Single vehicle run-off-road accidents colliding turned down terminals of guardrails

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Abstract – Looking at the total of sum of fatal car accidents the number of single-vehicle accidents and particularly run-off-road (ROR) accidents are most frequent. In Austria on the Autobahn ROR accidents amounts to almost 45% of all fatal accidents, i.e. nearly every second fatal accident is caused by ROR accidents and interaction with infrastructure. Approximately 43 people were killed on Autobahns in ROR accidents with passenger cars. One possibility of protection against impacts with infrastructure is the use of guardrails. However, the initial element identified as a turned down terminal could become a dangerous impact object. These turned down terminals may lead a vehicle to roll over or the car "takes-off" when impacting the turned down guardrail. In many cases it is reported that the vehicle is jumping into road side objects such as traffic sign poles or overpasses. On average, nine people are killed in such accidents every year in Austria.

INTRODUCTION

An ambitious goal in European road safety was pronounced in the White Paper halving the number of fatalities between 2000 and 2010 [5, 2001]. Austrian Ministry for Transport, Innovation and Technology introduced an extensive road safety program in 2002 and established a similar target: halve the number of fatalities by the year 2010 [6, 2004a]. A huge impact can be seen in reducing single vehicle accidents (SVA) and are identified as a major burden on Europe's roads. The portion of fatalities in this accident type varies from country to country but the average of single vehicle accident fatalities is one third of annual road fatalities [9, 2000]. Accidents involving only one vehicle, in most cases run-off-road (ROR) accidents bear a particularly high risk. Injury severity of these accidents is highly dependent on the interaction between the vehicle and the roadside infrastructure.
In Austria SVA (Autobahn and country roads) are the third most accident type and represents 21% of the total sum of accidents with personal injuries and 36% of fatal accidents (Figure 1). A relative fatality risk (RFR) of SVA is at 1.7 and indicates a particularly high risk (see Figure 2). The terminology of relative fatality risk used in this study is considered as the ratio of fatalities divided by the frequency of injuries of a specific accident type. The dashed diagonal line in the Figure 2 separates relative risk into a section of higher and lower risk and displays a RFR of 1 and indicates that the frequency of a specific accident type compared to the portion of fatalities is balanced.

One means of protection against single vehicle run-off-road accidents is the presence of guardrails. Guardrail within this study is used as a combined terminology for concrete barriers and steel safety barriers. According to National Statistics, accidents involving one vehicle and follow-up collisions with crash barriers, show a tendency of fewer fatally injured and minor injured casualties than in accidents without collisions with crash barriers. However, the initial element of this kind of protection systems is potentially of high risk. Especially blunt (non energy-absorbing) or turned down terminals of guardrails are critical elements. Turned down terminals may result in a vehicle-rollover. Another outcome of an impact between a vehicle and a turned down guardrail is the "take-off", where the vehicle is jumping into road side objects such as traffic sign poles or an overpass. Recently, this issue was frequently raised in road safety inspections and in discussions with police departments. Especially on the Autobahn, where vehicles are driving at higher speeds, the consequences of such single-vehicle run-off-road accidents can be dramatic. A scientific analysis of the relevance of accidents induced by ramped terminal ends is pending. Hence, a project was initiated to address single vehicle run-off-road accidents in combination with safety barrier termination on the Autobahn. In this study only passenger cars are discussed. Collisions of trucks with the ramped end of guardrails were considered as non-important. In real world cases trucks with their huge weight just were destroying the ramped end. No similar patterns such as the "take-off" can be identified with these vehicle types.

Approximately 2.145 kilometres Autobahn are present in Austria [8, 2010]. Based on on-site investigations it was assumed that overall about 6.000 initial elements of guardrails exist. Roughly 1.700 gaps within guardrails at an average gap distance of about 81 metres and about 600 exit areas are present on Austrian high-ranking roads. Another 3.700 road sites are simply identified as ramped terminals and needs to be considered as potentially dangerous.

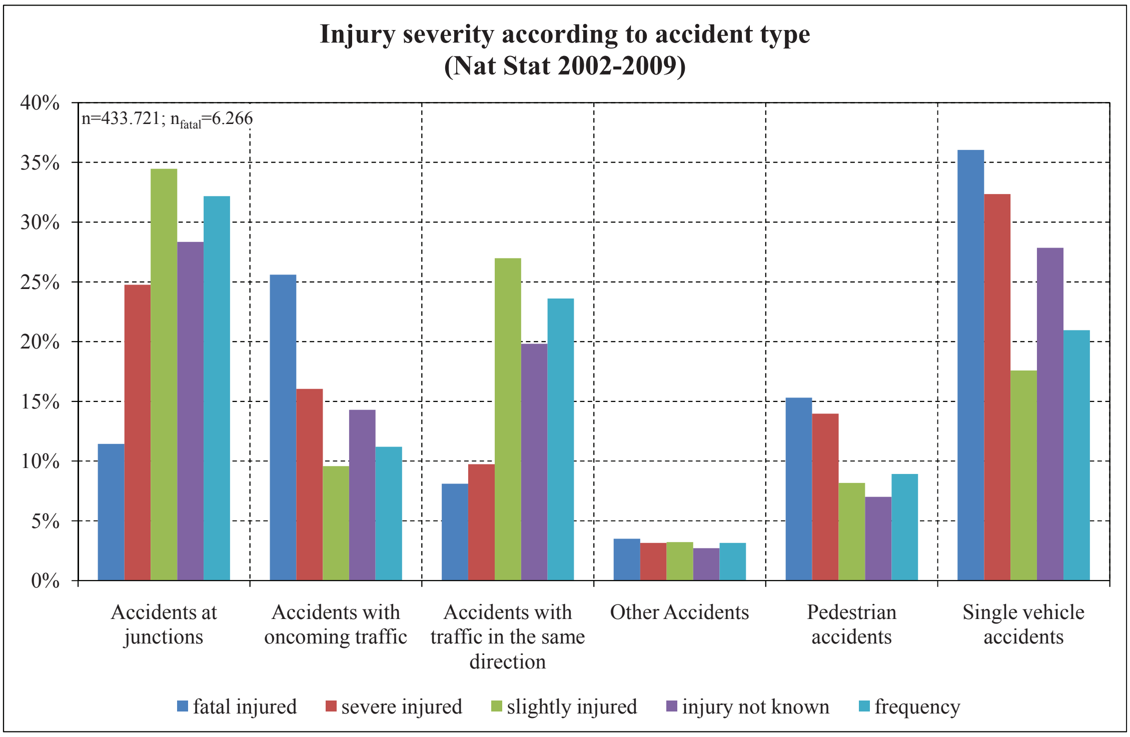

Figure 1: Injury severity according to accident types on Austrian roads

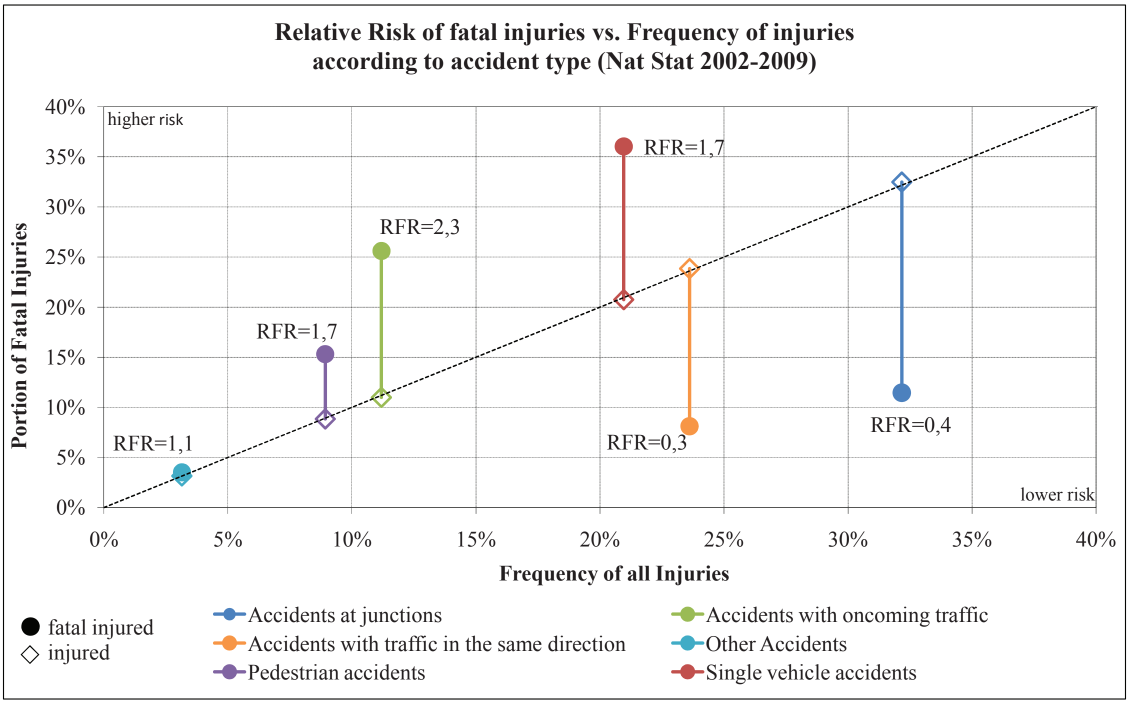

Figure 2: Relative Risk of fatal injuries related to accident types

PROCEDURE

Statistical analysis provides the basis determining the relevance of SVA. The analysis of statistical data enables an overview of accidents. Therefore Austrian National Statistics were examined [4]. In Austria traffic accidents with personal injuries are collected by police and the so called ÖSTAT accident reports are filled in and provided to the Austrian Bureau of Statistics. These data can be evaluated according to different types of accidents (as defined in Austria). The Austrian accident type catalogue comprises ten main groups with distinct sub-groups which describe the accident. In total about 105 different accident types can be distinguished.
Particular focus in this study was set to single-vehicle run-off-road accidents. Due to the nature of national statistics there is a lack of information with respect to vehicle speed, collision configurations, infrastructure such as presence of embankments, trees, objects etc. Hence, in a second step analysis of the in-depth database ZEDATU (Zentrale Datenbank tödlicher Unfälle) [22, 2007c, 24, 2008d, 23, 2006c] was performed. By the end of 2009 the database contained roughly 700 cases and comprises a set of fatal accidents from 2003 (containing approximately 60% of all fatalities, 514 out of 848 cases with 931 fatalities) and all fatal accidents of Upper Austria from 2007 (139 fatal accidents). In total about 765 database arrays per accident are collected. These arrays are based on the STAIRS protocol [25, 1999] enhanced by additional arrays developed in the EC R&TD projects PENDANT [21, 2006b], RISER [17, 2006a] and ROLLOVER [11, 2005a]. From these in-depth accident cases all fatal accidents on the Autobahn were selected. A reconstruction of the complete accident was carried out by numerical simulation using PC Crash [19, 1996b, 20, 2004b].

RESULTS

National Statistics

Consideration of accidents on the Autobahn the ratio of SVA increases to 43% (see Table 1) compared to 36% of fatalities on all Austrian roads (see Figure 1). At average 105 fatalities are on Autobahns every year. Out of these fatalities 45 persons are dying every year in single-vehicle run-off-road accidents. These kinds of accidents are dominant and when looking at KSI (Killed and Severe Injured) close to half of the accidents can be related to this accident category. In the past eight years examined in this study 54 pedestrian accidents occurred on the Autobahn. 123 accidents with oncoming traffic were reported. However, all road sections on the Autobahn where frontal collisions can take place have been identified and consequently these sections are equipped with road restraint systems at the median line. The number of fatalities in this type of accident is reduced from 33 in 2002 to four deaths in 2009. Comparable figures can be found for pedestrian accidents. Since 2005 when the use of a vest with reflective items when leaving the vehicle on the Autobahn became mandatory the number of fatalities was subsequently reduced to one death by last year. Accidents at junctions are probably an outcome of miscoding and the number of fatalities in the category “others” are consequences of collision with parked vehicles. To summarize these figures: the main challenge reducing the number of fatalities on the Autobahn network in Austria will be dominated by analysing *“single vehicle accidents”* and *“accidents with traffic in the same direction”*.

Table 1: Accident distribution on Autobahn (National Statistics 2002-2009)

	fatal		severe		slightly		unknown		frequency	
Accidents at junctions	2	0,2%	22	0,6%	141	0,7%	25	0,5%	190	0,6%
Accidents with oncoming traffic	123	14,6%	246	6,5%	596	2,9%	179	3,8%	1.144	3,8%
Accidents with traffic in the same direction	289	34,2%	1.656	43,6%	13.145	64,0%	2.706	56,7%	17.796	59,4%
Other Accidents	14	1,7%	15	0,4%	70	0,3%	27	0,6%	126	0,4%
Pedestrian accidents	54	6,4%	63	1,7%	77	0,4%	32	0,7%	226	0,8%
Single vehicle accidents	362	42,9%	1.794	47,3%	6.515	31,7%	1.804	37,8%	10.475	35,0%
	844	100,0%	3.796	100,0%	20.544	100,0%	4.773	100,0%	29.957	100,0%

In SVA subgroups passenger cars *leaving the road to the right* are predominant with roughly 81% in the category of fatal accidents whereby the overall frequency of this accident subgroup is at 66%. In more detail, 75.8% of fatal run-off-road accidents are on *straight road* sections. On average, 29 persons are killed every year. Only a small portion of fatal run-off-road accidents take place at *right* (2.0%) or *left* (3.0%) *bends*. Altogether two persons are killed in bends. However, because of lack of information on bend radius it can not be judged whether ROR accidents take place on straight sections or in bends. This probably leads to a shift between the categories straight road and bends if detailed information are present. Hoschopf et al [13, 2008b] reported that accident types had to be adjusted when the entire and critical situation of an accident were considered. In national statistics entire movements are not judged.
Second most important subgroup is identified as *leaving the road to the left* with an overall frequency close to 30% and about 17% of fatalities. Within the observed period seven fatalities (2.3%) were documented as leaving the road to the *left* of a *right bend*. 14.2% of fatalities are on *straight road* sections and only a small number of fatalities are found as leaving the road to the left in a left bend (0.3%).
ROR accidents to the right combined to killed and severe injured (KSI, fatalities and severely injured are combined) mounts to 74% and *leaving the road to left* leads to almost 22.8%. The ratio of passenger car accidents *leaving the road to right in a bend* is approximately 4.7%. KSI ratio of *ROR accidents to left* is almost at 1.8%. SVA in the area of an exit mounts to approximately three victims every year.

Table 2: Distribution of injury severity in SVA on Autobahn between 2002 and 2009 (Nat Stats)

Single vehicle accident subgroups			fatal	severe	minor	unknown	Total
leaving the road to the right side	straight road		229	1.012	3.445	1.006	5.692
			75,8%	68,0%	59,5%	64,2%	62,3%
			4,0%	17,8%	60,5%	17,7%	100,0%
	right bend		6	26	97	18	147
			2,0%	1,7%	1,7%	1,1%	1,6%
			4,1%	17,7%	66,0%	12,2%	100,0%
	left bend		9	43	142	38	232
			3,0%	2,9%	2,5%	2,4%	2,5%
			3,9%	18,5%	61,2%	16,4%	100,0%
leaving the road to the right side		∑	244	1081	3684	1062	6071
			80,8%	72,6%	63,7%	67,8%	66,4%
			4,0%	17,8%	60,7%	17,5%	100,0%
leaving the road to the left side	straight road		43	332	1665	420	2460
			14,2%	22,3%	28,8%	26,8%	26,9%
			1,7%	13,5%	67,7%	17,1%	100,0%
	right bend		7	19	127	30	183
			2,3%	1,3%	2,2%	1,9%	2,0%
			3,8%	10,4%	69,4%	16,4%	100,0%
	left bend		1	6	64	7	78
			0,3%	0,4%	1,1%	0,4%	0,9%
			1,3%	7,7%	82,1%	9,0%	100,0%
leaving the road to the left side		∑	51	357	1856	457	2721
			16,9%	24,0%	32,1%	29,2%	29,8%
			1,9%	13,1%	68,2%	16,8%	100,0%
leaving the road in the area of an exit or junction, applied to all types of junctions			5	19	68	12	104
			1,7%	1,3%	1,2%	0,8%	1,1%
			4,8%	18,3%	65,4%	11,5%	100,0%
other single vehicle accidents			2	31	179	35	247
			0,7%	2,1%	3,1%	2,2%	2,7%
			0,8%	12,6%	72,5%	14,2%	100,0%
Total		∑	302	1.488	5.787	1.566	9.143
			100,0%	100,0%	100,0%	100,0%	100,0%
			3,3%	16,3%	63,3%	17,1%	100,0%

In-depth analysis of real-world cases

The narrowed number of data fields in the national statistics limits the analysis possibilities such as interaction with the infrastructure or vehicle parameters. There is only one single parameter present in the National Statistics, namely *"collision with guardrails"*. Around 39% of all accidents with one vehicle involved were related to this specific circumstance. According to data analysis from the National Statistics, accidents involving one vehicle and follow-up collisions with crash barriers, show a tendency of fewer fatally injured and minor injured casualties than in accidents without collisions with crash barriers. However, detailed information regarding collisions with ramped terminals of guardrails is not present. Analysis of in-depth database ZEDATU showed that fatal accidents with ramped terminals of guardrails make about 20% of all run-off-road accidents, i.e. about nine people are killed per year.

The most involved collision object was obviously the guardrail. Altogether almost fifty percent of all collisions were addressed by guardrails. A huge number of impacts were identified at the initial element, which is reported as a ramp inducing take-off of the vehicle by police and road maintenance staff. Another critical subject which needs to be discussed are cut and fill slopes at the road side and the soft soil where the wheels of the vehicles can stuck and roll over accidents arise. Two cases were identified to be a hazardous when colliding with crash cushions. Analysing these cases it was found out that the vehicle catched fire and the occupants died. No autopsy was undertaken.

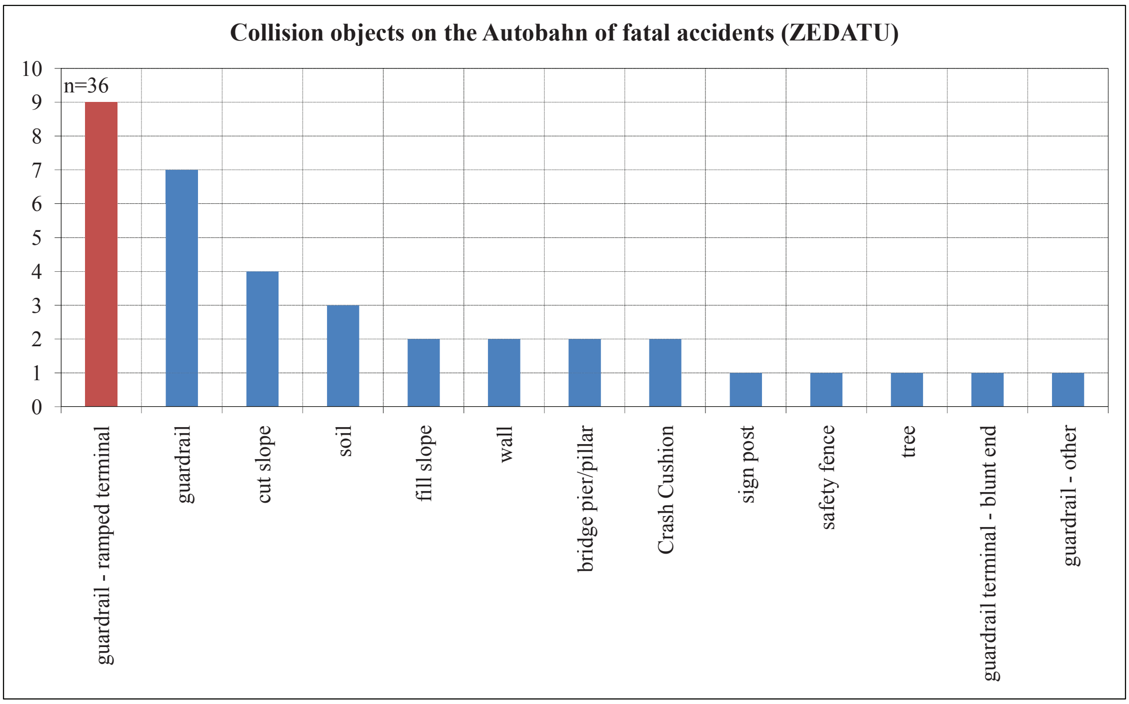

Figure 3: Collision objects on the Autobahn of fatal accidents

The predominant cause of rollover/take-off accidents identified was the ramped terminal of guardrails (~35%, Figure 4). After colliding with the ramped end of the barrier, the vehicle collides with other hazards (road signs, bridge pillars etc.). With accidents causing serious injuries or minor injuries for car passengers, it is difficult to determine their corresponding percentage in respect to all run-off-road accidents, because in Austria collisions with the initial element of the guardrail were not reported by the police to be registered in the national statistics. No array in the national statistics is available to code this circumstance. Anyway, the information given in the ZEDATU database is the solely data source for analysis interaction with infrastructure. Fill and cut slopes can be identified as a further reason for rollover accidents. In some cases the wheels are stuck into the soil causing the vehicle to roll over.

These rollover accidents induced by ramped terminal ends of road restraint systems are independent of the passenger car type (e.g. SUV, saloon, hatchback, etc.). Even vehicles equipped with anti-rollover assistance systems can not prevent rollovers triggered by ramped terminal ends.

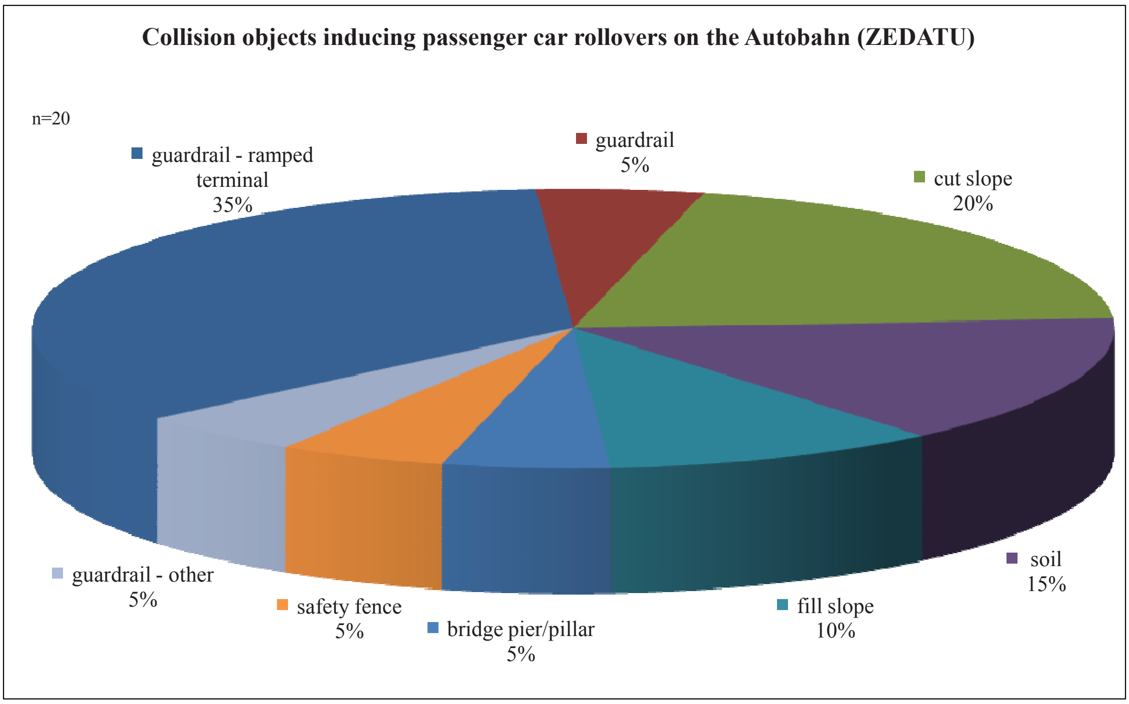

Figure 4: Collision objects inducing passenger car roll over on the Autobahn

An important parameter for the design of protective devices, apart from others, is the collision speed of vehicles. Furthermore the collision speed is dependent of the run-off-road speed and possible deceleration. The average run-off-road speed was about 114 kph (SD=16). The speed was measured at the hard shoulder immediately beyond the carriageway edge line. Median speed was about 113 kph, whereas 50 % of all run-off-road accidents were below this value and 50 % were above. The speed range for 95% of fatal traffic accidents is about 130 kph. This shows that at least 95% of the drivers' run-off the road at a speed of up to 130 kph. 5% of the drivers involved have exceeded 130 kph and hence, exceeded the present maximum speed limit of 130 kph on motorways and speedways in Austria. The 85% percentile speed was calculated to approximately 127 kph. The 85th percentile distribution is a most frequently used parameter in designing roads [16, 2005b].
The resulting angle reaches a span up to 18° when the car run-off the road. The maximum impact angle for guardrails according to EN 1317 [1] lies at 20° for passenger cars thus represents real accidents very well. In the EC R&TD project RISER [17, 2006a] it was found out that roughly 85% of the reconstructed accidents had an initial departure speed below 110 kph. No information is given to specific road types and allowed speed limit and is summarized for all roads.
Another important piece of information for single-vehicle run-off-road accidents is the velocity angle. The most critical angle is the vehicle trajectory angle (=velocity angle). In combination with run-off-road speed, velocity angle is an indicator how far the vehicle will travel into the roadside [16, 2005b]. The average value in this study is calculated at around 7 degrees (SD=4.8) and the median angle, where 50 % of all run-off-road accidents were below this value and 50 % were above, results in 5 degrees. At the 85th percentile a velocity angle was observed at 11 degrees. Within the RISER study it was noted that 85% of vehicle initial run-off-road angles are below 20 degrees.
In the following figure the velocity angles of the real world cases in the database ZEDATU are summarized. One spot in the picture can indicate more than one accident. However, fifty percent of the vehicle angles are within the coloured box. Furthermore the diagram shows that velocity angles of passenger cars leaving the road without outliers are up to 13°. Angle exceeding this angle can be identified as outliers.

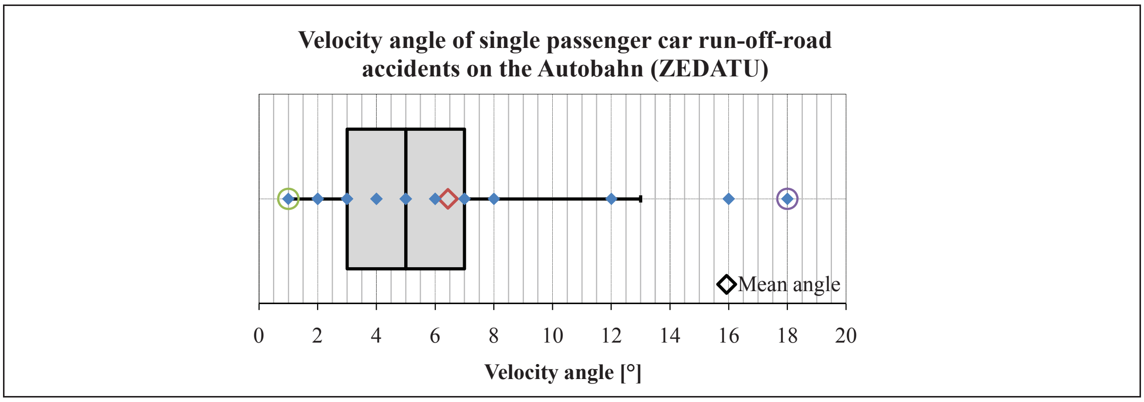

Figure 5: Velocity angle of single passenger car run-off-road accidents on the Autobahn

If speed is compared with velocity angle at the point of leaving the road, then the velocity angle tends towards a smaller angle when the run-off-road speed increases. Similar tendency was already reported by Hoschopf et al [12, 2007a]. The authors reported a smaller run-off-road angle with increasing vehicle speed.

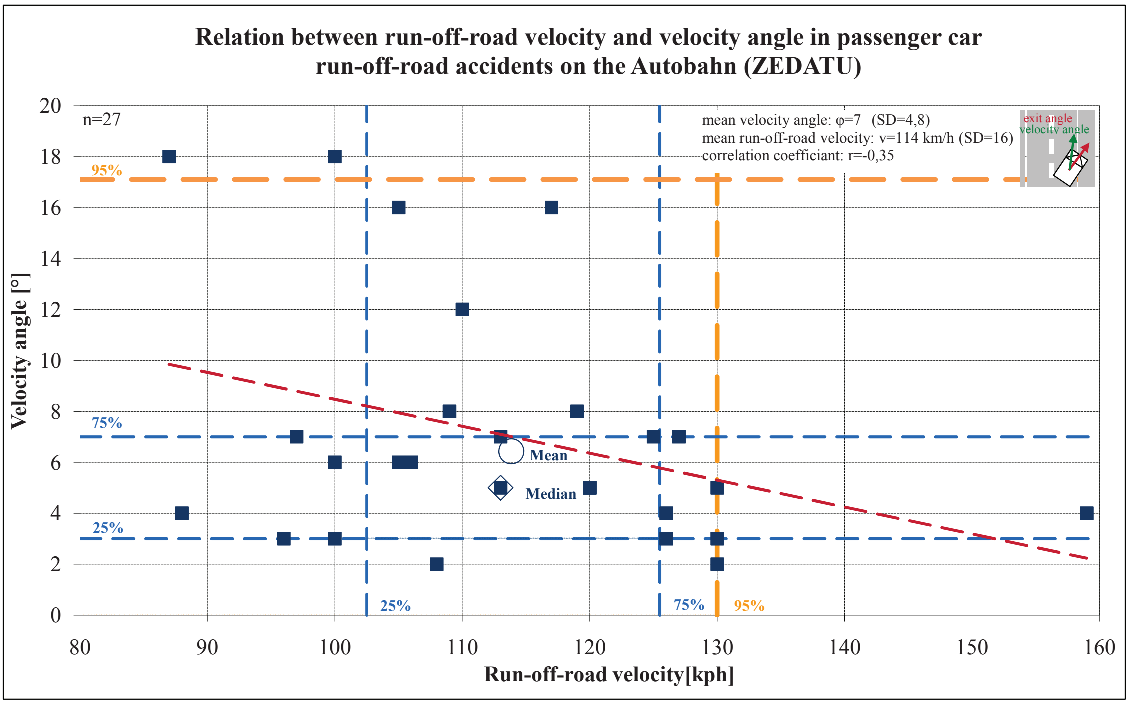

Figure 6: Relation between run-off-road velocity and velocity angle in run-off-road accidents

For energetic consideration the mass of vehicle is important. The average mass of vehicle of a passenger car according to ZEDATU database can be calculated for run-off-road accidents on Autobahn at around 1,276 kg (SD=259). The cumulative share of passenger cars in these accidents shows a quite similar picture as it can be found for all passenger cars in ZEDATU database. Median mass of passenger cars were found at a weight of 1.272 kg. Fifty percent of all fatal run-off-road accidents are found between the amount of approximately 1,066 kg and 1,391 kg of mass of vehicle. As a 5% percentile, vehicle masses of approx. 925 kg are addressed (corresponds to TB 11 of EN 1317). EN 1317 test with the heavier car at 1.500 kg would address close to 85% of passenger cars on Austrian roads. 95% of vehicle weight is found up to around 1,712 kg.

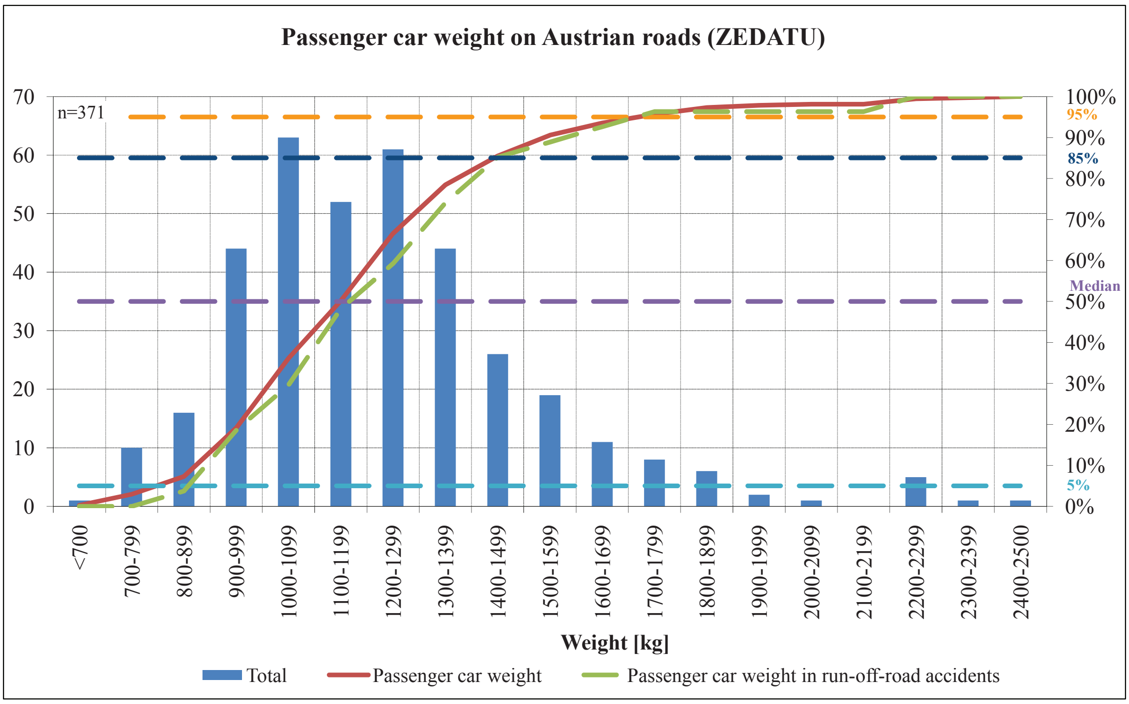

Figure 7: Mass distribution of passenger cars in ZEDATU database

DISCUSSION

Due to the fact that it often depends on mere chance whether there has been a collision with the ramped terminal or whether there has been a follow-up collision with the guardrail. Road restraint systems (RRS) on roads are generally speaking, systems positioned in a certain radius to restrain lane departing vehicles. Furthermore these systems are designed to limit damage and injuries of road users and other people in the vicinity.
In order to be allowed to install road restraint systems in Austria, successful testing according to EN 1317, which confirms in principle the adequacy for the intended use in traffic, is necessary. The final release is carried out by the Federal Ministry of Traffic, Innovation and Technology (BMVIT). When implementing permanent road restraint systems on Austria's roads, the relevant version of specifications RVS 05.02.31 [18] have to be applied, which are based on regulation EN 1317.
One standard for the initial elements of steel and concrete safety barriers is designing these elements as ramped terminals. The purpose of this is on the one hand, to avoid colliding into a blunt end of a crash barrier causing severe accidents and on the other hand to anchor the appropriate crash barrier. According to RVS 05.02.31 the ramped terminals at the initial and final position of a guardrail has to be carried out at an angle of ≤ 1:12. In some cases shorter ramped terminals are allowed.

Studies carried out by BASt – (Federal Highway Research Institute) [10, 1996a] investigated different inclinations of ramped elements of crash barrier according to the test requirements EN 1317-4. Within a first test a vehicle travelling at a speed of 80 kph was accelerated rectilinearly on to a short ramped terminal of 1:4 (TT 2.1.80 – mass of vehicle 900 kg, speed 80 kph, vehicle trajectory No. 2; [3]). In this test the vehicle crashes in to the ramped guardrail and changes over to a fast flight phase, inclined to the right side. The vehicle completely loses contact to the ground and lands on its right side. It is discovered that this short ramped terminal implemented at present, does not guarantee vehicle guidance according to the norm because the vehicle rolled over during the test. These characteristics can be observed in real world accidents, but in these cases the collision speed might be much higher and under certain circumstances collisions with bearing constructions of crossover bridges occurred.
Another test was carried out with the same impact configuration but with a regular ramped terminal of 1:12. As in the case of the short ramped terminal the vehicle is lifted off on one side but more moderate due to the reduced angle of the ramped terminal. The vehicle was travelled along the top of

the barriers and deceleration of the vehicle is equally low compared to the short ramped terminal in spite of a smaller angle of ramped end and a longer distance of contact.
The tests carried out at the regular ramped terminal ran consistently positive. The loading on occupants remained on a low level in both tests carried out. Precise analysis of the test conducted at a speed of 80 kph showed that the vehicle was not decelerated securely after the impact. The authors have come to the conclusion that the regular ramped terminal has reached its limit of functional capacity at an impact speed of 80 kph.

The problem with ramped initial elements of crash guardrails was confirmed by several investigations carried out in the US. Investigations on traffic accidents with terminals were analysed in detail in an ongoing research project over a period of three years [14, 2008c]. During analysis of the observed data set it was discovered that in connection with ramped ends of crash barriers – compared to other terminals in use, an increase of fatal and severe accidents had to be noted. About 24% of crashes were addressed by turned down end treatments but more than 51% fatal and severely injuries occurred in these collisions. These figures results in a relative fatality risk of about 2.1. Energy absorbing initial elements (in the study present elements: ET-2000, MELT, SKT-350, SRT-350) had a portion of fatalities of approximately 24.3% but the total numbers of accidents with the initial elements mounts to 55.9% and indicates a relative fatality risk of 0.4. Comparing these two categories (ramped end terminal and energy absorbing terminal) it is evident that ramped guardrail ends have a five times higher risk than those initial elements which are designed as energy absorbing structures. Another terminal namely BCT (Breakaway Cable Terminal) was analysed and it was found out that this type of construction is high of risk too. Roughly 24.2% of fatalities took place at this construction but the portion of total accidents was at 16.4% which indicates a relative fatality risk of 1.5.
It was obvious that energy-absorbent constructions would be an effective solution to reduce the severity of accidents with initial and end terminals of crash barriers. Another very obvious result was the fact that ramped terminals of crash barriers showed the worst safety protection of all analysed terminal constructions.
For this reason it was recommended to replace ramped terminals of crash barriers in future maintenance or clean-up operations to improve traffics safety, by energy-absorbing initial and end constructions.

The authors of the EC R&TD project RISER [17, 2006a] concluded that turned-down terminals should be replaced by energy-absorbing initial and end constructions. Furthermore, the beginning of initial elements can be flared away from the road. No specific flare angle is given. Blunt ends should be replaced with ramped ends, to achieve a minimum safety, even if this is not the perfect solution. All of the suggested countermeasures are provided to European Commission to develop a directive on a broad European basis for safer roads and reducing the number of fatalities.

A flared end of the initial elements of guardrails in order to prevent collision with the ramped terminal, or respectively the possibility moving behind the system has been discussed repeatedly. Hence the real accident situation has to be taken into account for this alternative so that a necessary flare angle can be scientifically justified.
Data such as collision speed and velocity angle gathered from real accident situations are essential parameters for justifying a maximum flare angle allowed. If velocity angles without possible statistical outliers are taken into account, a velocity angle of up to 13° can be observed within this study (see Figure 5). According to testing specifications EN 1317-2 protective devices with impact angles of 20° are tested. From this difference a flare angle of 7° would be the result, corresponding to a ratio of 1:8. Even the combination of a maximum velocity angle of 18° as well as the flare angle of 7° and thus an impact angle of 25°, would be sufficient to lead a passenger car back to the lane at a crash barrier according to a containment level H2. This level is a minimum requirement on Austrian Autobahn [7, 2008a]. Reid et al [15, 2007b] suggested a maximum flare rate of 1:5 based on full-scale crash tests and computer simulations. Furthermore the authors concluded that this flare rate will still provide acceptable safety performance without significantly increasing risks of injury of fatality.

Due to the distribution of mass (see Figure 7) of vehicle and the expected collision speed, kinetic energy was evaluated, which protective devices will finally have to receive. This consideration was based on the 85% percentile collision speed of 127 km/h and the maximum impact angle of 18°. Therefore a maximum of expected kinetic energy of approx. 150 kJ can be calculated. As seen in the bibliographic reference (EN 1317), protective devices will have to be designed with a much higher possibility to hold back, level H2 for at least 288 kJ [2]. This on the other hand implies that level H2 prevents a passenger car from lane departure and collision with hazards.
In the next picture different collision speeds at a flare angle of seven degrees and an observed run-off-road angle of 18 degrees are summarized. Collision speed is assumed to be at the level of run-off-road speed due the relative short distance of guardrails to the road. The vertical axis represents the vehicle weight distribution. It can be concluded that cars driving on Autobahn within the legal Austrian speed limit of 130 kph road restraint systems at a containment level H2 will protect vehicles leaving the road against impacts with roadside objects.

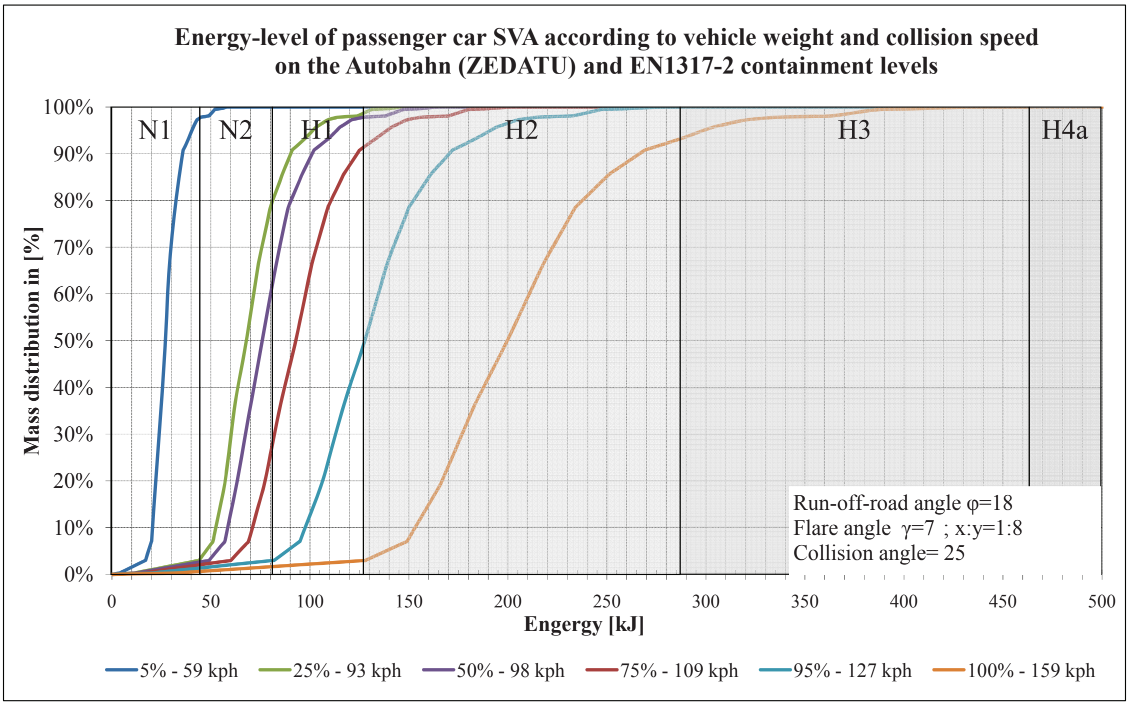

Figure 8: Energy-level of passenger car impacts according to vehicle weight and speed on the Autobahn

CONCLUSIONS AND RECOMMENDATIONS

Studies carried out in the US indicated the problem with ramped terminals. The increased risk of injuries in comparison to other initial elements is clearly pointed out. From the viewpoint of the authors it is recommended that ramped terminals of guardrails should be avoided or be replaced by energy absorbent constructions in future rehabilitation and reconstruction road-way improvements.
Results of a series of BASt test, showing vehicles colliding at a speed of 80 kph with the ramped end, are quite similar. The degree of injury severity could not be defined more specifically because merely information on the testing process was possible. On these findings limiting values in case of a collision were derived. But at these collision speeds the performance limit of the regular ramped terminal (1:12) was reached and thus it can be assumed that at higher speed, an increase of injury severity can be expected.

In the EU Project RISER accidents involving single vehicle accidents were investigated and suggestions for reduction of injuries at initial elements of guardrails were given. As shown in the US studies, the authors come to the conclusion that the ramped terminals of guardrails as explained should be replaced by energy absorbing constructions. The initial elements of the crash barriers at slopes should be pointing outwards in order to make a straight collision with the ramped end impossible. By these means a run-off-road vehicle can be prevented from moving behind the crash barrier and subsequently colliding with a shielded obstacle. As far as blunt ends are still in use, these should be replaced by ramped terminals in order to fulfil a reference standard.

The real accidents investigated in this study, show a very similar picture. Fatal traffic accidents with ramped terminals addressing around 20% of run-off-road accidents i.e. approx. nine people are killed every year in Austria. Information on injury severity in collisions with terminals or crash cushions is not available from national statistics.

In order to reduce collisions with ramped terminals, the following feasible issues are recommended.

- Gap closing at interruptions

During an on-site investigation of the participants of this project it was discovered that closing a guardrail interruption of less than 200 metres leads to a reduction of 1/3 of initial elements. Hence it is recommended to close gaps to reduce the number of initial elements.

- Flare the end of guardrails

In order to avoid a collision with ramped terminals, the first elements should be flared away to the side of the traffic lane and should be turned into the slope. A very crucial result of this study was the maximum flare angle. From the evaluated real accidents a flare ratio of 1:8 was calculated. Steeper flare angles should be avoided because of increased collision severity. Basically each initial element of guardrails should be flared and if possible turned into the slope. Hereby the chances of colliding with the ramped end are reduced. If this is not possible subsequent topic comes into account.

- Terminals

If initial elements cannot turned into the slope at some road sections, or respectively flared initial elements cannot be realized because of regional conditions and the expected collision speed of impact at ramped terminals is above 80 kph, energy absorbing terminals or crash cushions should be implemented. Fill slopes, which have to be secured according to the current national guidelines, should be shielded with guardrails and energy absorbing initial elements (collision speed at impact above 80 kph).

- Crash Cushions

Crash cushions are especially recommended at places where redirection by a crash barrier is impossible and a front- impact collision with the object can be anticipated. For example at access roads to parking sites, motorway exits, intersections etc. and in front of tunnel entrances.

To summarize, closing the gaps and positioning of crash cushions and energy absorbing terminals at exit areas in addition to flare the first elements of guardrails into the roadside (identified as ramped terminals) would reduce the number of ramped terminals by two third.

OUTLOOK

Further investigation needs to be performed at a higher number of run-off-road accidents. Due to the accessibility of fatal accidents only the study needs to be extended by cases with minor and severe injuries to represent an overall accident picture. Another important impact can be seen in newer vehicle which are already equipped with driver assistance systems such as ESP, lane departure warning, etc. But not only systems in the vehicle can reduce accidents. It needs to be discussed how much “rumble strips” do influence run-off-road accidents.

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