Single Vehicle Accidents, Incidence and Avoidance

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Abstract
In a first step, we have examined approximately 23 000 single vehicle accidents within the Austrian National Statistics database. In a second step, we considered 15% of all fatal 'running off the road' accidents that occurred in Austria in 2003. As a result, two accident categories were specified; 'leaving the road without preceding manoeuvre' and 'leaving the road with preceding manoeuvre'. These two categories can be basically characterised by the vehicle's heading angle and its velocity angle. In this report, we further suggest theoretical approaches for the dimensioning of a safety zone, an area adjacent to the road free of fixed objects or dangerous slopes. We also show the link between the two accident categories mentioned above and the real world accidents analysed in detail. These observations also form the basis for the required length for safety devices. Finally, we summarise accident avoidance strategies.

NOTATION

α	exit angle
a	acceleration, deceleration
d	lateral distance to the roadside
g	acceleration due to gravity
η	driven slope angle
φ	slope angle
R	curve radius
s	braking distance
μ	coefficient of friction
v	velocity

INTRODUCTION

Injuries and fatalities due to single vehicle accidents (SVA) are a significant component of annual road casualties; in the European Union, one third of all fatalities result from SVA. The challenge for road safety professionals lies in finding methods and designing strategies to reduce these casualties.
The objective of this investigation was to analyse the incidence of single vehicle accidents and the corresponding infrastructural safety measures with a particular view to frequency and dangerousness of different accident types as well as the accident causation action.
On the basis of the detailed investigation of real world accident data, two major accident categories were specified, namely 'Leaving the road without preceding manoeuvre' and 'leaving the road with preceding manoeuvre'. The accidents in the first category represent the main part of the running off the road accidents on straight roads. These accidents are typically caused by inattentiveness, distraction, fatigue, alcohol, etc. Characteristic for these kinds of accidents is, the small running off angle on the one hand and the fact that the running off angle is equal to the velocity angle on the other. In contrast, the accidents in category two typically show a yaw angle, i.e. the running off angle and the velocity angle are not equal.
Trees were identified as the most dangerous collision objects involved. Their partially small lateral distance to the road - often in combination with a fill slope - represents an increased risk compared to other collision objects. Embankments are also a big problem for running off the road accidents as they often initiate a rollover. In addition, the transitions between different inclinations are a problem if they are not rounded. As for cut slopes, an impact against the embankment frequently occurs, and this impact is the initial cause for the subsequent rollover. The beginning and end ramps of guardrails represent further risk objects.
For the dimensioning of the safety zone, that shall provide an area for drivers to control or stop their vehicles if they have had an unplanned departure from the road, we point out appropriate theoretical observation and we further outline the link between the two accident categories mentioned above and

the real world accidents analysed in detail. These observations also form also the basis for the required length for safety devices. In addition, accident avoidance strategies are summarised.

PROCEDURE

Statistical data provides the basis for determining the relevance of single vehicle accidents. At first, we examined Austrian National Statistics in order to receive an overview of SVA [1, 2]. National Statistics uses census templates with defined data fields, which are filled out by the police [3]. We used these data to analyze the distribution of the individual accident types with a particular view to their frequency and severity [5, 9].

This enabled the comparison with statistical data of other countries that we used to measure whether such accident scenarios can be considered as a purely local problem or if they show similarities even in different countries [5]. These evaluations formed the basis for the selection of the real world accidents, which we analyzed in further consequence to measure their causes and their avoidance potential.

To determine the accident inducing event, the performance of infrastructure and the avoidance strategies, detailed accident data is necessary. We selected the real world accidents according to the quality of the respective available data (documentation, photo, sketch, court records, medical reports, etc.) [4, 6], and according to the statistic distribution. Furthermore, the selected accidents were simulated with the accident reconstruction program PC-Crash [7, 8]to illustrate both the accident-inducing event and the possible avoidance scenarios. With the results of the analysis we defined two typical categories of SVA that show different characteristics. They represent the two main groups of running off the road accidents. Additionally, we analysed objects in the road side area and their hazardous potential. [9].

We derived and compared characterizing parameters for the two accident types and the different infrastructural objects and used these parameters to develop avoidance scenarios.

RESULTS

Austrian Statistics

We investigated approximately 23 000 single vehicle 'running off the road' accidents out of the National Statistics data with respect to KSI (killed and severe injured) participants. The Austrian accident types catalogue comprises ten main groups. Each main group is divided into distinct sub-groups which describe the accident configuration more or less exactly [10].

For the investigation of SVA, however, not all accident types are of interest. Secondary collisions, i.e. accidents in which the actual cause was an event that resulted in a running off the road and/or impact into a object in or near the road, are not considered in this study.

Accident type 0 „Single vehicle accident"		
UG 01	„Single vehicle accident due to leaving the road on the right side"	
UG 02	„Single vehicle accident due to leaving the road on the left side"	
UG 03	„Single vehicle accident due to leaving the road in the area of an exit or junction"	
UG 04	„Single vehicle accident due to leaving the road while reversing or turning around"	
UG 06	„Single vehicle accident due to driving into hindrances, securings; rear-end collision w/o another vehicle or animal"	
Accident type 1 „Collision between two vehicles driving in the same direction"		
UG 12	„Collision between two vehicles driving in the same direction due to changing into the lane "	
	UT 122	„Collision between two vehicles driving in the same direction due to changing into the right lane and leaving the road on the right side"
	UT 124	„Collision between two vehicles driving in the same direction due to changing into the left lane and leaving the road on the left side"
Accident type 2 „Collision between two vehicles proceeding in opposite directions"		
UG 22	„Leaving the road to the right/left due to a vehicle proceeding in the opposite direction, no collision "	

Table 1: Accident types and sub-groups

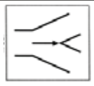
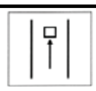
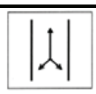
SVA - SUBGROUP	Fatal		Severe		Minor		Not Defined		Total	
LEAVING THE ROAD LEFT 		402		1 959		4 529		1 170		8 060
		5.0%		24.3%		56.2%		14.5%		100.0%
	38.0%		27.7%		27.5%		29.4%		28.2%	
LEAVING THE ROAD RIGHT 		563		3 160		7 413		1 939		13 075
		4.3%		24.2%		56.7%		14.8%		100.0%
	53.2%		44.7%		45.0%		48.7%		45.7%	
LEAVING THE ROAD AT JUNCTIONS… 		36		387		1 082		176		1 681
		2.1%		23.0%		64.4%		10.5%		100.0%
	3.4%		5.5%		6.6%		4.4%		5.9%	
DRIVING INTO HINDRANCES… 		11		70		231		36		348
		3.2%		20.1%		66.4%		10.3%		100.0%
	1.0%		1.0%		1.4%		0.9%		1.2%	
REVERSING OR TURNING AROUND 		4		27		55		7		93
		4.3%		29.0%		59.1%		7.5%		100.0%
	0.4%		0.4%		0.3%		0.2%		0.3%	
OTHER SINGLE VEHICLE ACCIDENTS		1		16		47		3		67
		1.5%		23.9%		70.1%		4.5%		100.0%
	0.1%		0.2%		0.3%		0.1%		0.2%	
FALL FROM AND IN THE VEHICLE		41		1 450		3 121		649		5 261
		0.8%		27.6%		59.3%		12.3%		100.0%
	3.9%		20.5%		18.9%		16.3%		18.4%	
TOTAL		3.7%		24.7%		57.6%		13.9%		100.0%
	100%	1 058	100%	7 069	100%	16 478	100%	3 980	100%	28 585

Figure 1: SVA in Austria between 2000 and 2002

Three accident types with the corresponding sub-groups are important for this investigation, namely accident type 0 'Single vehicle accident', accident type 1 'Collision between two vehicles driving in the same direction' and accident type 2 'Collision between two vehicles proceeding in opposite directions'. As described in this paper, the classification of the real world accidents with respect to the accident type catalogue is ambiguous, depending on the accident or the initiating event. Hence, accident type 0, defined as 'Single vehicle accident', is of main interest, but we also considered type 1 type 2 accidents as supplementing for detailed investigations.

For a general overview, the accidents in Austria were analyzed during a period of three years (2000 - 2002). In this period, 28 585 accidents with 37 730 injured people occurred in the category of 'Single vehicle accidents'.

With approx. 46%, the accident subtype 'Leaving the road on the right side' holds the highest share within SVA, whereas the accident subtype 'Leaving the road on the left side' represents 28% of the overall sum of SVA. Further relevant accident subtypes in SVA are: 'Fall from and in the vehicle' with 18% (this subtype is not relevant for this investigation), 'Leaving the road in the area of an exit or junction, applied to all types of junctions' with 6% and 'Driving into hindrances, securings; rear-end collision w/o another vehicle or animal' with a share of 1%. All other accident types are of minor relevance.

The occurrenace of the accident subtypes 'Leaving the road on the right side' and 'Leaving the road on the left side' increases if the frequency is compared to the severity of the accident subtypes (right: 46% of all SVA but 53% of all fatal SVA; left: 28% of all SVA, but 38% of all fatal SVA).

In the 'Leaving the road on the right side' and 'Leaving the road on the left side' accidents an increased risk for fatal accidents can be observed; it is interesting, however, that the subtypes 'Leaving the road on the left side of a right-hand curve' and 'Leaving the road on the right side of a left-hand curve' show an increased risk for injuries. This circumstance can be explained by the fact that these are typical accidents where speed is not adjusted.

If the so called KSI accidents, i.e. accidents that usually result in severe or fatal injuries, are investigated, 'Leaving the road on the right side of a left-hand curve' and 'Leaving the road on the left side of a right-hand curve' show an increased risk. Compared with 'Leaving the road on the left side of a right-hand curve' (11%), the subtype 'Leaving the road on the right side of a left-hand curve' also shows an increased frequency (18%) . This circumstance can be explained by the fact that the

oncoming traffic lane is still available as additional area for correction manoeuvres for right hand traffic in the case of ‘Leaving the road on the left side of a right-hand curve’.
An increased risk for fatal injuries is shown for accidents on straight road, for severe injuries there is an increased risk for leaving the road accidents at the exterior side of the bend. For KSI, again an increased risk results for leaving the road accidents in the exterior side of the bend.
Within the analysis of KSI accidents regarding the type of road, ‘Leaving the road on the right side of a left-hand curve’ and ‘Leaving the road on the left side of a right-hand curve’ showed an increased risk. This increased risk can be particularly observed for B-roads. For fatal accidents, an increased risk for leaving the road on straight roads was determined.
In 68 % of all ‘leaving the road’ accidents in the years 2000 – 2002 with well-known accident severity, passenger cars were involved. Considerable rates were also recorded for motorcycles (11 %), mopeds (9 %), bicycles (5 %) and trucks up to 3.5t without trailers. The participation of all other vehicles was below 1 %. If a reference value from frequency (occurrence) and risk (accident severity) is built, then an increased risk for KSI accidents is reported for motorcycles.
Regarding the participation of vehicles in fatal leaving the road accidents during the year 2003, passenger car accidents dominated. Further considerable shares were observed for motorcycles (13%), mopeds (4%) and trucks up to 3.5t without trailers (3%).

Riser Statistics

Within the RISER project (Roadside Infrastructure for Safer European Roads; project funded by the European Commission under the ‘Competitive and Sustainable Growth’ Programme) a database for statistical and detailed data of single vehicle collisions in Europe was generated. In a first step, statistical data from Austria, Finland, France, Spain, Sweden, the Netherlands and United Kingdom were collected. These data were harmonised and a common form was defined to build a representative European database with the aim of comparing the large amount of data, to identifying the distribution of the different accident types and their causation and to provide data and guidelines for further investigations [11].
Most of the RISER SVA occur on straight roads, whereas nearside (nearside means to the right, offside to the left for right-hand traffic; vice versa in the UK) on straight roads is the most important accident type. In Finland and Austria, *nearside in a left curve* and *offside in a right curve* are dominating the accidents in curves. In Great Britain, the opposite distribution can be found due to left-hand traffic. In the category *objects hit*, the relatively high rates of none object hit in Spain (40 %) and the Netherlands (24 %) are remarkable. The *Safety Barrier impact* lies between 20 and 24 % in France, Spain and Great Britain and represents 13 % in Austria (for Austria, only this category is reported) and 14 % in Sweden, but only 2 % in Spain. *Ditch accidents* are relevant for France (29 %) and Spain (15 %); for the Netherlands no *ditch accidents* are reported.
In about 80 % of all RISER SVA a passenger car was involved, in 8 % motorcycles and heavy trucks; bus accidents are below 1 %. Notable is the high rate of *motorcycle accidents* in Austria (17 %) as well as in Spain (11 %), France (10 %) and Great Britain (8 %). In Sweden and the Netherlands the ratio of *motorcycle accidents* is around 4 %, in Finland it is only below 2 %.
Compared to the occurrence in other countries, the ratio of *heavy truck accidents* is high in Finland and Sweden (single unit in Sweden 7.8 %, other countries < 3.2 %; truck trailer combination in Finland 8.3 %, other below 3.1 %).
Regarding the accident type, there are comparable data from Finland, Austria and Great Britain. In general dominates the SVA on straight roads (maximum frequency) and with higher risk for Austria. In Great Britain, *offside in a left curve* and *nearside in a right curve* are important accident types with high risk. These accident types are the corresponding types to *nearside in a left curve* and *offside in a right curve* for right hand traffic (Austria, Finland, etc.), with high frequencies and risk. These accident types typically occur in situation where speeding and inattention are found.

Real Word Cases

In a second step, we examined 15% of all fatal ‘leaving the road’ accidents in Austria throughour the year 2003. Criterion for the accidents selected was the availability of an appropriate documentation, in

order to be able to accomplish a meaningful simulation and thus investigation of the real word accident circumstances.
The detailed investigation of the real word accidents resulted in an adjustment of the accident types compared with the accident types of the statistics. For this investigation we considered the entire operational sequence of the accident. To give an example: the critical situation was in a bend, but the vehicle left the road on the straight section. Or to give another example: Due to driving manoeuvres the vehicle could still be held on the road over a certain distance and so the respective accident was coded as *leaving the road in a bend*. Thus, there was an adjustment of *leaving the road on a straight road* and *junction accidents* to *accidents in a curve*.
On the basis of the analysis of the data from the detailed investigation we specified two main accident categories:

- Leaving the road without preceding manoeuvres
- Leaving the road with preceding actions

It has to be said, however, that a clear demarcation cannot be made as a certain share is flowing as an exact allocation is problematic in case of absence of traces, no appropriate documentation and no clear testimonies.
'Leaving the road without preceding manoeuvre' accidents represent the main part at the *running off the road accidents* on straight roads. These accidents are typically caused by inattentiveness, distraction, fatigue, alcohol, etc. Characteristic for these kinds of accidents is the small running off angle. The running off angle (i.e. the angle between the longitudinal axis of the vehicle and the edge of the road) is equal to the velocity angle (i.e. the angle between the velocity vector of the vehicle and the edge of the road)
In contrast, the 'leaving the road with preceding actions' accidents typically show a yaw angle, i.e. the running off angle and the velocity angle are not equal. In all cases, the velocity angle is less than 20° and shows a tendency to smaller angles at higher speeds with exception of the exterior side of the bend with approximately constant tendency. As for the running off angles, a reverse tendency can be observed; at higher running off velocities a tendency to greater running off angles can be seen.
When analysing the distance from the actuating manoeuvre to the running off the road for the 'leaving the road with preceding actions' accidents, we found that the higher the increasing initial velocity, the longer the distances on the road.
Regarding the time, the vehicle moves on the road until the running off occurs. Particularly for *leaving the road on straight roads accidents*, an, average time interval between two and three seconds is shown, that is independent from the initial velocity.
An interesting fact for the 'leaving the road with preceding actions' is the low deceleration level(mean deceleration of 1.8 m/s^2) until the leaving the road sequence, although the majority of the accidents occurred on dry roads. This can be explained by the fact that the majority of the drivers tries to control their vehicle by steering manoeuvres and only moderate brake sequences. The full application of the brake is generally executed at the time when the vehicle leaves the road (e.g. average deceleration level from running off the road to the impact of 5.0 m/s^2).
For the 'leaving the road without preceding manoeuvre' accidents, the mean deceleration level until the impact is 3.1 m/s^2. This is a lower level compared to the 'leaving the road with preceding actions' accidents with a mean deceleration level of 5.0 m/s^2. This can be argued by the fact that the reaction and the following brake sequence are executed after the vehicle runs off the road, and therefore the distance for deceleration is reduced.
The comparison of the two categories regarding running off velocity, shows that the mean running off velocity for both types of accidents is app. 85 kph. The mean initial velocity for the 'leaving the road with preceding actions' accidents is app. 100 kph.
The mean velocity angle for the 'leaving the road without preceding manoeuvre' accidents is app. 8° and the mean running off angle is app. 9°, compared to 16° of mean velocity angle and 31° of mean running off angle for 'leaving the road with preceding actions' accidents. Therefore, different requirements have to be claimed for roadside safety systems of the two categories. The 'leaving the road without preceding manoeuvre' accidents are on a lower level compared with the required test conditions from EN 1317 [13] regarding velocity and angles. With containment level N2 (car with 900

kg and 100 kph with an angle of 20°, car with 1500 kg and 110 kph with an angle of 20° against safety barrier), nearly all passenger car ‘leaving the road’ accidents on standard roads could be handled as only heavy vehicles and vehicles with exceeded travel speed exceed the requirements N2.
The ‘leaving the road with preceding actions’ accidents show higher demands for the safety systems regarding running off angles, and are also more problematic to be handled, since they occur with a yawing movement of the vehicle.
The mean impact velocity for both categories is app. 70 kph, with a large range from a minimum of 25 kph and a maximum of 113 kph for ‘leaving the road with preceding actions’ to a minimum of 20 kph and a maximum of 135 kph for ‘leaving the road without preceding manoeuvre’. An accumulation can be seen between 60 and 70 kph impact velocity.
Regarding the crash causing collision partner, 11 different objects could be identified. The most frequent collision object was a tree (12 cases) followed by fill slopes (7 events), cut slopes (6 cases) and guardrail ramps (5 accidents).
Trees were identified as the most dangerous collision objects. The partial small lateral distance to the road often in combination with a fill slope represents an increased risk compared to other collision objects. Embankments also are a big problem for leaving the road accidents as they often initiate a rollover. These rollovers are often released by the fact that no uniform ground exists and thus it comes to hooking in the soil with simultaneous skidding movements of the vehicle. In addition, the transitions between different inclinations are a problem if they are not rounded. For cut slopes, an impact against the embankment frequently occurs which is the initial cause for the following rollover. The beginning and end ramps of guardrails represent a further risk object.
Concerning the lateral distance of the impact objects it can be stated that the mean lateral distance was 2.4 m, whereby the minimum was 0 m and the maximum was 9 m. The majority of the fatal accidents happened, however with an impact against an object whose lateral distance was smaller than 6 m.

THEORY

The path of the centre of mass of a vehicle leaving the road can be expressed as a function of the lateral distance to the roadside (d) and the speed (v), assuming that the steering system is the determining factor for the motion of the vehicle. For straight roads (Figure 2 right, Formula [2]) the maximum exit angle (α) can be derived over the centripetal acceleration and the maximum coefficient of friction (μ).
With similar considerations the exit angle (α) in curves can be derived (Figure 2 left, Formula [1]), whereby however, not the vehicle speed (v), but the lateral distance to the roadside (d) and the curve radius (R) are the determining factors, with the assumption that the vehicle is not steered in the curve (Figure 2 left).

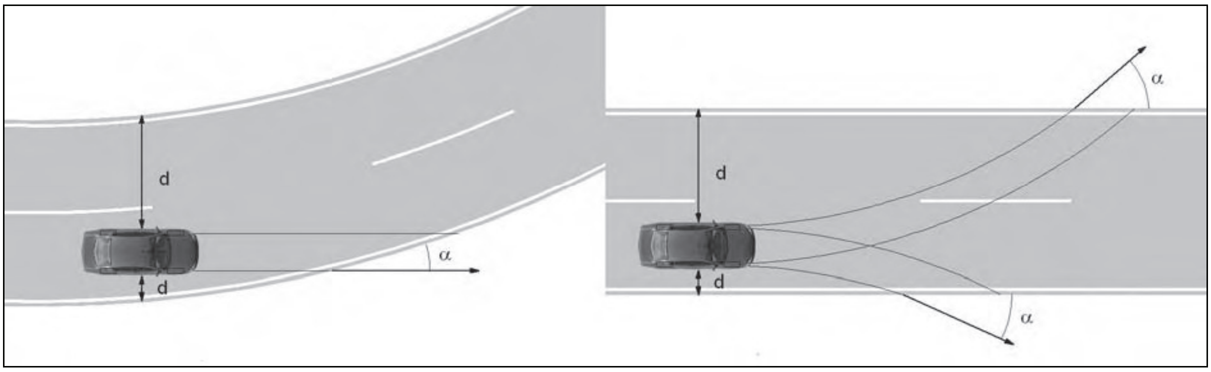


Figure 2: Exit angle for curves and on straight roads

$$\alpha = \arccos\left[1 - \left(\frac{d}{R}\right)\right] \qquad [1]$$

$$\alpha = \arccos\left[1 - \left(\frac{\mu \cdot g \cdot d}{v^2}\right)\right] \qquad [2]$$

From the formula for straight roads [2] it results that the exit angle (α) increases with the coefficient of friction (μ) and the lateral distance to the roadside (d) and decreases with the speed (v) of the vehicle. The tendency to smaller exit angles with higher speeds also is a result of the evaluation of the real world accidents. From the theoretical considerations it can be verified that for conventional roads with two lanes, dry pavement and a vehicle speed of 100 kph the accident results in a maximum exit angle smaller than 20°. This is in accordance with the EN 1317 [13] regulation tests for road restraint systems. For conventional curve radii, the maximum exit angle is also smaller than 20°.

For the theoretical considerations we assumed that the vehicle moved stable. Due to an abrupt steering manoeuvre, in real world accidents a rotation of vehicle around the vertical axis (yaw) can be observed. It must be differentiated between the trajectory of the vehicle's centre of gravity (speed angle) and the vehicle orientation (heading angle). If now yawing arises, both angles are identical.

If it is assumed that the human body cannot survive without additional protective mechanisms in collisions with impact speed above 40 kph, this value results for the definition of the maximum needed stopping distance and/or the lateral surface, which is needed to decelerate the vehicle to this value. During the impact, part of the energy is absorbed by the vehicle structure and by the occupant restraint system. The vehicle structures and the restraint systems are optimized for standard crash-tests, hence SVA accidents are not sufficiently considered within legal crash-test scenarios. Thus, an accumulation of impact speeds above 50 kph could be observed for the fatal real word accidents as well (in 87% of all evaluated cases the impact speed was higher than 50 kph and in 92% higher than 40 kph).

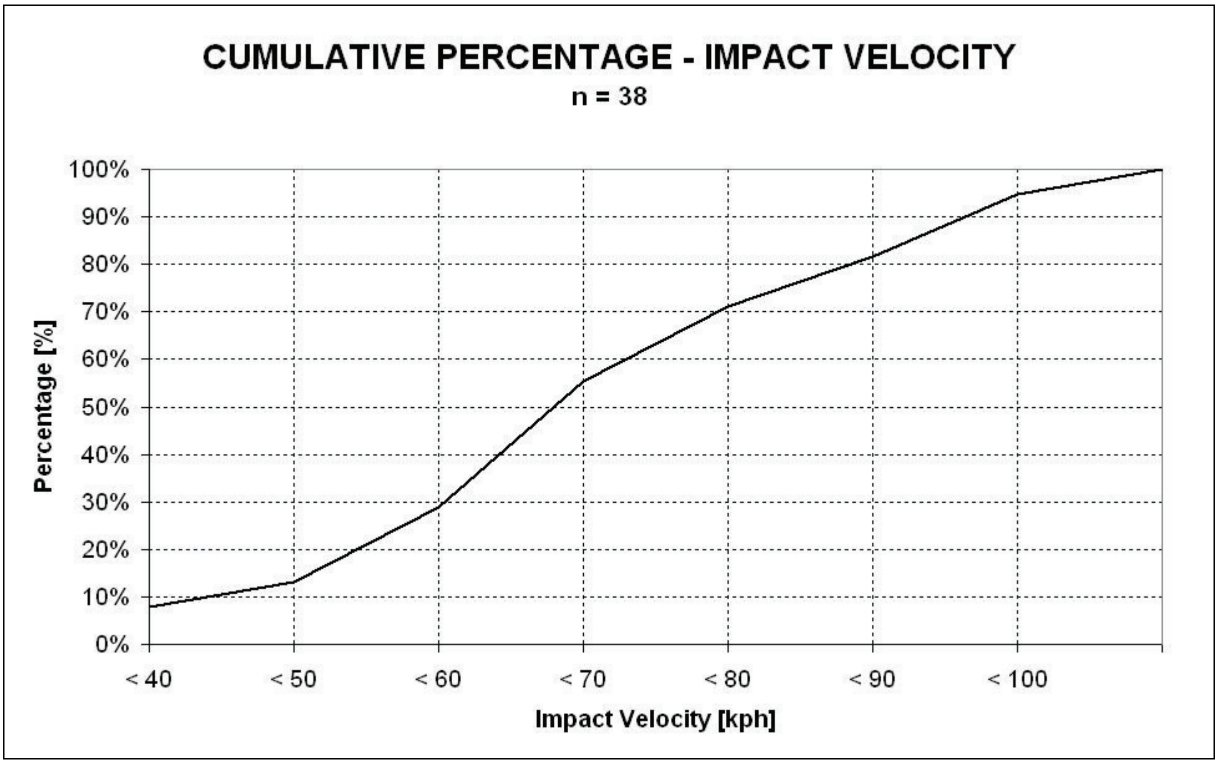


Figure 3: Cumulative Percentage of impact velocity for fatal real world accidents

If the safety zone is designed to eliminate impacts with objects for impact speeds higher than 40 kph, then the lateral distance of the safety zone must be designed in such a way that the vehicle can decelerate until this speed is reached. The approximate braking distance of a vehicle from the speed of the roadway to 40 kph (11.1 m/s) may be determined from the following equation:

$$s = \frac{v^2 - 11.1^2}{2 \cdot a} = \frac{v^2 - 11.1^2}{2 \cdot \mu \cdot g} \qquad [3]$$

Previous studies documented that most drivers decelerate at a rate greater than 4.5 m/s² during braking. Approximately 90 percent of all drivers decelerate at rates greater than 3.4 m/s². Such decelerations can be handled by most drivers [14]. The friction levels of the different roadside sections are often not consistent. In case of wet grass for a vehicle leaving the road the worst case is a friction coefficient of 0.3 (with exception of ice). This results in an available deceleration rate of 2.9 m/s².

Roadside geometry has a great influence on the frequency of serious injury and fatal crashes; especially the design of the side slopes has influence on the occurrence of rollovers, which is one of the most dangerous events in single vehicle accidents. The US Roadside Design Guide [15] defines recoverable, traversable and non-traversable slopes. A recoverable slope is a slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle by slowing or stopping. Slopes flatter than 1:4 are generally considered recoverable, where motorists can stop their vehicles or slow down enough to safely return to the roadway. A non-recoverable slope is a slope which is considered traversable but on which an errant vehicle will continue to the bottom. Embankment slopes between 1:3 and 1:4 may be considered traversable but non-recoverable if they are smooth and free of fixed objects. A clear run-out area is the area at the toe of a non-recoverable slope available for safe use by an errant vehicle.

For fill slopes, the approximate stopping distance of a vehicle may be determined from the following equation:

$$s = \frac{v^2 - 11.1^2}{2 \cdot a} = \frac{v^2 - 11.1^2}{2 \cdot g \cdot (\mu \cdot \cos(\varphi) - \sin(\varphi))} \qquad [4]$$

The formula above also contains the maximum slope angle for a given coefficient of friction. If the upward gradient of the slope is equal to the coefficient of friction, the limit for a safe deceleration is reached.

$$\tan(\varphi) = \mu \qquad [5]$$

Thus, for slopes 1:3 and coefficient of friction 0.3 there will be no safe stop possible (the border inclination for a coefficient of friction of 0.3 is 30%, which means no speed reduction despite full brake application).

The absolute inclination of the slope is not relevant for leaving the road situations, but the resulting inclination when driving under a certain course angle. The vehicle's heading angle changes while driving on the slope due to the driver input. The driven inclination can be determined by the side inclination and the speed direction using the following correlation:

$$\sin(\eta) = \sin(\varphi) \cdot \sin(\alpha) \qquad [6]$$

Using the information presented previously, the width of the safety zone can be defined as the width necessary to stop a vehicle to avoid serious impact. As an example, the following table lists the recommended safety zone widths if the road, speed, and slope conditions are:

- Coefficient of friction 0.3 (grass)
- Initial manoeuvre on the road was abrupt steering
- Vehicles decelerate on roadside without manoeuvre
- Impact velocity 40 kph after crossing the safety zone
- Flat Ground (ideal conditions)

Exit angle	Slope	µ	a	30	40	50	60	70	80	90	100	110	120
°			m/s²	Posted speed kph, Impact speed = 40 kph									
35	0	0.3	2.9	0	7	15	25	37	50	64	80	98	117
28	0	0.3	2.9	0	6	12	21	30	41	52	66	80	96
22	0	0.3	2.9	0	4	10	16	24	32	42	52	64	76
19	0	0.3	2.9	0	4	9	14	21	28	36	45	55	66
16	0	0.3	2.9	0	3	7	12	18	24	31	39	47	56
14	0	0.3	2.9	0	3	6	11	15	21	27	34	41	49
12	0	0.3	2.9	0	2	6	9	13	18	23	29	35	42
11	0	0.3	2.9	0	2	5	8	12	16	21	27	32	39
10	0	0.3	2.9	0	2	5	8	11	15	19	24	30	35
9	0	0.3	2.9	0	2	4	7	10	14	17	22	27	32
8	0	0.3	2.9	0	2	4	6	9	12	16	19	24	28

Table 2: Theoretical Safety Zone Widths

DISCUSSION

A comparison of the values in Table 2 with actual safety zone dimensions in current guidelines demonstrates that the theoretical values are much higher than in practice. This is a practical problem for the road owner/operator and local conditions must be considered. However, this approach can be useful for applying local modifications to the safety zone.
The dimensioning of a safety zone is a difficult process. A theoretical process using vehicle dynamics and human tolerance information provides rather large safety zone dimensions. An alternative is to use the struck object setback obtained from the accident data. In this approach, the data coming from Austria and the RISER real world cases appear to support information from France, the US, and the Netherlands which shows that the risk of contact with an obstacle drops dramatically after the first few meters and most impacts with roadside obstacles occur in the first 10 m.
Most safety zones in Europe are specified to be between 6 and 10 m for travel speeds around 100 kph. Safety zones are smaller for lower speeds and for 80 kph roads, investigated European countries use 4.5-7 m as a safety zone width.
There should be no dangerous objects within an area of 5 to 7 m to the roadside; if this is not possible, the objects should be removed or protected by safety barriers.
Dangerous objects are

- Trees with a defined diameter
- Poles and posts
- Slopes (fill and cut slopes have nearly the same risk potential)
- Noise protection walls (if they are within the working with of the barrier system)
- Barrier terminations are also of high relevance and have great design potential

Driving behind a safety barrier (moving back the start and end elements) and lacks within some meters of safety barrier systems should be avoided [16, 17].

CONCLUSION

On the basis of the detailed investigation of real world accident data in general, two accident categories could be specified. ‘Leaving the road without preceding manoeuvre’ accidents represent the main part of the leaving the road accidents on straight roads. These accidents are typically caused by inattentiveness, distraction, fatigue, alcohol, etc. Characteristic for these kinds of accidents are the small running off angle and the fact that the running off angle is equal to the velocity angle. In contrast, the ‘Leaving the road with preceding actions’ accidents show typically a yaw angle, i.e. the running off angle and the velocity angle are not equal.

Objects are collision-relevant if they are located within a distance between five to seven meters on the road side. For SVA leaving the road accidents the velocity angle generally is below 20 degrees. The typical leaving the road velocity is about 80 kph but however, can be strongly deviate. Nearly all vehicles get off the road within three seconds after the conflict situation.
Trees were identified as the most dangerous collision objects. The partial small lateral distance to the road - often in combination with a fill slope - represents an increased risk compared to other collision objects. Embankments are also a big problem for leaving the road accidents as they often initiate rollovers. In addition, the transitions between different inclinations are a problem if they are not rounded. For cut slopes often occurs an impact against the embankment which is the initial cause for the following rollover. The beginning and end ramps of safety barriers represent a further risk object.
Nearly twice as many vehicles get off the road on the exterior side of a bend compared to the interior side and in left bends the injury risk is twice as high as in right bends.
For the dimensioning of the safety zone, appropriate theoretical links are pointed out and the link with the detailed analysed real world accidents is shown. These observations also form the basis for the length of need for safety devices.
The requirements for the safety zone are that:

- the consequences of running of the road accidents are reduced
- the width is designed in such a way that most vehicles leaving the road do not leave the safety zone
- there are only slopes that do not cause rollovers
- the surface is homogenous and even to prevent rollovers
- there are no unprotected fixed objects located within the safety zone

The safety zone should only contain objects that will collapse or break away when impacted without significantly damaging an errant vehicle. Where allocation of an appropriate safety zone is not possible, appropriate barriers should be used to protect dangerous objects [16, 18].

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