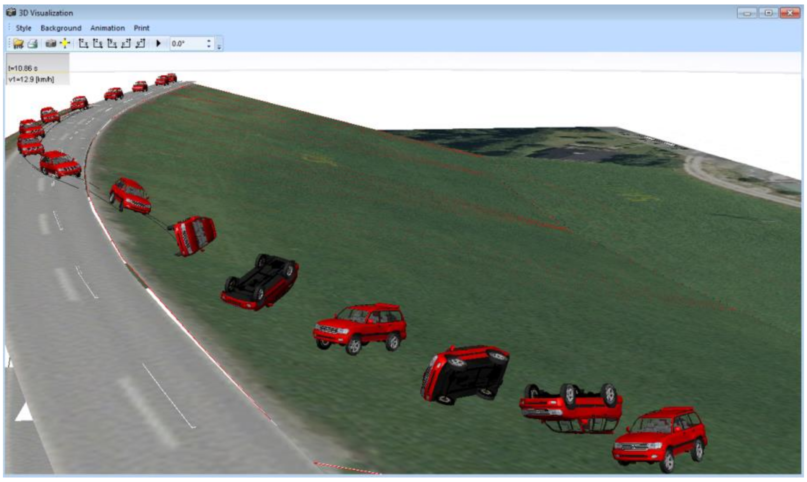


Figure 36 Leaving the road to the left side of a left-hand curve

4.4 Concepts for detection of traffic conflicts

In 55% of all single vehicle accidents on state roads the causes are not known. The second most common cause is an excessive speed. Of course there are other causes for traffic conflicts on state roads, such as animals on the road, micro sleep or distraction. However, there are already developed brake assistants which are able to recognize obstacles on the road. Also assistants to monitor the driver´s fatigue exist already. These record the behaviour of a driver through special software in order to identify deviations in the driving style. If the deviations are too big the software raises an alarm.

This thesis focuses on conflict detection depending on the velocity of a vehicle. The concepts are established and explained on the following pages. Furthermore it was not only detected a conflict, but also considered how to avoid it.

4.4.1 On a straight section of a road

Departing accidents on a straight road are by far the most common accident types of single vehicle accidents (more than 50%). A vehicle has to have an inclined position (angle φ) in order to run off the road. This inclined position can be corrected with a corresponding steering manoeuvre. This manoeuvre is explained and defined later. Of course, this steering manoeuvre requires a certain space (figure 37).

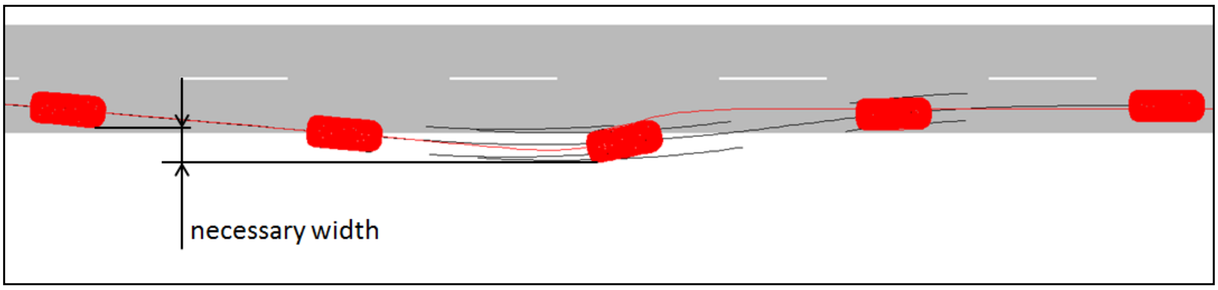


Figure 37 Necessary width for a steering manoeuvre

This necessary width was determined during the generic accidents. The idea behind is that a vehicle knows how much space is for a steering manoeuvre. This necessary width is compared to the available space in reality. Then it is possible to point out the position of a vehicle before it enters into a traffic conflict (position 2). If this position (position 1) can be determined then a conflict can be detected. Figure 38 illustrates an example with a tree next to the road and an evasive action to avoid an impact.

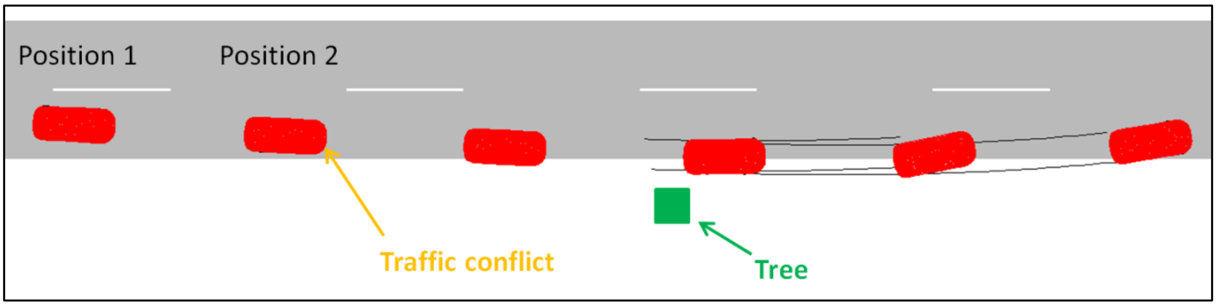


Figure 38 Example with an obstacle next to the road and a steering manoeuvre

Figure 39 shows the two possible cases when running off the lane. In case 1 the vehicle is running off the lane to the right side. In this case the vehicle leaves the road and has the risk of impacts on obstacles next to the road, such as trees, fences or slopes. State roads have a road bank and side stripes outside the regular lane. This is available space which can be used for the steering manoeuvre. On motorways it is easier due to a constant emergency lane on the right side, which is between 2,5m and 3m in Austria [50, 2013]. The only exceptions are construction areas. The potential for such a concept would be the greatest on these streets. The possibility of a vehicle knowing the end of its own lane is already given. The mark of the lane serves as reference line. A camera recognizes the mentioned mark and knows when the vehicle exceeds this border.

In case 2 the vehicle intends to leave the own lane to the left side. The available space for a steering manoeuvre increases due to the oncoming lane. But a conflict appears anyway due to the danger of oncoming traffic on a two lane road (e.g. state road). A problem could occur during an overtaking manoeuvre. A vehicle veers to the opposing lane and goes back into the own lane. During this manoeuvre, the vehicle drives at a steep angle to the lane. The vehicle would think it will leave the road and calculate a high value of the necessary space. This would happen without a traffic conflict taking place. In other words: the system would announce multiple fault alarms. A solution for it can be a limitation of 6° for the angle. This value was also the highest one in the generic accidents. If the value is higher than 6°, the vehicle would not send an alarm. Or it gives just a signal without intervening. A signal could be a vibration of the steering wheel. Such a signal would not confuse the driver.

The idea is that a vehicle recognizes if it is driving into a traffic conflict and warns the driver in an early stage. The influencing parameters are the reaction time of the driver, the road conditions, the current velocity of the vehicle and the angle. It can be possible to detect a conflict before it even appears.

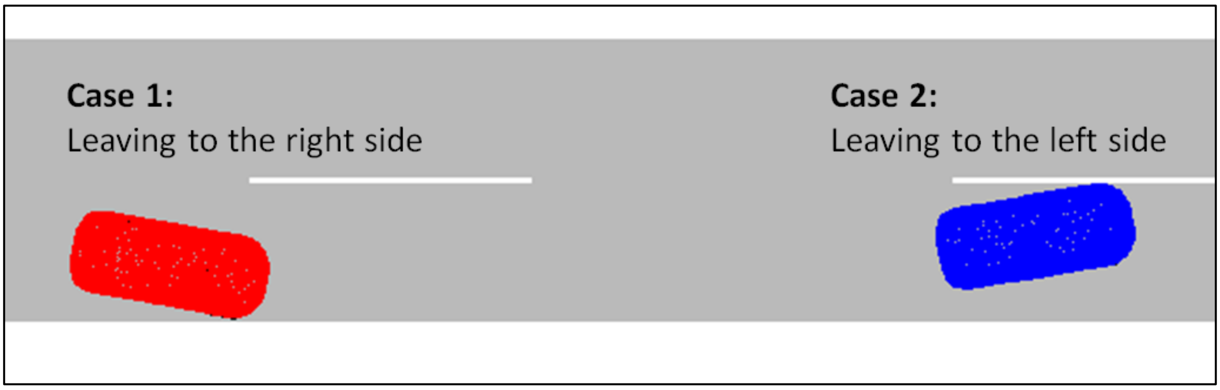


Figure 39 The two cases when running off the road on a straight section

4.4.2 In a bend

These simulations were carried out to determine the critical velocity for different curves and road conditions. This is necessary to point out the position where a traffic conflict can be detected. Figure 40 illustrates a departing accident in a bend due to high velocity. Position 2 is when the vehicle is entering the bend. If the velocity is above the critical velocity, a traffic conflict has already taken place. Therefore position 1 has to be determined in order to detect the conflict early enough. The distance Δs is the space between the detection of the conflict (Position 1) and the entrance of the conflict (Position 2).

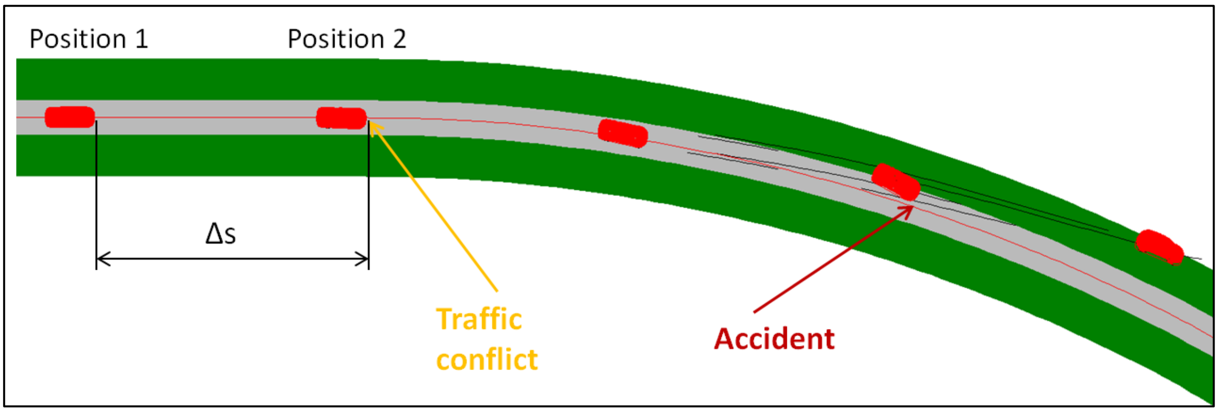


Figure 40 Departing accident due to excessive velocity

After the detection of a traffic conflict it was calculated the distance Δs for different deceleration values. The idea behind this was to point out the position where the driver has to decelerate the vehicle to avoid a conflict. If a car drives at 100 km/h before a bend (e.g. critical velocity of the bend = 90 km/h), the driver could be warned several seconds before the bend starts, to decelerate the car to a maximum velocity which is less than or equal to the critical speed. The conflict has been detected and through an appropriate reaction of the driver an accident has been prevented.

Requirements

The vehicle has to know the exact position and the following courses of the road at each point in time. The accuracy of today´s GPS-receiver is between 2m and 50m. Nevertheless, an accuracy of 2cm is already possible. [3, 2013] [1, 2013] [2, 2013]

4.5 Developing of generic accidents

This chapter deals with the development of generic accidents, based on the data of the simulations from real accidents. The goal of these generic accidents is to find out the critical velocity of a car in a bend and the necessary width for a steering manoeuvre on a straight section. This is necessary to identify the position where a traffic conflict appears. If this position is determined it is possible to avoid this conflict if the driver is capable of reacting in an appropriate way. Reaction in this sense means a deceleration of the velocity or a steering manoeuvre to avoid a conflict and thus a departing accident.

4.5.1 Relevant parameters for the simulations

The most important influencing factors for these simulations are the current friction values of the road, the reaction time of the driver, the available space outside the vehicle´s own lane, the width of the vehicle´s own lane, the tyres, the vehicle data, the current velocity and of course the vehicle angle while leaving the lane.

Friction values

Different friction values were considered during the simulations. Almost 96% of the evaluated real accidents occurred on a road with a friction value between 0.5 and 0.8. The simulations have been constructed with those two values. A value of 0.8 indicates a dry road and a value of 0.5 indicates a wet road due to rain or melted snow.

Reaction time

A reaction time cannot be assumed with a standard value. It differs greatly among individual people. Studies, which were explained in the previous chapter showed that an average reaction time is between 0.8 and one second. But this value is just an indication. It depends on distraction, medical conditions, influence of alcohol, downiness and weather conditions. In the real accidents the reaction time was not known, it can only be assumed.

Available space outside the own lane

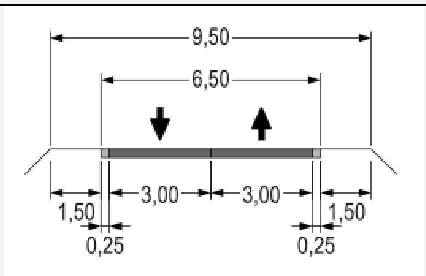
The reason why the available space has an influence is simple. Departing accidents on a straight road were simulated. The driver started an evasive manoeuvre when the vehicle was about to leave the road. A certain space is necessary for this steering manoeuvre. This necessary space has to be bigger than the real space (before an obstacles or a slope).

Width of the own lane

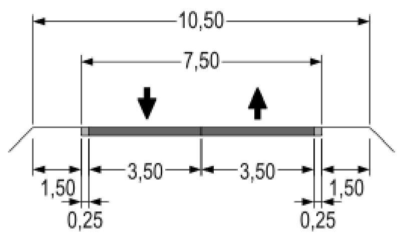
The width of the vehicle´s own lane is also important for the simulations. It makes a difference if a lane has a width of 3 meters or 3.5 meters. If a vehicle is driving through a bend with a high velocity and starts to drift to the outside of a bend than it has more space available. The critical velocity of a wider road is higher than for a narrower road. The same maximum lateral acceleration in both cases is assumed here. Lane widths of 3 meters and

3.5 meters were used during the generic accidents. The construction of three example roads is shown in figure 41. The road RQ 9.5 is mostly used for country roads and federal roads. It has a width of three meters per lane, 0.25 meters side stripes and 1.5 meters road bank. The road RQ 10.5 is mostly used for federal roads and has a lane width of 3.5 meters. The mostly used road type for motorways is the road RQ 29.5. Its lanes are 3.75 meters wide and have a hard shoulder of 2.5 meters. [50]

RQ 9.5



RQ 10.5



RQ 29.5

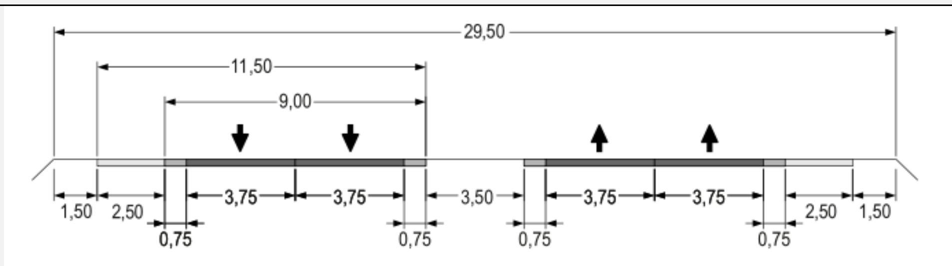


Figure 41 Different road types in Austria and their construction [4, 2013]

Tyres of a car

The tyres of a vehicle also have an influence on the driving and drifting behaviour. A wider tyre has a different behaviour than a narrower one. Figure 42 shows and explains the car tyres which were used during the simulations of the generic accidents. The “R” in “Code for construction of tyres” stands for radial tyres. A “D” would mean “Diagonal Construction”. To point out the load-index, tables are used. The “Speed symbol” indicates the maximum velocity of a tyre. A speed symbol “T”, for example, means a maximum velocity of 190 km/h [15, 2012].

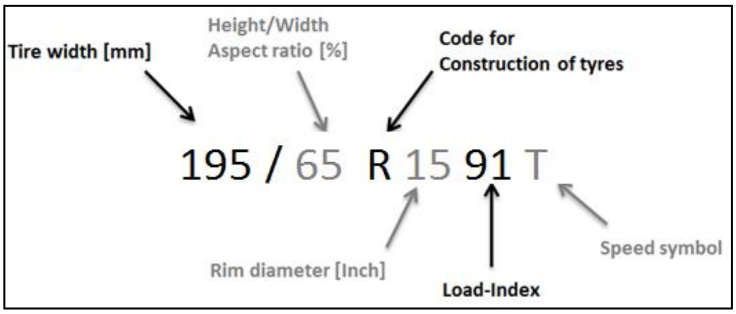


Figure 42 Used car tyres and explanation of the symbols [15, 2012]

Vehicle data

The choice for the vehicle fell on a Volkswagen Golf 1.4 from 2010. The reason for that choice was the fact that the VW Golf was the most popular car in 2010 and 2012 (from autobild.de and oe24.at). Some relevant details about the car are listed in table 2. [8, 2013]

Table 2 Relevant technical details from the VW Golf 1.4

Power	59 kW
Weight	1140 kg
Length	420 cm
Width	178 cm
Height	148 cm
Center of gravity height	50 cm (from the ground)
Distance of center of gravity from front axle	129 cm
Tire model	195/65 R 15 (635mm)
max. suspension travel	10 cm
Maximum lateral slip angle	10°
Drive mode	front-wheel drive
max. steering angle (Wheel)	25°
max. steering angle (Steering)	500°
Track - Axle 1	154 cm
Track - Axle 2	154 cm
Wheelbase 1 - 2	258 cm
ABS	yes
ESP	no
Look ahead duration	0.5 seconds

4.5.2 Simulations on a straight section of a road

The goal of these simulations was to determine the necessary width when a vehicle makes a steering manoeuvre. Figure 43 describes the position of a vehicle when it runs off the road.

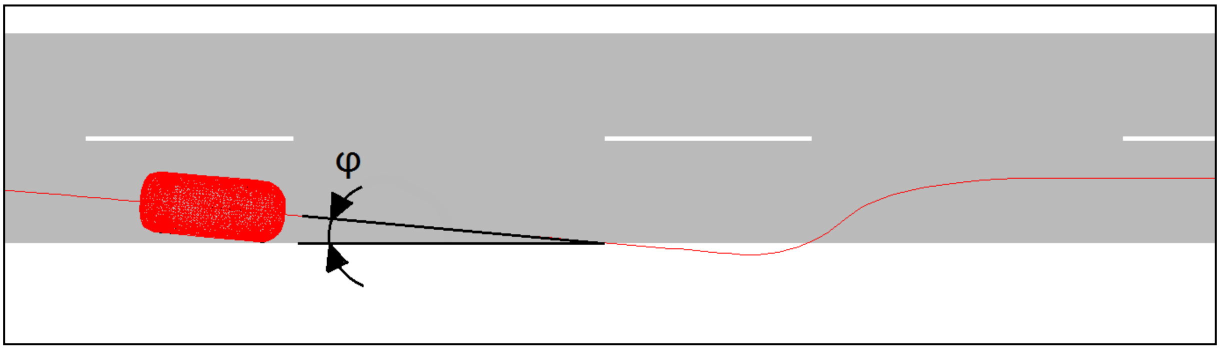


Figure 43 The track taken by the car with a defined angle

A traffic conflict has already taken place if a car has reached this position and the driver is not able to avoid running off the road anymore. A reaction time has to be considered first. The simulations were executed with different variable parameters (table 3).

Table 3 Variation parameters (min. and max.) for the generic simulations

	Minimum	Maximum	Interval
Vehicle angle φ	1°	6°	1°
Velocity	50 km/h	130 km/h	5 km/h
Friction value µ	0.5	0.8	0.3
Reaction time	0.1 sec	2 sec	0.1 sec

Figures 44-45 show an example of the simulations and different positions of the vehicle during the steering manoeuvre from different points of views.

Position 1

Starting position. The driver recognizes that a steering manoeuvre has to be carried out in order to avoid a running off the road. This is the position where a driver tries to react immediately. It now depends on the reaction time (RT) how long it takes to arrive at position 2.

Position 2

The reaction time is over now. This position is the starting point of the steering manoeuvre. It is possible to determine the exact position when the vehicle starts to steer in PC-Crash.

Position 3

The vehicle is in the middle of the steering manoeuvre. It has now achieved the outermost point which is important for the necessary width. The width was measured between the outermost point of the vehicle (position 3) and position 1.

Position 4

The steering manoeuvre is over now and the vehicle has driven back to the own lane.

Position 5

End position of the simulation

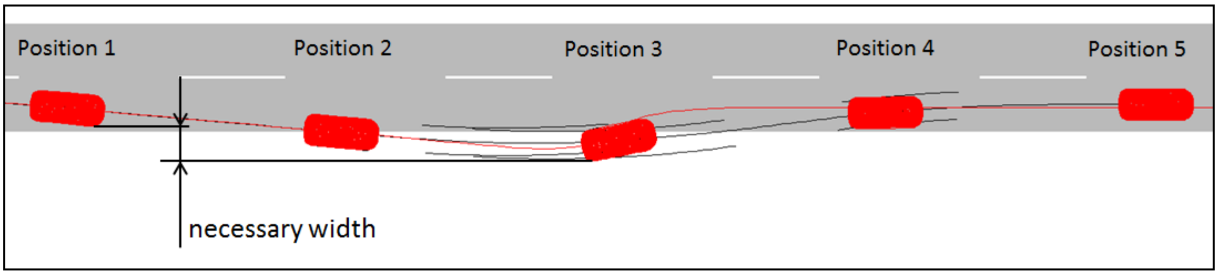


Figure 44 Example for a steering manoeuvre at 70 km/h (μ=0.5; φ=5°; RT=0.8 sec) and the necessary width

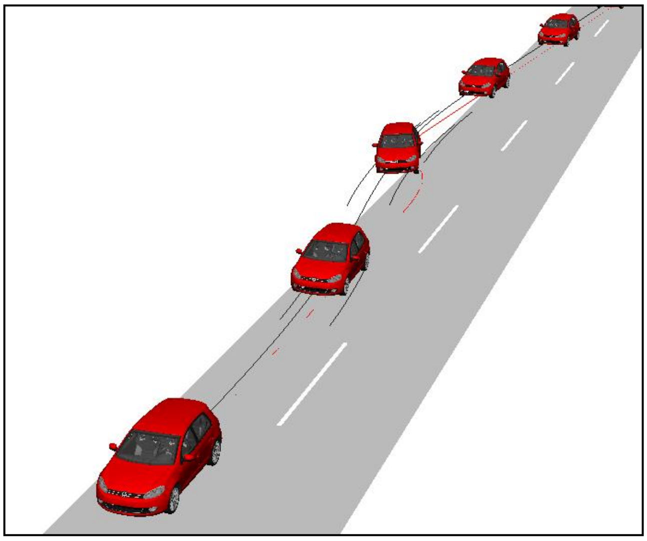


Figure 45 Example for a steering manoeuvre at 70 km/h (μ=0.5; Reaction time=0.8 sec)

Steering angle

An important question was the realistic behaviour of the evasive manoeuvre of the vehicle. It is important to know if a driver is able to perform such a steering manoeuvre. For that reason it the steering angle of the vehicle during this manoeuvre was examined. An example of the steering angle characteristics is shown in figure 46 (70 km/h; φ=5°, µ=0.5). On the abscissa is the time and on the ordinate is the steering angle. A positive value of the angle means a steering to the left and a negative value means a steering to the right. The abbreviations LF stands for “left front wheel” (red) and RF for “right front wheel” (blue). The diagram shows that the steering manoeuver (Position 2) starts after 4.5 seconds of the simulation start and reaches a maximum value of 14.5 degrees for LF and 12.8 degrees for RF. When both front wheels reached a value of zero degrees again, the steering manoeuvre was over (Position 4). Volkswagen equipped their new Golf and Polo with a steering ratio of 14,1 [Sportauto.de, 43, 2013]. A steering angle of 14.5 degrees for the wheel means in this case, that the driver has to turn the steering wheel at an angle of 204 degrees. According to VDA a driver is indeed able to turn the steering wheel for 204° within a short time. The Automotive Industry Association (VDA) made an obstacle avoidance test, where a driver has to take a steering manoeuvre due to a sudden appearance of an obstacle on the road. They reached a maximum steering wheel rotation value of 220° [51, 2013].

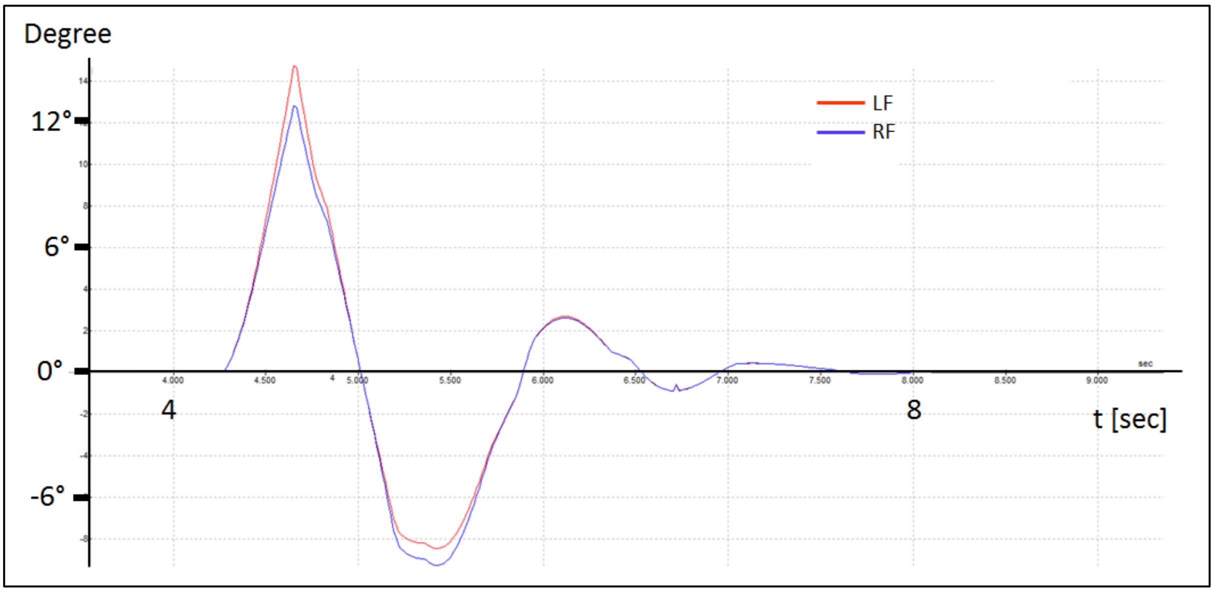


Figure 46 Characteristics of the steering angle at a velocity of 70 km/h and a vehicle angle of 5° (µ=0.5)

4.5.3 Simulations in a bend

These simulations were carried out to determine the critical velocity for different curves and friction values. The idea behind this was to identify the position where the driver comes into a traffic conflict. If the conflict is detected it can be avoided by decelerating the vehicle before the car enters the bend. If, for example, a car drives at 100 km/h and a curve is coming (e.g. critical velocity of the curve = 90 km/h), the driver could be warned through an acoustic or visual signal. The driver could start with an appropriate reaction and decelerate the car to a maximum velocity which is less than or equal to the critical speed. This would avoid running off the lane and thus also avoid a traffic conflict.

Other causes for traffic conflicts in a bend could be distraction, micro sleep, road conditions or animals on the road. But the most common known cause is excessive speed. It was the cause in almost 24% of all real accidents which were examined. Considering that in 55% of the accidents the causation is not known, excessive speed has the second highest share of causation in real accidents.

Theoretical critical velocity in a bend

The theoretical velocity before the vehicle started to skid was calculated. The radius of the curve and the friction value were considered for the calculation. This gives a direct comparison between theory and the real values in "PC-Crash". For this calculation, the vehicle is considered as a mass point (Figure 47-48).

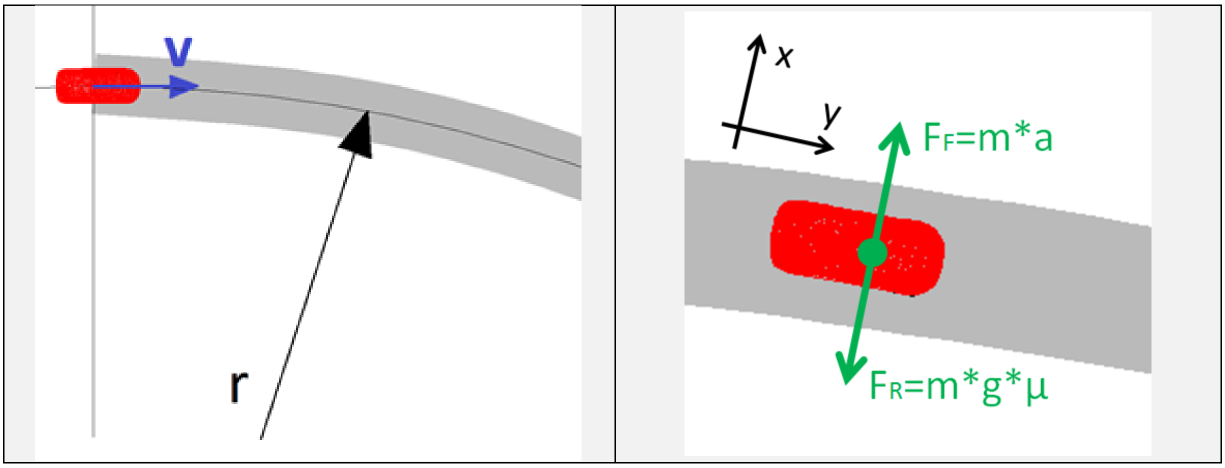


Figure 47 Course of the vehicle, radius of the bend, centrifugal force and friction force

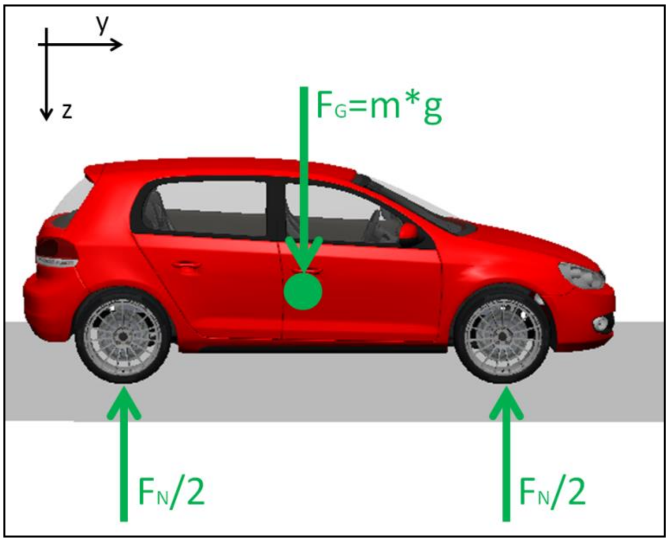


Figure 48 Normal force and weight force

$$F_G = m * g$$

Formula 2 Weight Force

F_G .... Weight Force [N]

m .... Mass [kg]

g .... Gravitation [m/s^2]

$$F_N = F_G = m * g$$

Formula 3 Normal Force

F_N .... Normal Force [N]

$$F_R = F_N * \mu = m * g * \mu$$

Formula 4 Friction Force

F_R .... Friction Force [N]

µ .... Friction Value

$$F_F = m * a$$

Formula 5 Centrifugal Force

F_F …. Centrifugal Force [N]

a …. Radial Acceleration [m/s^2]

$$v = r * \omega$$

Formula 6 Velocity

v …. Velocity [m/s]

r …. Radius [m]

ω …. Angular Velocity [s^{-1}]

$$a = r * \omega^2$$

Formula 7 Radial Acceleration

$$\sum F_x = 0$$

$$m * a = m * g * \mu$$

$$a = g * \mu$$

Formula 8 Acceleration/Deceleration depending on friction value

$$r * \omega^2 = g * \mu$$

$$r * \frac{v^2}{r^2} = g * \mu$$

$$\frac{v^2}{r} = g * \mu$$

$$\rightarrow v = \sqrt{r * g * \mu}$$

Formula 9 Critical velocity depending on radius and friction value

The critical velocity v is the speed limit when the vehicle reaches its highest lateral acceleration. If this value is exceeded, the vehicle will start to skid. It does not mean that the vehicle can be driven at this velocity without leaving its own lane. The vehicle can leave its own lane without reaching the maximum deceleration of 4.91 m/s^2 for a friction value of 0.5

and 7.85 m/s^2 for a friction value of 0.8 (see formula 7). The results for the mentioned speed limits for different friction values are shown in figure 49.

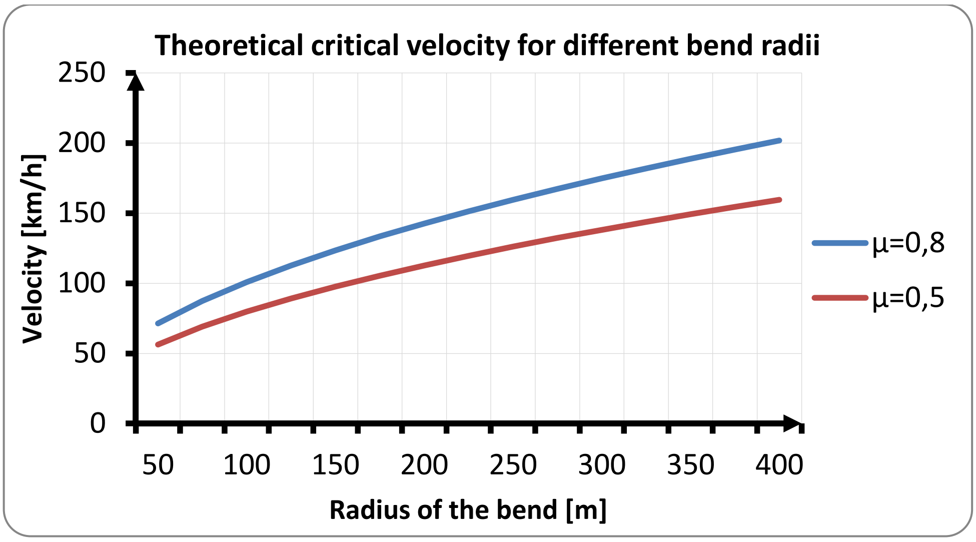


Figure 49 Speed limit for different friction values depending on the radius

The two different functions in figure 49 can be seen as a theoretical limit before reaching a maximum lateral acceleration. If the vehicle drives above those boundary lines, it will start to skid. Considering the speed limit for country roads in Austria (100 km/h), the critical curve radius (before skidding) for a friction value of 0.5 would be 157.3 meters (μ=0.5) and 98.3 meters (μ=0.8).

Relevant parameters and execution of the simulations in a bend

The goal of the simulations was to determine the critical velocity of a bend with a certain radius under realistic conditions. Realistic conditions in this context mean that an average driver will not be able to use the whole friction value. This means that the theoretical velocity will not be reached. An average driver will run off the lane with a lower velocity. The reason therefore is the lateral acceleration. Theoretically it is possible to drive through a bend with a lateral acceleration of 7.85 m/s^2 (μ=0.8). But in reality a driver is not capable to reach such a value. Inexperience of such extreme situations is the reason for this.

Figure 50 illustrates a running off the lane to the right side (vehicle 1) and a running off the lane to the left side (vehicle 2). The critical velocities for running off the road in both cases were determined. Vehicle 1 could have an accident because it is running off the road and a slope or a tree could lead to a dangerous situation. Vehicle 2 could have an accident because it´s leaving its own lane and drifting to the oncoming lane. Oncoming traffic could cause a dangerous situation.

The environment on the outside of the road was simulated as an even surface. There was no correlation between the slope angles or height of the real accidents.

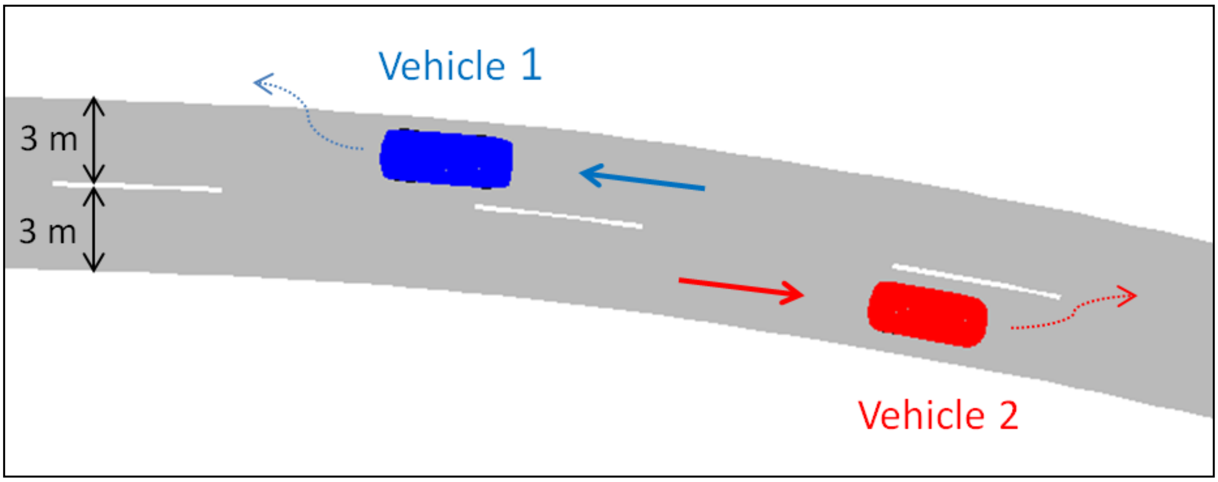


Figure 50 Running of the lane to the right side (Vehicle 1) and running off the lane to the left side (Vehicle 2)

PC-Crash´s linear tyre model was used. This model assumes that the horizontal tyre force is independent of the moving direction of the tyre. The tyre lateral forces depend on the lateral slip angle. PC-Crash assumes a linear increase of the lateral tyre forces in the region where the lateral slip angle is less than the maximum slip angle. That means this model does not use the whole capacity of a vehicle while driving through a bend. This represents the behaviour of an average driver very well.

A second tyre model is called TM-Easy model. It allows non-linear tyre effects to be modelled. A comparison between those two models showed a difference in the behaviour of the vehicle. With the TM-Easy model the critical velocities were significantly higher. But it also had a significantly higher lateral acceleration during the steering process. These values were not realistic. For that reason the linear model was used for the simulations.

The fuzzy-model was used as a kinetic path steering model. It is a rule-based model which uses the distance between follow point and point on the follow path and difference between path slope angle and vehicle heading angle as its two inputs. A set of rules define the steering angle and those rules are calculated in each integration step. The results of all rules combined lead to the actual steering angle. The simulations in a bend were executed with different variation parameters (table 4).

Table 4 Variation parameters and their interval

	Minimum	Maximum	Interval
Radius of the bend	100 m	400 m	25 m
Velocity	50 km/h	130 km/h	5 km/h
Friction value µ	0.5	0.8	0.3
Width of the road	3 m	3.5 m	0.5 m

Figures 51-52 show an example of the simulations in a bend. The grey stripe illustrates a lane with a width of 3 meters. If the vehicle passes over the edge of the lane, an accident can occur if another vehicle is coming in the oncoming lane. Therefore the point where the vehicle crossed the border was captured and the velocity was measured.

Position 1

Starting position. The vehicle is intended to enter into the bend.

Position 2

Starting of the steering process. The vehicle starts to steer and tries to follow the course of the road after a straight incoming section.

Position 3

The outermost point of the vehicle is intended to cross the edge of the lane. This is the critical velocity which was searched for. The outermost part of the vehicle could drift to the oncoming lane and could cause a dangerous situation.

Position 4

It is obvious to see that the vehicle has crossed the edge of its own lane and is now drifting on the oncoming lane. A conflict exists already and a crash could occur if other vehicles are on the oncoming lane.

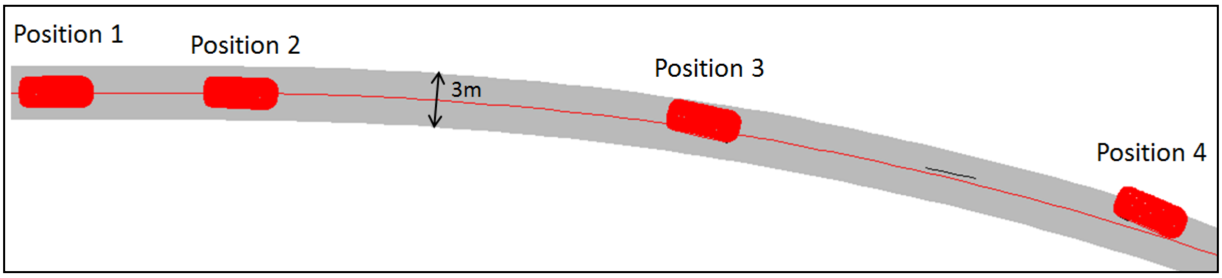


Figure 51 Example for a departing scenario in a bend (r=175m v=120 km/h µ=0.8)

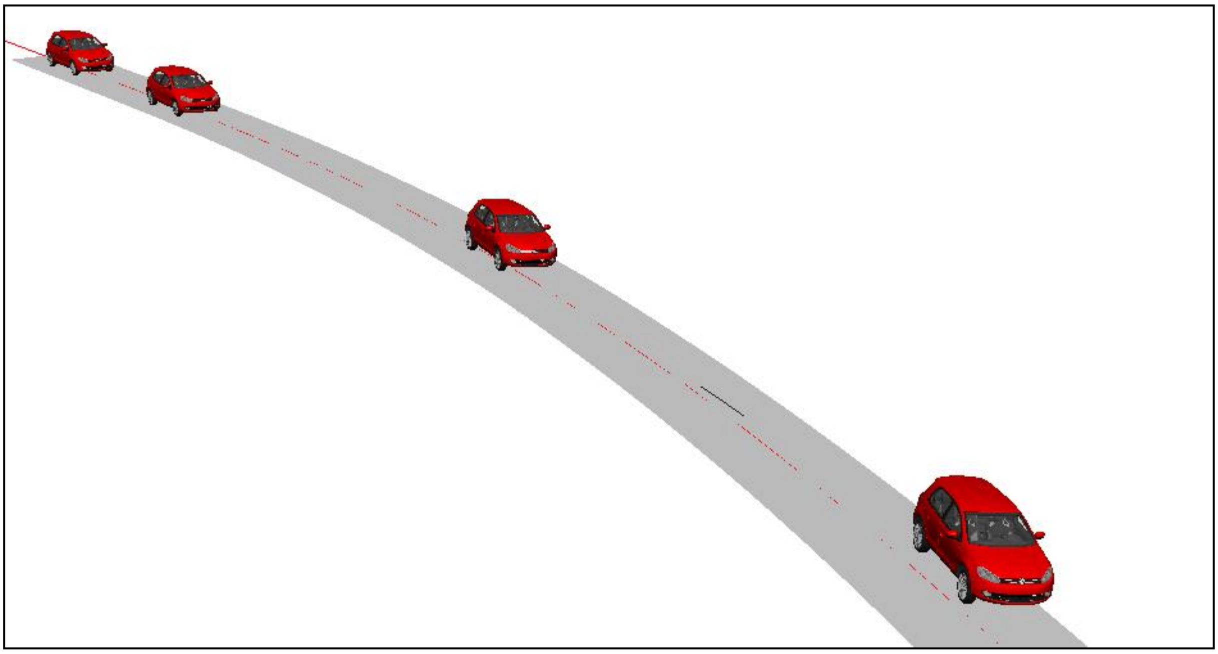


Figure 52 Example for a critical departing scenario in a bend (r=175m v=120 km/h µ=0.8)

Distance for deceleration before entering in a bend

In order to warn the driver early enough, a calculation regarding the minimum distance for a deceleration was made. Position C indicates the beginning of the bend (figure 53). The goal of these calculations was to point out the necessary distance to decelerate a vehicle from a velocity $v(t_0)$ to a velocity $v(t_1)$. Knowing the critical speed of the bend a driver could be warned if the vehicle is above the mentioned critical velocity.

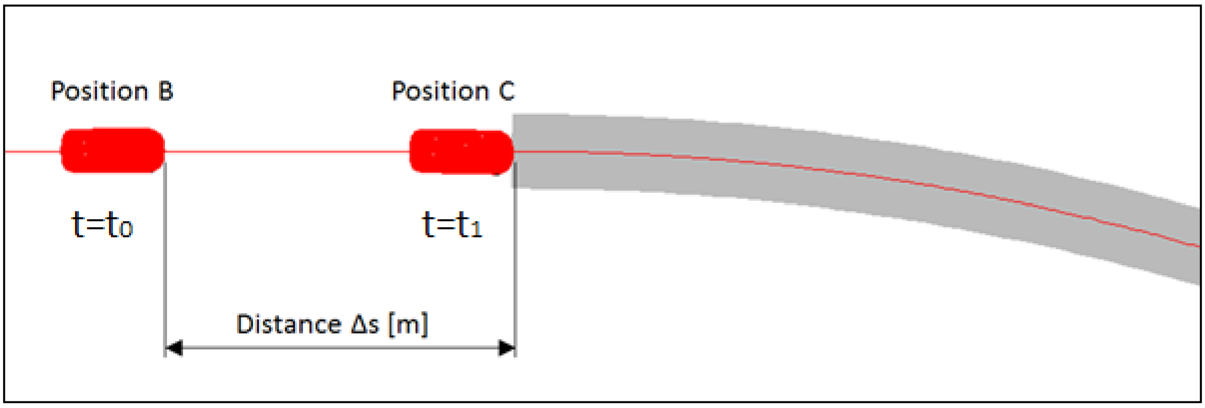


Figure 53 Description of the calculated distance Δs

In formula 10-13, each step of the calculation is shown and explained.

$$a = \frac{\Delta v}{\Delta t} = \frac{v(t_1) - v(t_0)}{t_1 - t_0}$$

Formula 10 Acceleration/Deceleration

$v(t_0)$ …. Starting velocity (Position B)

$v(t_1)$ …. End velocity (Position C). Should not exceed critical speed

t_0 …. Time Start Position (Position B) → is set to zero!

t_1 …. Time when entering the beginning of the bend (Position C)

$$\rightarrow \Delta t = t_1 = \frac{v(t_1) - v(t_0)}{a}$$

Formula 11 Difference of time

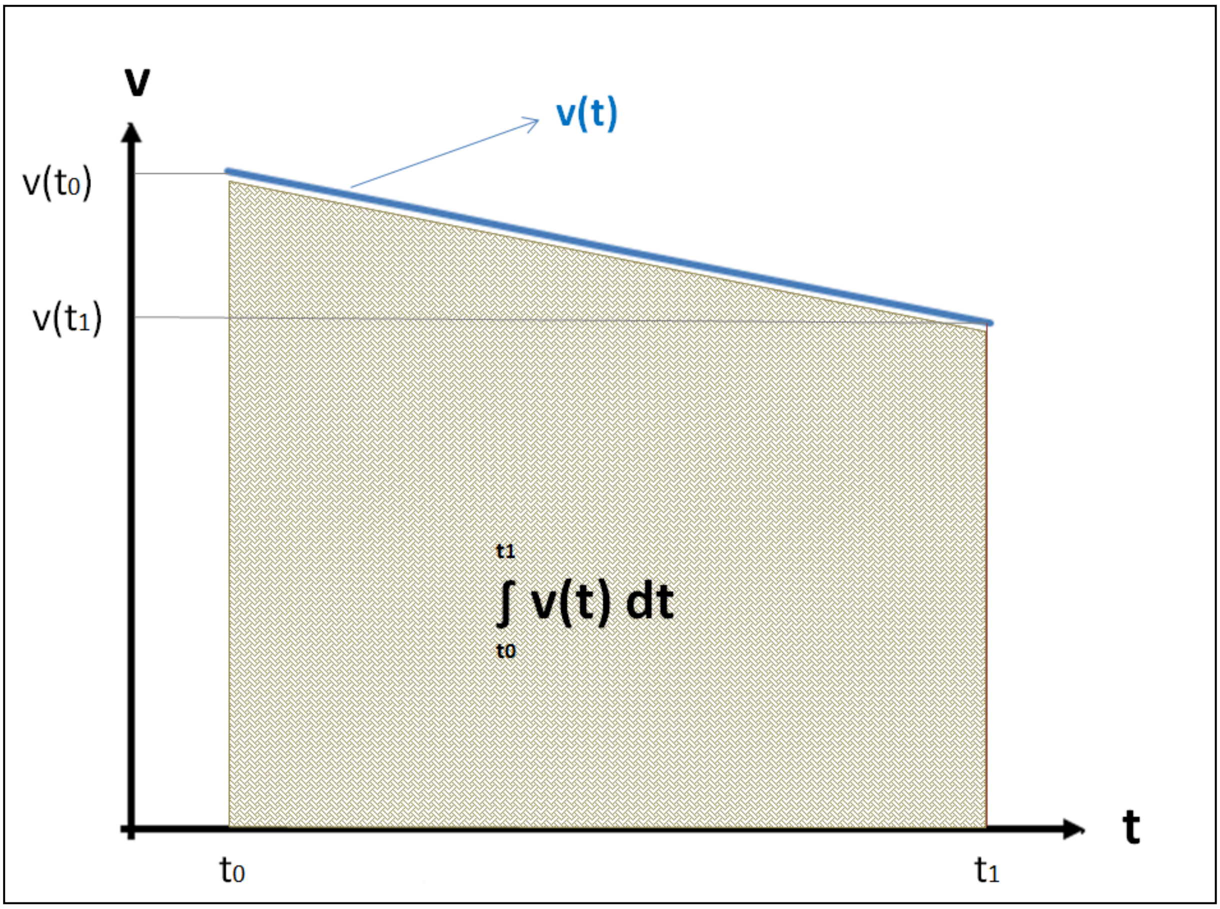


Figure 54 Velocity function and surface of it (Integral of velocity function = calculated distance)

The integral of the velocity v (depending on moment in time t) leads to a surface, which is equal to the distance Δs (figure 54 and formula 12).

$$\Delta s = s_1 - s_0 = \int_{t_0}^{t_1} v(t)dt$$

Formula 12 Distance

Due to the linearity of the velocity-function v(t), the distance Δs can also be calculated in a different way, which is shown in formula 13.

$$\Delta s = \frac{v(t_0) - v(t_1)}{2} * (t_1 - t_0)$$

Formula 13 Distance

5 RESULTS AND DISCUSSION

5.1 Simulation results of the real single vehicle accidents

Real accidents were reconstructed and simulated. On the next pages the simulation results and the determination of different parameters can be seen.

5.1.1 Causations for the accidents

The causation for an accident is important for the detection of a traffic conflict. It is necessary to determine the causation in order to understand why a conflict and thus an accident even occurred. An appropriate approach for a solution can only be found if the causes of different accidents are determined. To determine the cause of an accident is the task of a surveyor. Due to different marks (skidding or braking marks), witness statement and experience of a surveyor it is possible to give an overview of the accident occurrence and the causation.

During the examined accidents the following causations were determined by the responsible surveyor:

- **Not known:** the causation of 43 accidents is not known (more than 55%)
- **Excessive speed:** 18 accidents were caused due to excessive speed.
- **Influence of alcohol:** in 5 cases the driver had an alcohol value of more than 0.05% BAC (Blood Alcohol Concentration).
- **Icy road:** the road conditions during 3 accidents were icy.
- **Animal on the road:** 3 accidents occurred due to an animal on the road. An animal was suddenly on the road and the driver steered the vehicle off the road.
- **Healthy reasons:** the cause of 1 accident was an apoplexy of the driver.
- **Aquaplaning:** 1 accident occurred due to aquaplaning.
- **Distraction of attention:** in 1 accident the driver was distracted by the children on the backseat
- **Suicide:** there was 1 accident examined where the driver left a suicide note

To determine a distraction as causation for an accident can be difficult. In almost 62% of the examined accidents the drivers were alone in the car and were fatally injured. There are no witnesses from the inside of the vehicles who can say if the driver was distracted or not. Another cause which is very difficult to prove is micro sleep. Figure 55 shows the number of passengers in a vehicle during an accident. If there are more people in a vehicle, there is a possibility of having an intensive discussion and therefore of creating a distraction.

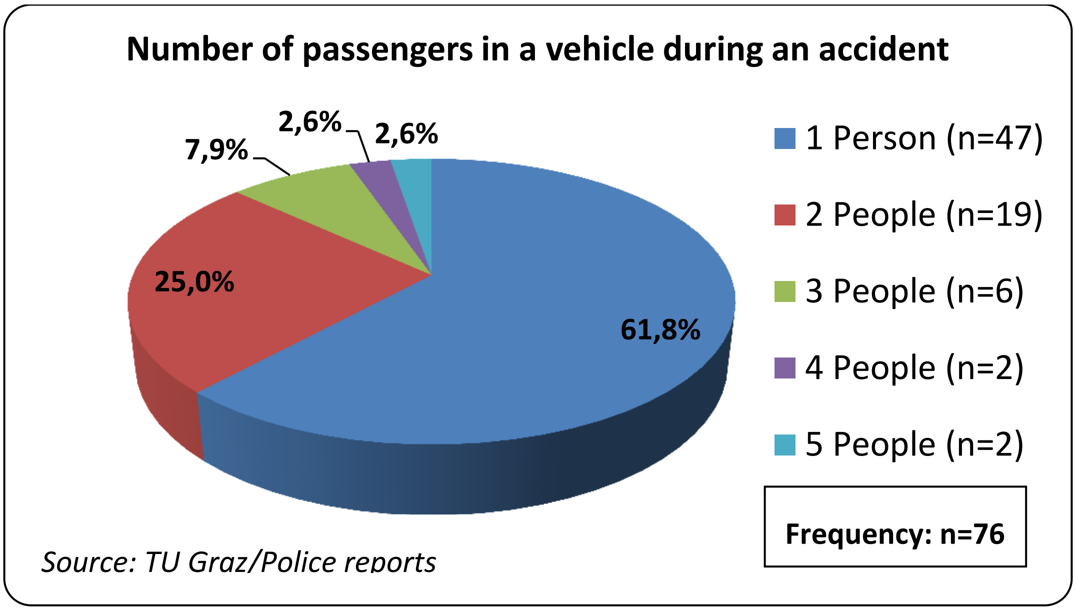


Figure 55 Percentage of involved passengers in a vehicle during an accident

5.1.2 Radii of the bends

The different radii of the bends, where the vehicles left the road were pointed out. Figure 56 illustrates that the majority (23.1%) of these 52 accidents (52 of the 76 accidents appeared in a curve) happened within a curve of a radius between 200 meters and 300 meters. The radius with the second highest value was between 100 meters and 200 meters (19.2%).

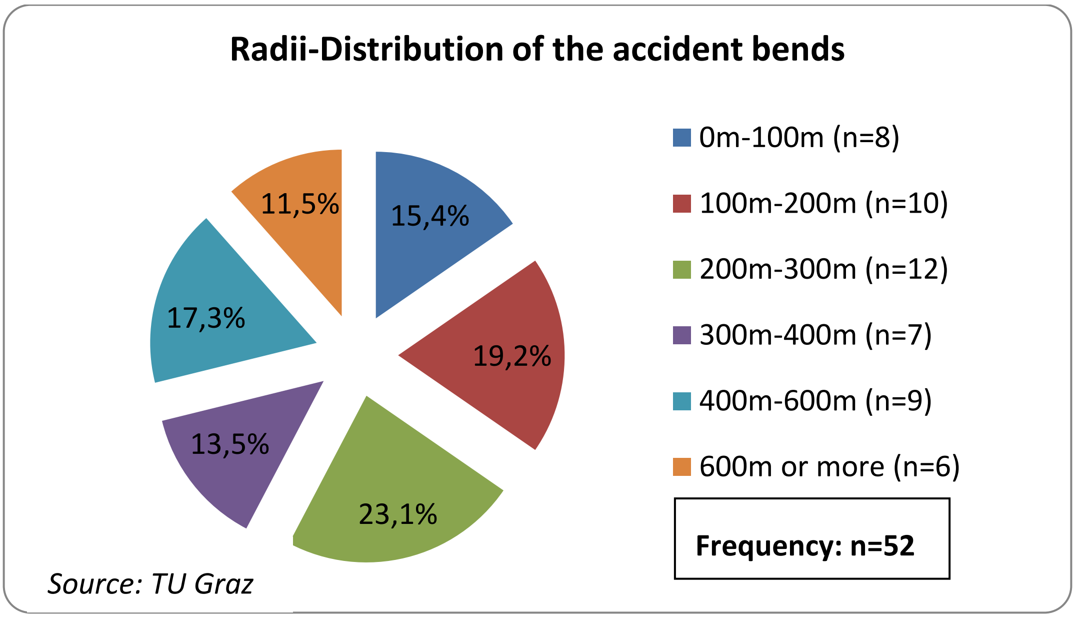


Figure 56 Radii-Distribution of the different bends where the accident occurred

5.1.3 Vehicle angle when leaving the road

Definition of the angles and restrictions

The vehicle angles φ when the car leaves the road were determined. Point A is defined as the outermost point of the vehicle. The vehicle angle for a straight section of a road was determined (position 2) in the moment when point A exceeds the road (figure 57-58).

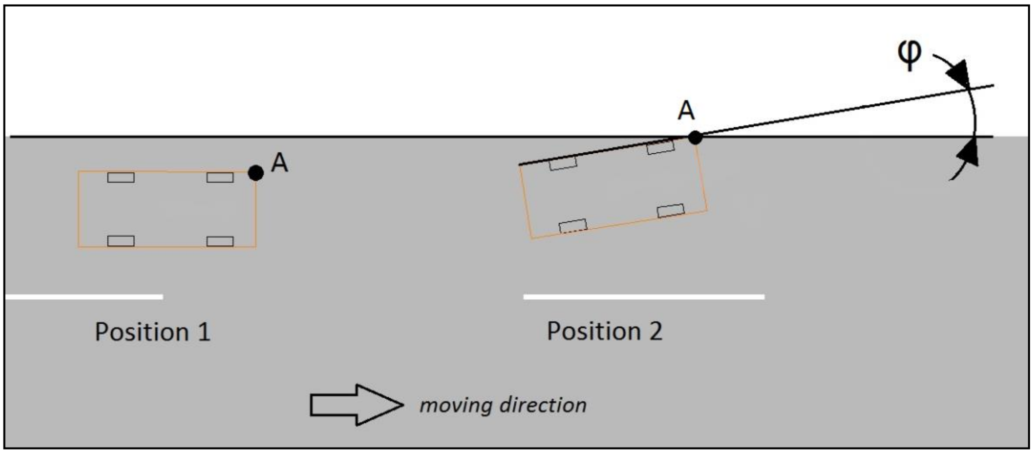


Figure 57 Vehicle angle φ when leaving the road on a straight section to the left side

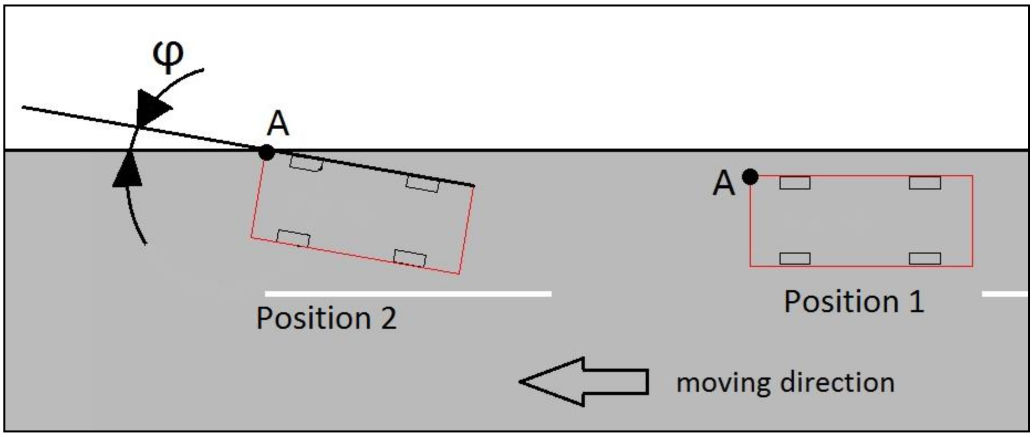


Figure 58 Vehicle angle φ when leaving the road on a straight section to the right side

Simulations in a bend were evaluated as well regarding the vehicle angle. The definitions of the angles are described in figure 59-60. The angle between the tangent and the vehicle was measured (position 2 and position 3).

One limitation of the results was that in almost 40% of the reconstructed accidents the vehicle started to skid before it left the road and these angles could not be evaluated. If a car is already skidding on the road it is reasonable to evaluate these vehicle angles. Accidents departing to the right side of a left-hand curve had the highest share of skidding vehicles (34.5%). Accidents departing to the left side of a left-hand curve had the second highest share (24.1%). Almost 60% of the skidding accidents occurred in a left-hand bend. The following results are valid for accidents without skidding before leaving the road.

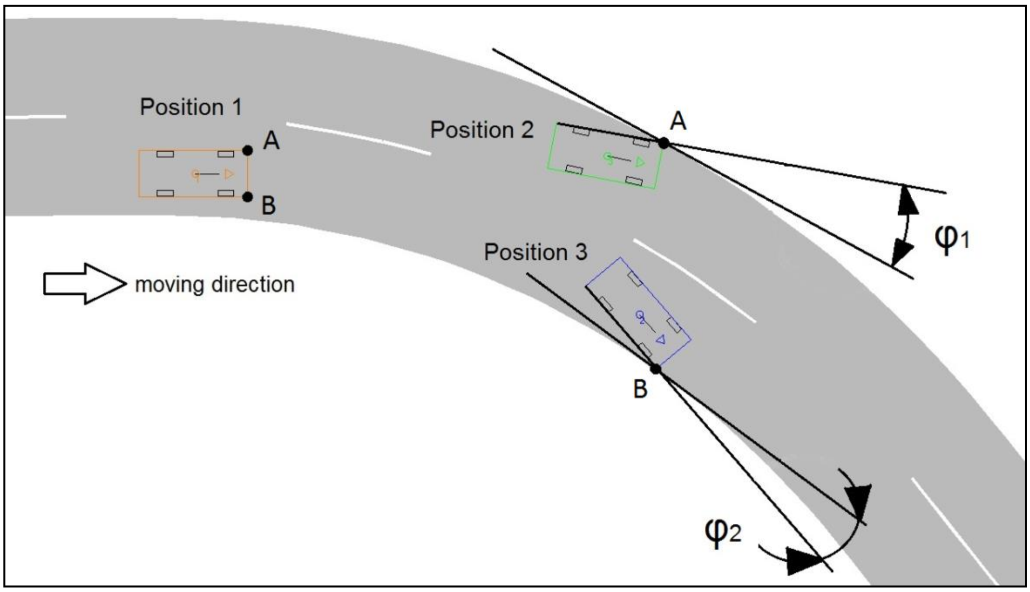


Figure 59 Vehicle angle φ when leaving the road right-hand bend

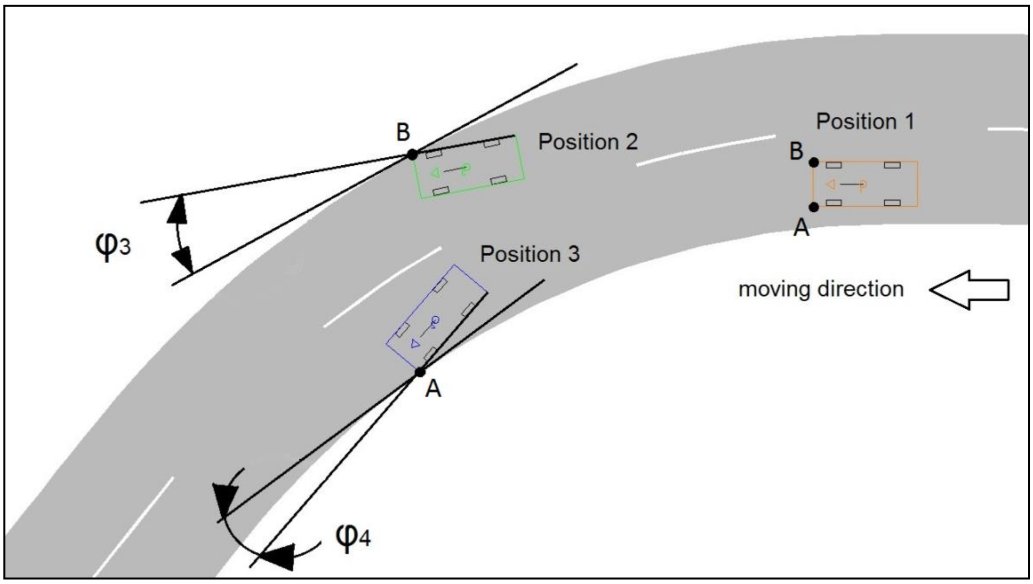


Figure 60 Vehicle angle φ when leaving the road left-hand bend

Vehicle angles for departing accidents on a straight section of a road

Apart from the angles, the velocities of the vehicle in the moment when the car leaves the road were also determined. The mean variation of the vehicle angles related to the velocity is high (figure 61). Due to this high variation a clear statement cannot be made (table 5). The variation is too high to see a tendency of the most frequented angles. Neither for the velocity nor for the vehicle angle on a straight section.

Figure 61 shows that a departing accident to the left side of the road has higher vehicle angle than accidents which occurred on the right side. An obvious explanation for this phenomenon cannot be found.

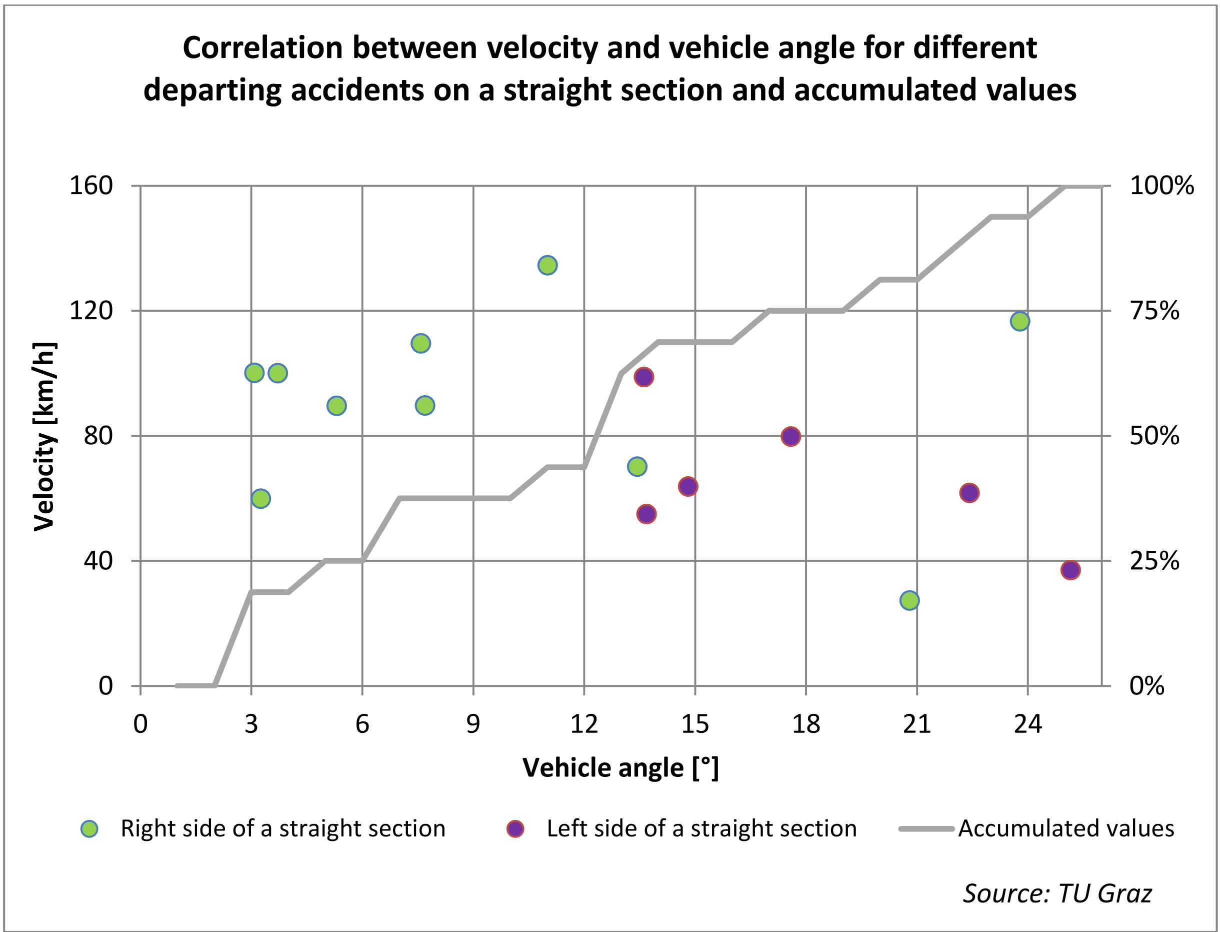


Figure 61 Correlation between velocity and vehicle angle for different departing accidents on a straight section and accumulated values

The maximum velocity had a value of over 135 km/h and the lowest value was below 30 km/h. These values demonstrate that a fatality does not necessarily mean a high velocity. An accident can also be fatal if the speed of a car is quite low. This is also valid for departing accidents in a bend, which are discussed during the next chapter.

Table 5 Arithmetic values and standard deviations of the velocity and the vehicle angle on a straight section

	Arithmetic value of the velocity	Standard deviation of the velocity	Arithmetic value of the angle	Standard deviation of the vehicle angle
Departing accidents on a straight section	80.8 km/h	29,3 km/h	12,9 °	7.5 °

Vehicle angles for departing accidents in a bend

Also for departing accidents in a bend a clear tendency of the most frequented angles depending on the velocity cannot be seen (table 6 and figure 62).

Table 6 Arithmetic values and standard deviations of the velocity and the vehicle angle in a bend

	Arithmetic value of the velocity	Standard deviation of the velocity	Arithmetic value of the angle	Standard deviation of the vehicle angle
Departing accidents in a bend	88.4 km/h	21.8 km/h	9.5 °	6.7 °

More than 50% of these values have a vehicle angle above 8°. The smallest values regarding vehicle angle and the highest value regarding velocity have accidents where the vehicle left the road to the right side of a left-hand bend.

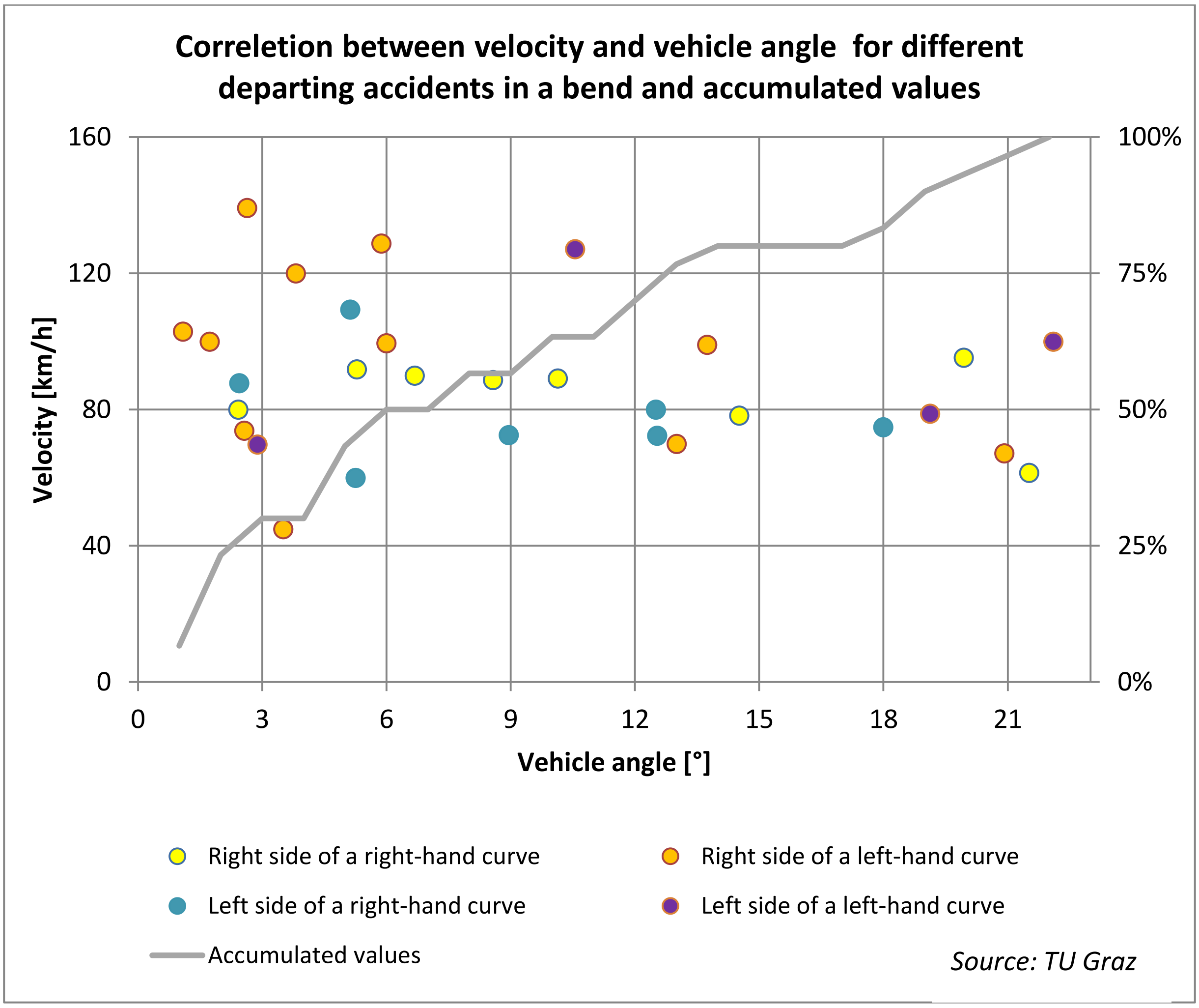


Figure 62 Correlation between velocity and vehicle angle for different departing accidents in a bend

5.1.4 Velocity when leaving the road

Velocity for departing accidents in a bend

Here can be seen a tendency when comparing velocity and radius of the bend where the accident occurred. Over 43% of all accidents happened in a bend with a radius of less than 200 meters. Almost 67% of the accidents occurred in a curve with a radius of less than 400 meters. The distribution of all different departing accidents in a bend is illustrated in figure 63. Accidents in a radius of over 600 meters happened only four times.

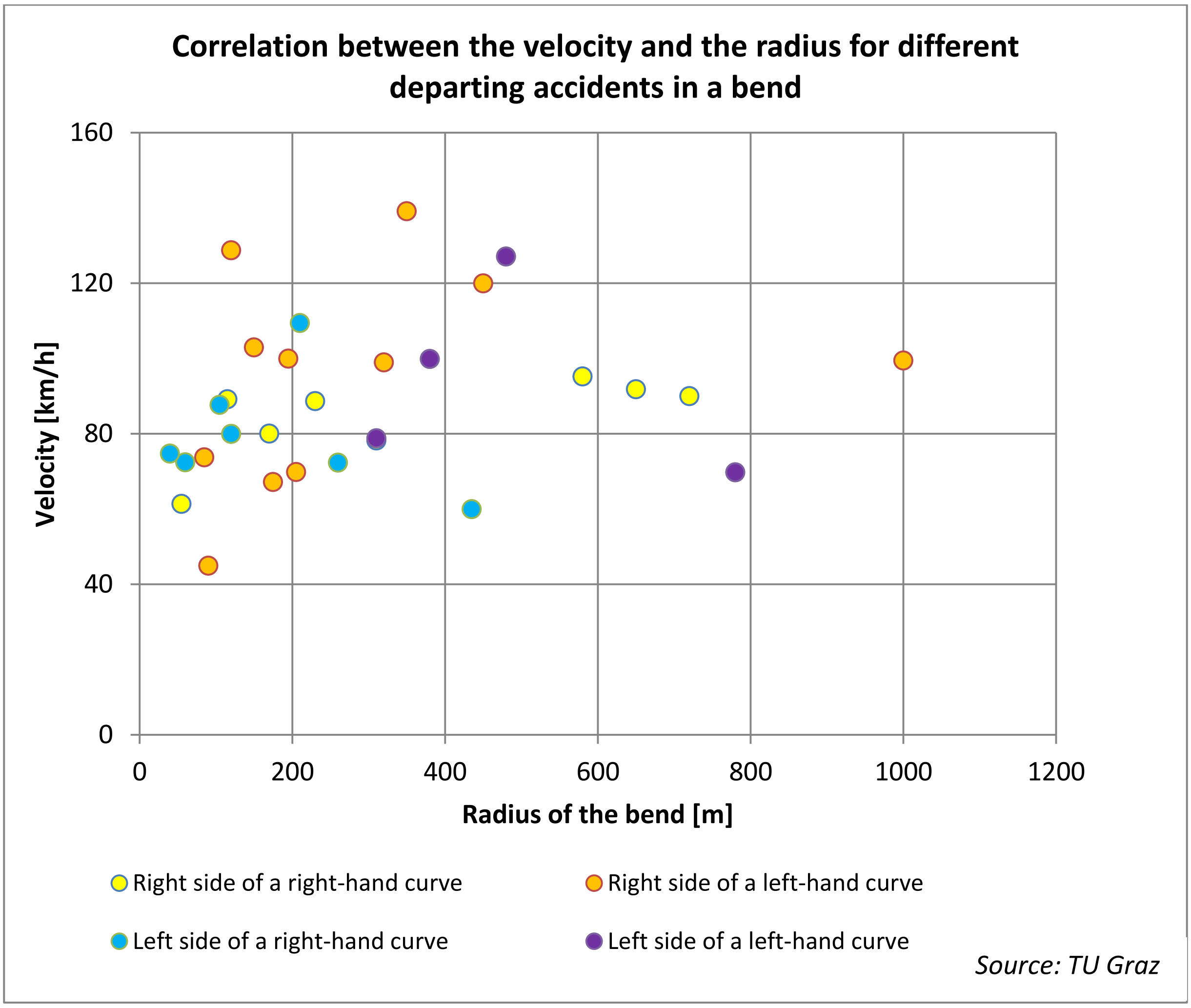


Figure 63 Correlation between the velocity and the radius for different departing accidents in a bend

Comparison of the velocity in a bend and on a straight road

Most of the accidents occurred at a velocity between 70 km/h and 80 km/h. That velocity led to 8 accidents in a bend and 2 accidents on a straight section of a road (figure 64). The second highest amount occurred at a velocity between 90 km/h and 100 km/h. Almost 22% of these accidents happened at a velocity higher than 100 km/h. The velocity was measured in the moment when the outermost point of the vehicle left the road.

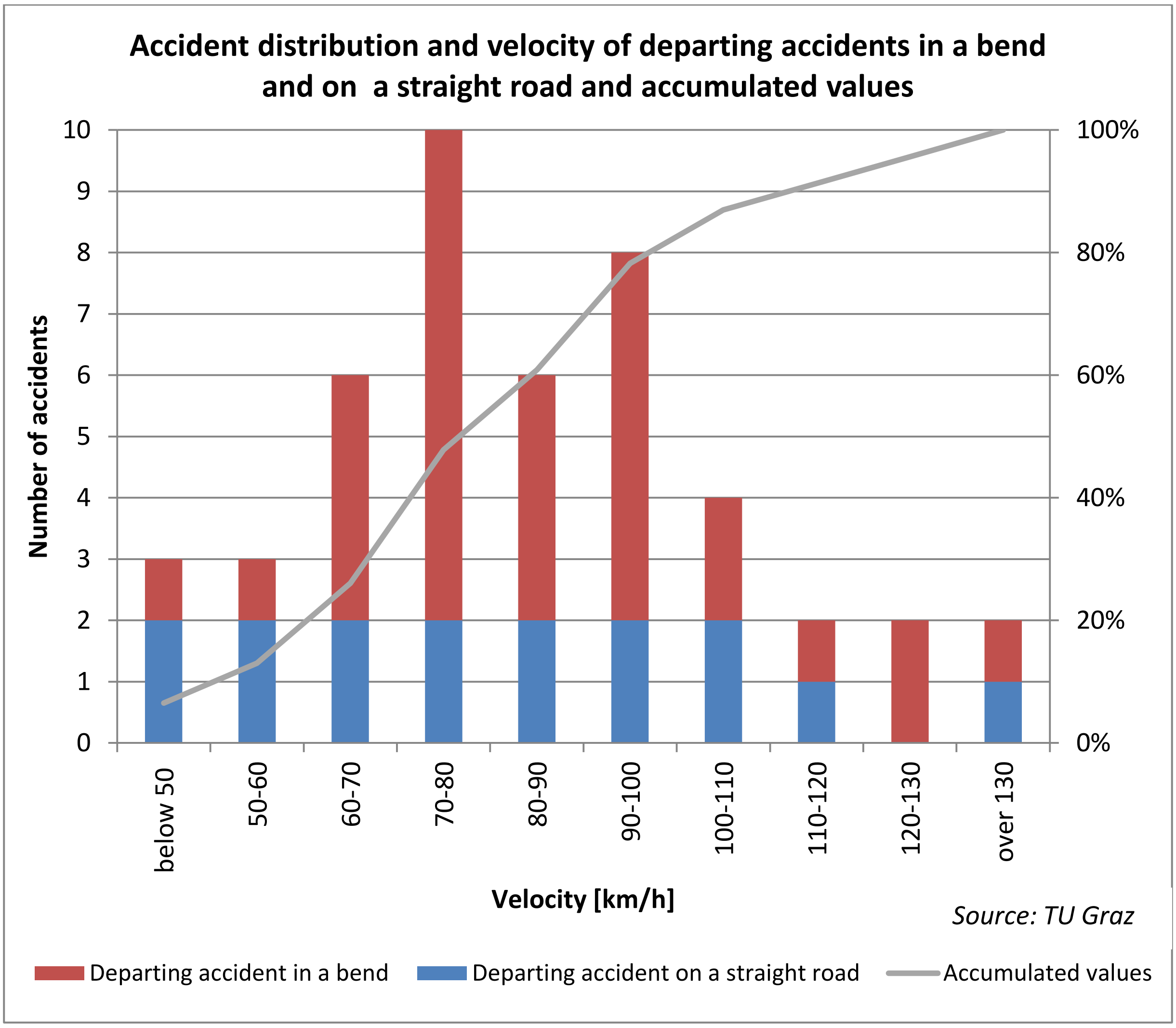


Figure 64 Accident distribution and velocity of departing accidents in a bend and on a straight road

Comparison and correlation of the velocity and the friction value

The friction values for the simulation were evaluated. A comparison between the friction values and the velocity was carried out (figure 65). It is noticeable that the lowest friction value (μ=0.3) only occurred at a speed between 50 km/h and 70 km/h. This comes from the fact that this value means a very wet or snowy road and driver drives slower than during dry conditions.

Almost 74% of all real accidents occurred on a road with a friction value of 0.8. This value is used for dry conditions. In the figure can be seen that the highest velocities were reached by accidents with a friction value of 0.8.

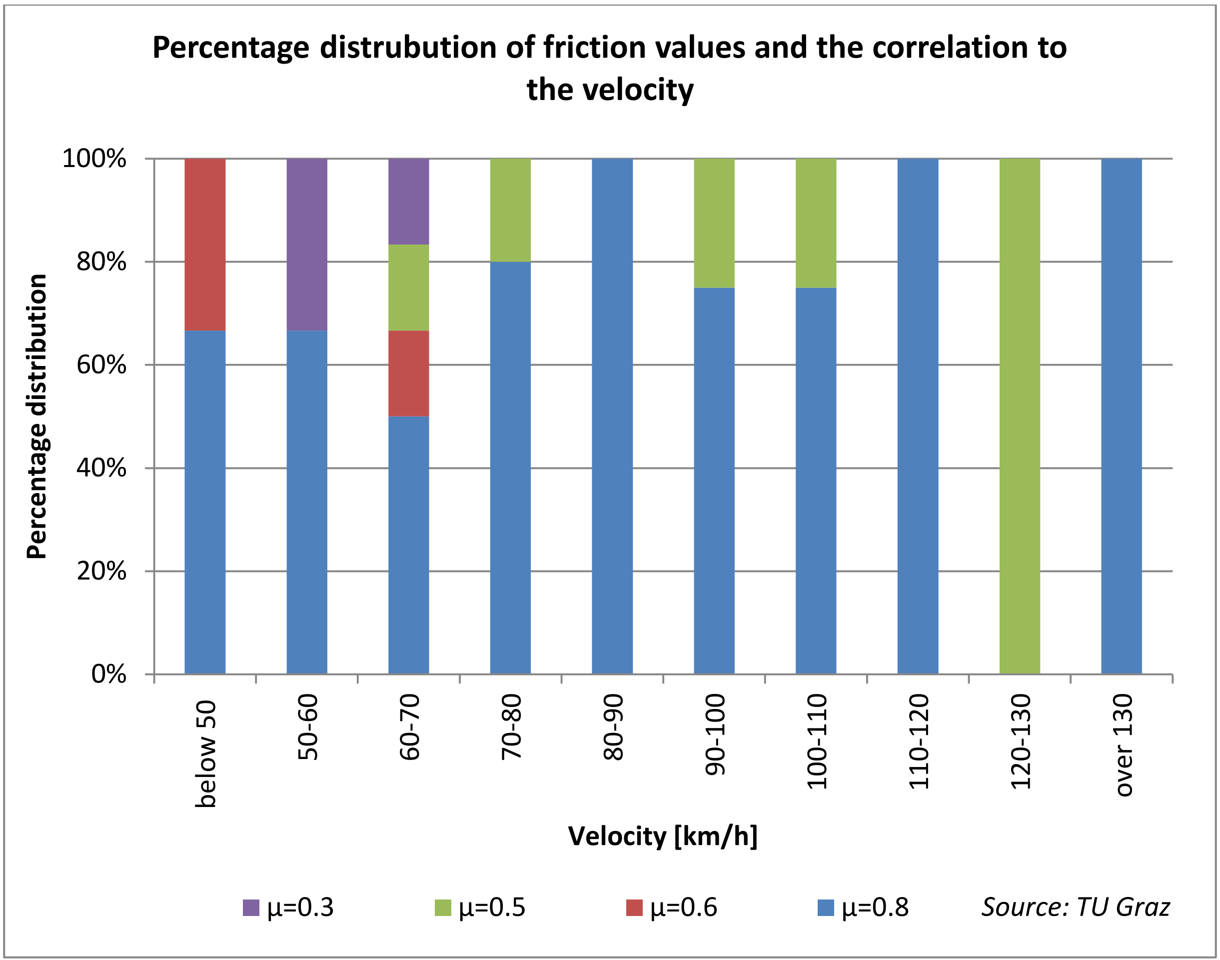


Figure 65 Percentage distribution of frictions values and the correlation to the velocity

The simulation results for the real single vehicle accidents were necessary for the generic accidents. They were used as an indication for the dimension of all influencing parameters, such as road conditions, velocity, reaction time, radius of the bend and others.

The next chapter shows the simulation results of the generic accidents, which were explained in the previous chapter.

5.2 **Simulation results of the generic accidents**

5.2.1 Leaving the road on a straight section

The necessary width under several different conditions was measured (figure 66). This chapter shows the results of the influencing factors. The main influencing factors are the friction value of a road, the reaction time of the driver, the current velocity of the vehicle and the vehicle angle while leaving the lane.

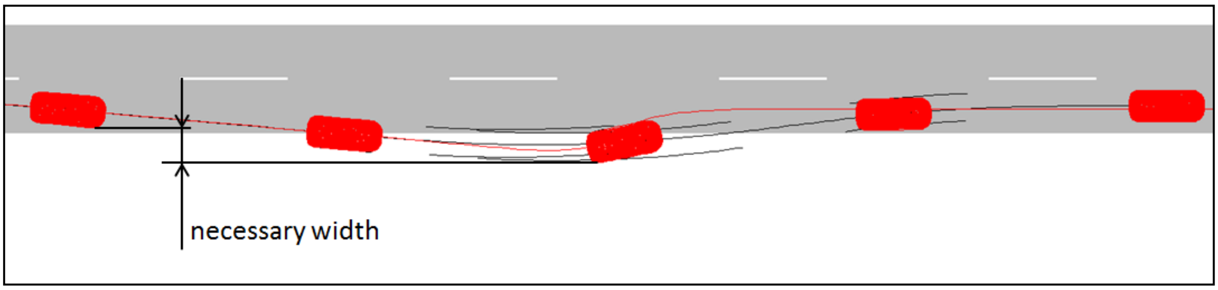


Figure 66 Necessary width after a steering manoeuvre (v=70 km/h; μ=0.5; φ=5°; RT=0.8 sec)

Necessary width for different road conditions

The difference between the width of a wet road (μ=0.5) and a dry road (μ=0.8) was determined and compared (figure 68). Almost linear behaviour can be seen. The reason for this linear behaviour can be explained through the start point of the steering process. Figure 67 illustrates two vehicles which carried out the steering manoeuvre, which was defined in the previous chapter. Vehicle 1 drives at a velocity of 110 km/h and vehicle 2 at a velocity of 60 km/h. The start point of the steering process of vehicle 1 begins earlier than for vehicle 2. Position B indicates the outermost position of the vehicles. In position B both vehicles are nearly on the same vertical position. The vertical differences in position B are very small for all simulated velocities. It is the steering process which starts earlier at higher velocities. Therefore it has a linear behaviour.

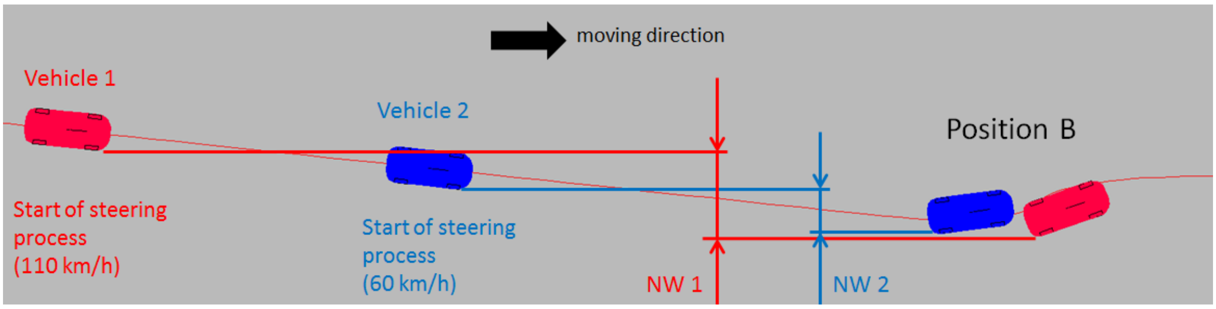


Figure 67 Comparison of a steering manoeuvre between vehicles at different velocities (NW=necessary width)

A wet road leads to a higher value of the necessary width. The dashed lines indicate a wet road and the continuous lines indicate a dry road. It can be seen that for an angle of 1° there is no difference between a wet road and a dry road. The differences between wet and dry conditions increase with an increasing angle. The highest difference between a friction value of 0.5 and a friction value of 0.8 occurred at an angle of 6°. At a velocity of 50 km/h there were no differences regarding the necessary width (independent from the angle).

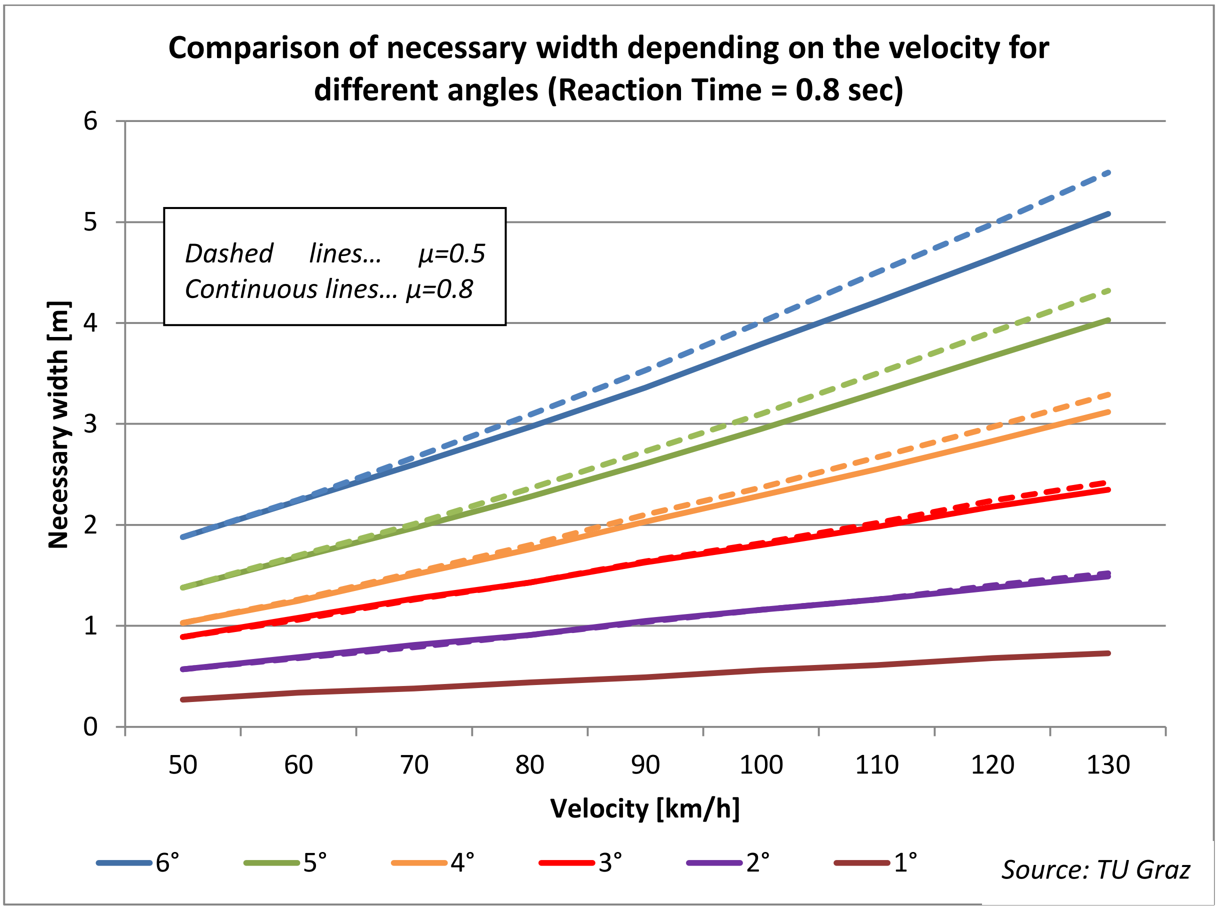


Figure 68 Comparison of necessary width depending on the velocity for different angles (RT=0.8s).

Necessary width for different reaction times

The reaction time of a driver has a huge influence on the necessary width after a steering manoeuvre (figure 69). The linear behaviour can be explained through the later start of the steering process. Calculating with a reaction time of 0.8 seconds it can be seen that the necessary width at a velocity of 130 km/h and φ=6° has already reached a value of 5 meters.

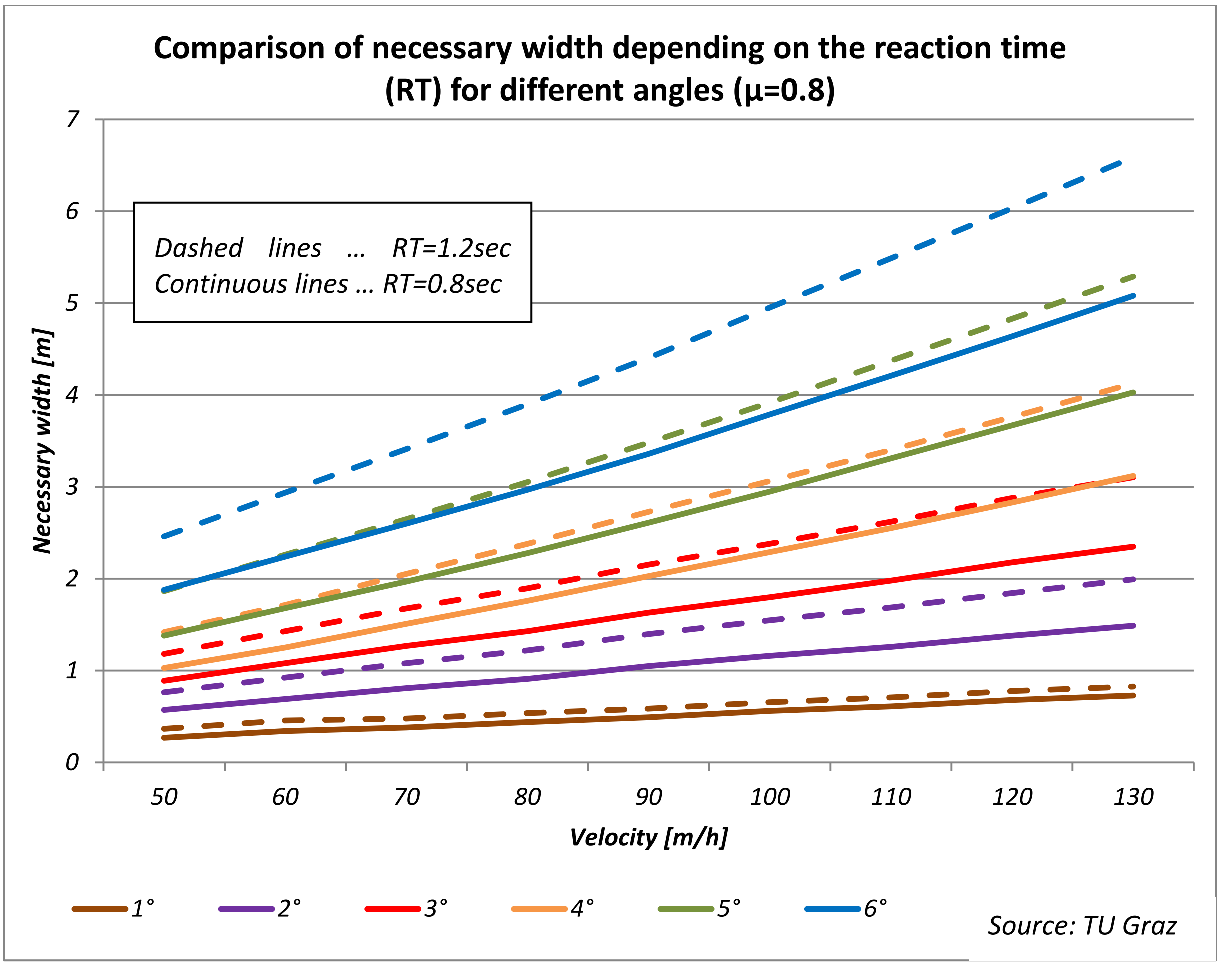


Figure 69 Comparison of necessary width depending on the reaction time for different angles (μ=0.8)

A calculation of the increase of the necessary width for every tenth of a second has been made (figure 70). The illustration gives an impression of how important the reaction time of a driver can be. For every tenth of a second, at a speed of 100 km/h, the vehicle needs between 0.048 meters (for φ=1°) and 0.29 meters (for φ=6°) more space to get back on the lane. With a speed of 130 km/h and an angle of 6°, the space required increases to as much as 0.38 meters per every tenth of a second.

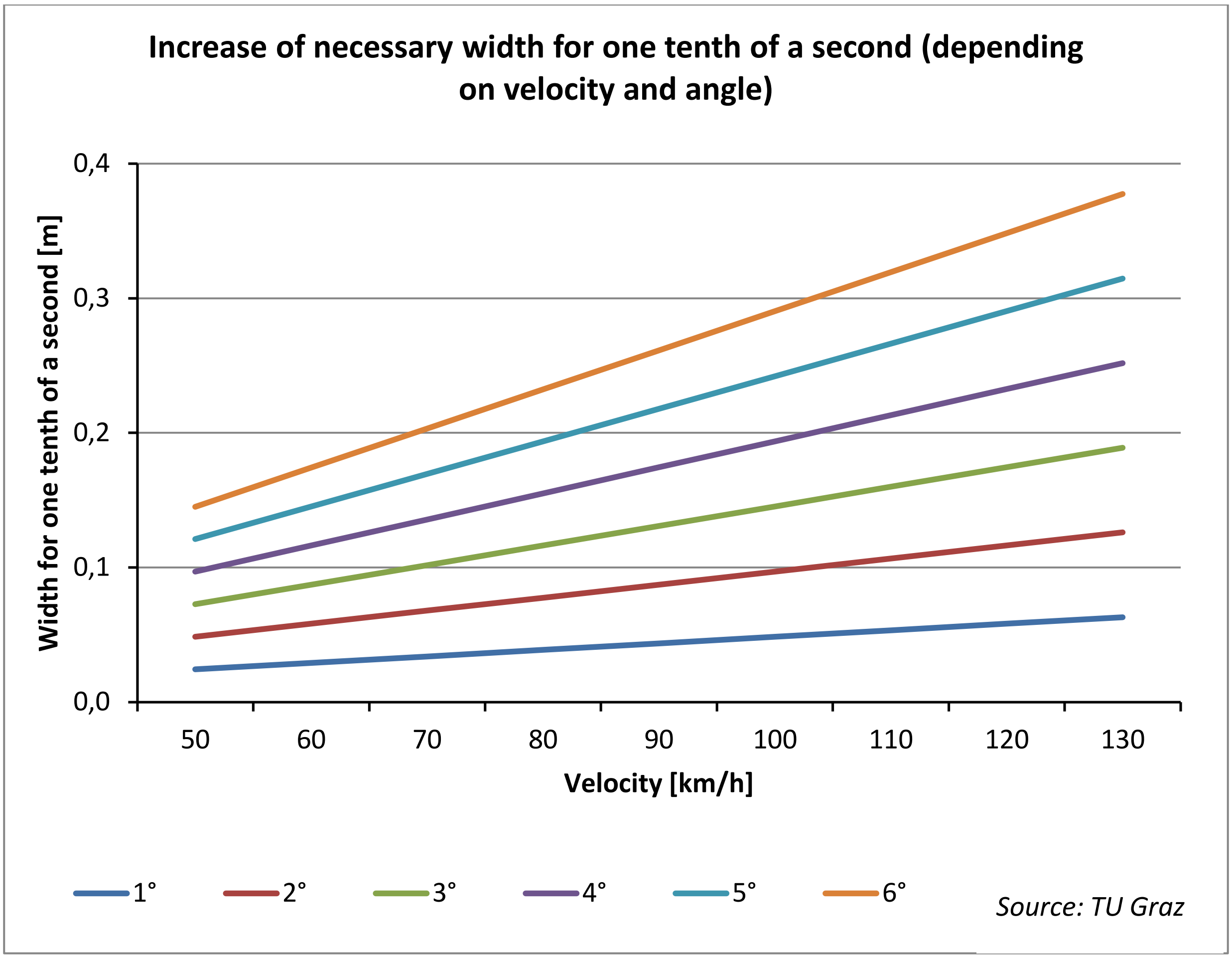


Figure 70 Increase of necessary width for one tenth of a second depending on velocity and angle

The correlation between the friction values and the reaction time is shown in figure 71. It illustrates the increase of the width when comparing a wet road and a dry road. The lines represent the difference between a friction value of 0.5 and 0.8. That means the values in this diagram show the increased width for a wet road (when comparing it with a dry road). Example: vehicle drives at 100 km/h and an angle of 6° → increased width = 0.22 meters. That means a vehicle needs 0.22 meters more space when the road is wet (compared to a dry road).

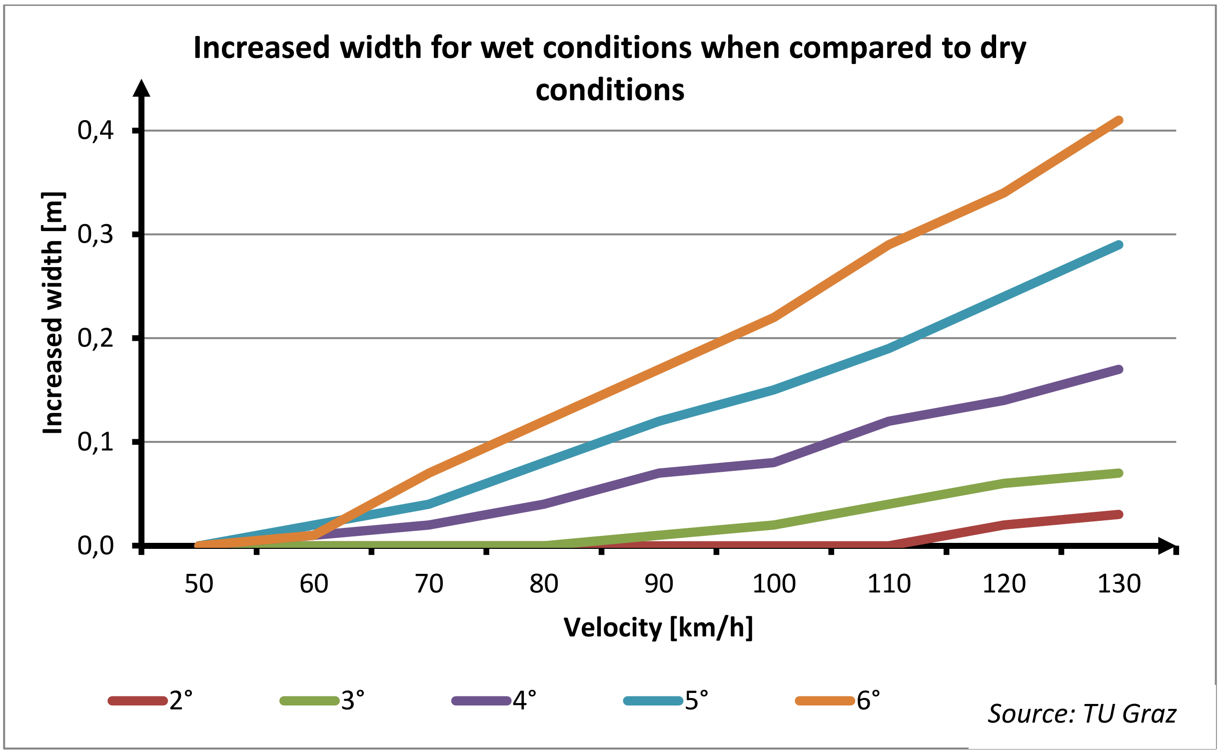


Figure 71 Increase width for wet conditions when comparing to dry conditions

5.2.2 Leaving the road in a bend

Critical velocity depending on the radius of a bend and the width of the lane

Table 7 contains the critical velocities and the maximum lateral acceleration for different radii and friction values. The critical velocities (v_{max}) were defined as the velocity when the vehicle crossed the edge of its own lane for the first time (figure 72). The maximum lateral acceleration ($a_{lateral}$) was measured. An exact curve of the acceleration behaviour in the vehicle can be illustrated within PC-Crash. This value is the highest one which was achieved during the steering process in the curve.

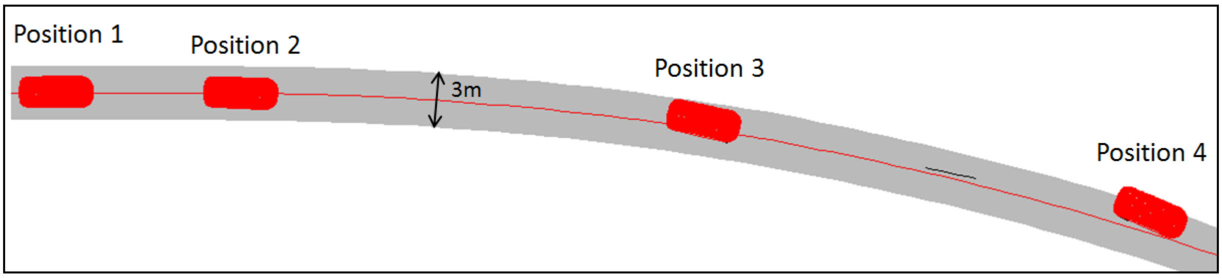


Figure 72 Example for a departing scenario in a bend (r=175m v=120 km/h µ=0.8)

It can be seen that the critical velocity for different road conditions is the same for a bend radius bigger than 150 meters. The reason for this is the nearly same value of the lateral acceleration. The maximum lateral acceleration for μ=0.5 is 4.91 m/s^2 and for μ=0.8 a value of 7.85 m/s^2. As already discussed it is realistic that a driver will not reach the highest possible lateral acceleration.

Table 7 Critical velocity and lateral acceleration for a width of 3 meters and different road conditions

μ=0.5 Width=3m			μ=0.8 Width=3m		
Radius [m]	**V_{crit} [km/h]**	**$a_{lateral}$ [m/s^2]**	**Radius [m]**	**V_{crit} [km/h]**	**$a_{lateral}$ [m/s^2]**
100	75	4,91	100	80	6,59
125	80	4,58	125	85	5,66
150	90	4,89	150	90	4,91
175	95	4,89	175	95	4,7
200	100	4,43	200	100	4,43
225	100	3,93	225	100	3,9
250	105	4,12	250	105	4,12
275	110	3,86	275	110	3,52
300	110	3,69	300	110	3,69
325	115	3,7	325	115	3,7
350	115	3,39	350	115	3,4
375	120	3,5	375	120	3,5
400	120	3,21	400	120	3,21

A higher critical velocity can be reached if the width of the lane is 3.5 meters wide (table 8). The lateral accelerations for these values are nearly the same as on a width of 3 meters, therefore they are not listed in this table.

Table 8 Critical velocity for a width of 3.5 meters and different road conditions

μ=0.3 Width=3.5m		μ=0.5 Width=3.5m		μ=0.8 Width=3.5m	
Radius [m]	**V_{crit} [km/h]**	**Radius [m]**	**V_{crit} [km/h]**	**Radius [m]**	**V_{crit} [km/h]**
100	60	100	75	100	85
125	65	125	82	125	95
150	73	150	90	150	100
175	78	175	95	175	105
200	85	200	105	200	110
225	90	225	108	225	110
250	95	250	110	250	110
275	98	275	115	275	115
300	103	300	120	300	120
325	105	325	120	325	120
350	110	350	125	350	125
375	113	375	125	375	125
400	118	400	130	400	130

Figure 73 shows the critical velocities for different widths of a lane. Obviously it can be seen that there is a difference regarding the critical velocity. This is due to the additional space on the lane. On average, on a lane with a width of 3.5m, a vehicle can drive 8.3 km/h faster than on a lane with 3m width and the same radius. The information about the width of a lane is important for the detection of a traffic conflict. At a certain velocity there could be a conflict on a 3m wide lane, but not on a 3.5m wide lane.

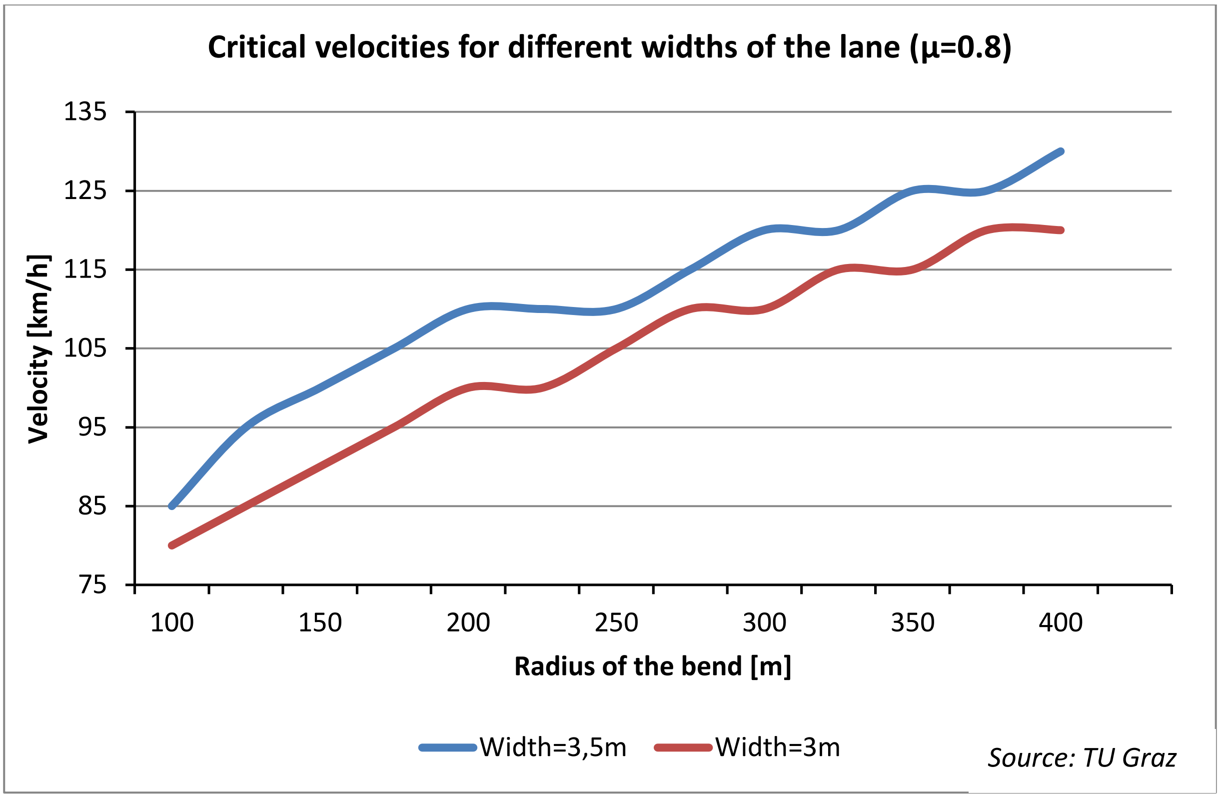


Figure 73 Critical velocities for different widths of a lane (μ=0.8)

Distance for deceleration before entering in a bend

All necessary minimum distances, for different decelerations, were calculated. The dependency on deceleration is important for comfort while decreasing the speed. A value of -5 m/s^2 was the maximum deceleration considered, which is already a value for a hard braking. A deceleration of 6 m/s^2 or the maximum value of 7.85 m/s^2 (for μ=0.8) would require almost full braking, which would influence the behaviour of a vehicle and the comfort of the driver. In figure 75, the calculated values are presented. All values were calculated for a critical velocity $v(t_1)$ of 80 km/h. That means, the diagram shows the minimum distance Δs from a given velocity $v(t_0)$ to 80 km/h. Certainly, also all other distances can be read from this diagram (e.g. the distance to decelerate, a=-3 m/s^2, from 120 km/h to 90 km/h is Δs = 81m). Figure 74 shows the mentioned distance.

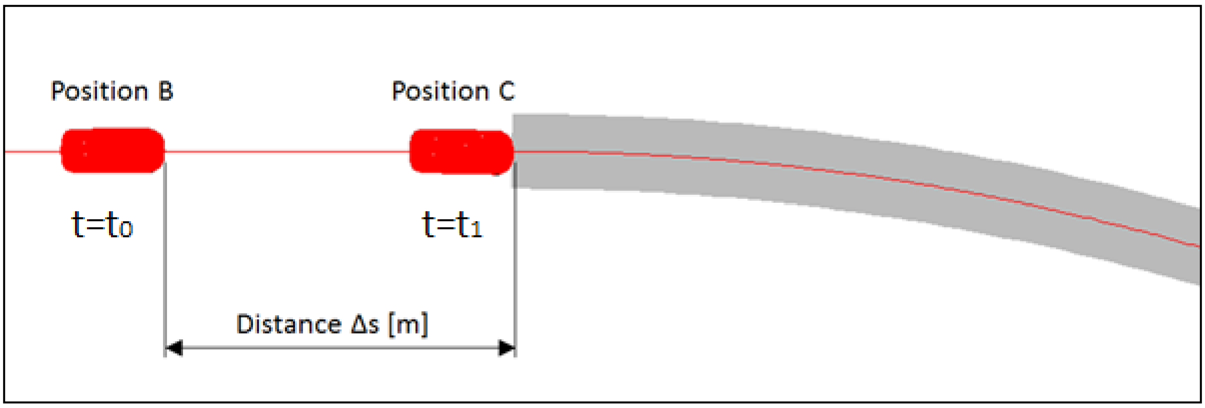


Figure 74 Description of the calculated distance Δs (Position C=entering the bend)

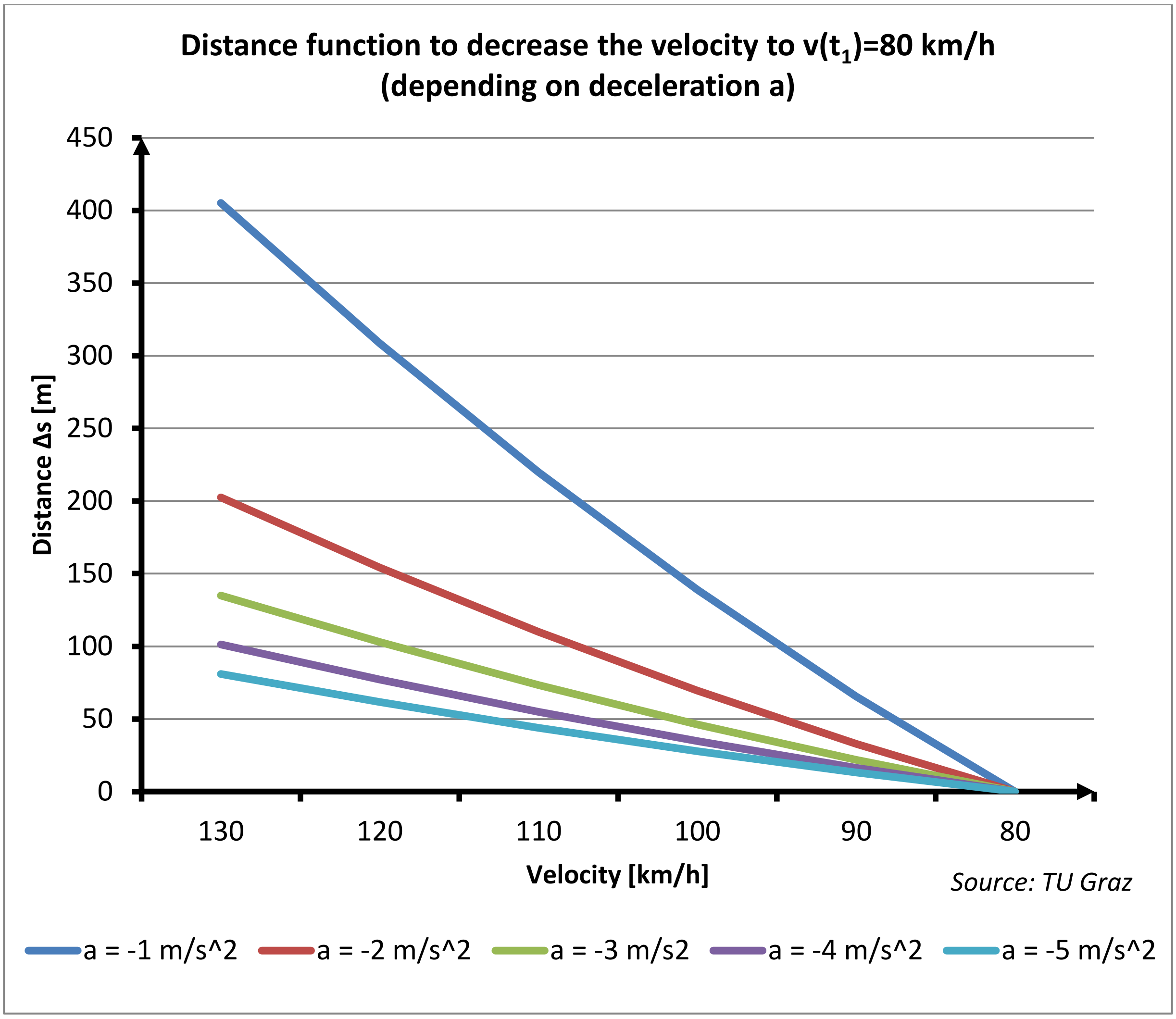


Figure 75 Distance function to decrease velocity to $v(t_1)$ = 80 km/h (depending on deceleration a)

The same method was used to calculate the values for the different times before the beginning of a curve was reached. These time values show the time needed (depending on deceleration a) to decelerate to a certain velocity from position B to position C (no reaction times were considered). The results of these calculations can be seen in figure 76. For example, the necessary time to decrease the speed from 130 km/h to a speed of 80 km/h, a time of 4,63 seconds is needed (for deceleration a = -3 m/s^2).

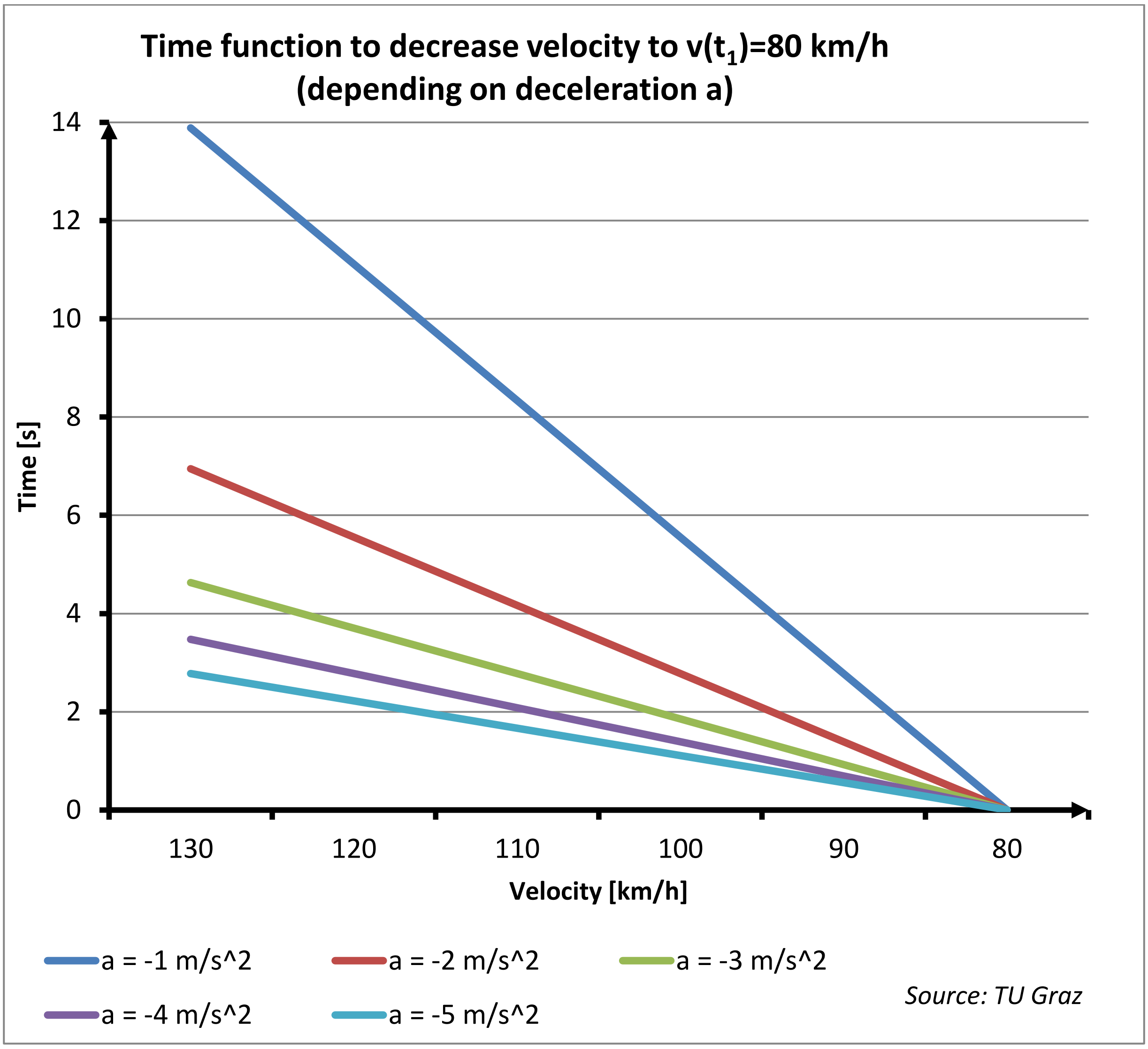


Figure 76 Time function to decrease velocity to v(t_1) = 80 km/h (depending on deceleration a)

The reason why a reference velocity of 80 km/h was taken is the fact that this value is the lowest one which came out from a radius of 100 meters during the simulations of generic accidents.

Table 9 gives results for a deceleration of 3 m/s^2 to a velocity of 80 km/h. The values for Δs mean that this distance is needed to decrease the speed to 80 km/h. For example, to decrease a vehicle from 130 km/h to a velocity of 80 km/h, a distance of 135.031 meters is needed and a time of 4.63 seconds. To decrease the speed from 130 km/h to 120 km/h a distance of 32.15 meters is needed (135.031m – 102.881m). For every 10 km/h speed decreasing, a time of 0.926 seconds is needed.

Table 9 Example calculation (a=-3 m/s^2)

	$v(t_0)$ [km/h]	t_1 [s]	Δs [m]
a = -3 m/s^2 $v(t_1)$=80 km/h t_0=0	130	4.630	135.031
	120	3.704	102.881
	110	2.778	73.302
	100	1.852	46.296
	90	0.926	21.862
	80	0.000	0.000

Summarized it can be said that it is possible to detect a traffic conflict before it appears. There are many relevant parameters which have an influence on the moment when a conflict can be detected. Therefore there is not just one result, but several results which are all variable and depending on each other. It is possible to determine the exact moment (time or distance) when a conflict appears in a bend. This moment depends on many factors. This also applies to the detection of a conflict on a straight section of a road. The moment for detection of a conflict is depending on the necessary space and the comparison to the available space. Many factors can influence the results.

6 SUMMARY AND OUTLOOK

Summarized it can be said that potential for the detection of traffic conflicts on a straight section of a road and in a bend is given. Concepts for an early detection and thus for a reduction of the accident occurrence in the future could be found. Certain constraints and requirements are assumed within these concepts.

The focus of this work was single vehicle accident situations on country roads and federal roads. According to police reports and reports of surveyors the causations for the departing accidents were not known in more than half of all examined single vehicle accidents. The second most common cause was excessive velocity. The focus of this work was therefore on the vehicle and the velocity of the vehicle.

Concepts have been developed to detect conflicts depending on the current velocity of the vehicle, the road conditions, the vehicle angle while leaving the lane, the radii of the bends and the width of the lanes. These variations parameter have a big influence on the moment when a conflict appears. Through the reconstruction and simulation of real single vehicle accidents the mentioned parameters have been determined, evaluated and integrated into the generic accidents. This was necessary to reconstruct the conditions for the generic simulations as realistic as possible.

To detect a traffic conflict in a bend in an early stage it was necessary to determine the critical velocity for a certain radius of a bend through the generic simulations. Critical velocity in this context means the velocity when a vehicle starts to drift away from its own lane. The driver is not able to keep the vehicle in the lane. At this point a traffic conflict appeared already and an accident could be the consequence. In a right bend an accident could take place by an oncoming vehicle and in a left bend through a slope, a tree next to the road or other obstacles. Based on this it was determined the distance and the time before this point is reached. If this moment is determined it is possible to warn the driver before a conflict even appears. The influence on the critical velocity through the different variation parameters was considered.

Reconstructions and simulations of real single vehicle accidents were also used to detect conflicts on a straight section of a road. The variations parameters were determined through the simulation results and integrated into the generic simulations. During a leaving of the lane to the right side, a possible scenario could be a collision with a tree or other obstacles which are next to the road. Therefore it is important to know the necessary width and the starting moment of a counter steering process in order to know when a conflict appears. This distance can be compared with the real distance. A conflict occurs if the necessary distance for the counter steering process is less than the real distance. A leaving of the lane to the left side causes also a conflict due to the possible oncoming vehicles. The simulations were performed with different variation parameters.

Only single vehicle accidents of passenger cars were investigated during this thesis. By including other road users (trucks, buses, motorcycles, etc.) additional important data could be collected. The implementation of these concepts requests the exact position of the vehicle and the course of the road. New GPS technologies are already able to reach an accuracy of two centimetres. An example therefore is the European Global Positioning System GALILEO. However, these technologies are not mature yet and need still development. Furthermore an additional study of other roads (motorways or expressways) could be interesting. Another investigation could find the advantages and disadvantages of an active intervention or a passive warning system if a conflict is detected.

7 LIST OF FIGURES

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10 LITERATURE

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