Tree impacts – still one of the most important focal points of road deaths

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Abstract – Tree impacts are still one of the most important focal points of road deaths in Germany. For the year 2008, the latest figures in the national statistics show a share of 28% of road users killed in crashes with trees alongside a road amongst all crashes on rural roads (except the Autobahn). The official German statistics show the attribute "impact on a tree" since 1995. For this first reported year, the share of road users killed in such crashes was 30%.
During the last 14 years, fatal accidents with road users killed on rural roads (except the Autobahn) after impacts on a tree declined by 60% from 1,737 (year 1995) to 696 (year 2008). But this is more or less in line with the general evolution of vehicle and traffic safety in Germany. For Germany as a whole the accident statistics do not show a reduction for "tree crashes" which is clearly more than the average for all accidents. But, as shown with the paper, there are different evolutions in the several German States. In public awareness the topic „tree impacts" is mostly associated with the situation in Germany after the reunification. At that time a lot of road users were killed on the avenues in the so called "new countries". The fact that "tree impacts" are still a big share within the figure of killed road users seems to be little-known.
Using updated information coming from the official statistics and in-depth-studies, accident researchers can identify a big potential for further improvements of traffic safety on the associated district roads, state roads and federal highways. There is still a need to analyse more details of the accident occurrence with impacts on trees to generate new and updated findings on the current limits and potentials of measures to improve vehicle and traffic safety.
To make further efforts in reducing the figures of victims of "tree impacts" the intensification of well-known conventional solutions – for example implementation of guard rails and reduction of speed - is an option. Measures related to vehicle-safety technology especially in the field of primary (active) safety will have additional benefit within the physically imposed limits. With this background it can be seen that the subject "tree impacts" should be analysed with a holistic approach taking into account the entire system of driver, vehicle, road, the environment and a social consensus as well.

1 HISTORICAL EVOLUTION OF GENERAL FIGURES IN THE GERMAN FEDERAL ACCIDENT STATISTICS

For the Federal Republic of Germany sustainable achievements with the improvement of traffic and vehicle safety are proven since almost 40 years. This is displayed with imposing figures coming from the road-accident statistics. On the one hand, in the year 1970 alone for the states of the former Federal Republic of Germany with 19,193 killed road users a plaintive all-time record was reached. On the other hand, at that time the trend of (more ore less) continuously increasing figures of casualties as in the years before was successfully stopped, see **Figure 1**.

In the reunified German Federal Republic 11,300 road fatalities were counted for the year 1991. This figure decreased by 60% down to 4.477 until the year 2008. Nevertheless, it has to be remarked that every week 86 humans are killed on German roads. This is not in line with the need for safety in a highly developed society and therefore not acceptable. Further efforts are still needed to continuously reduce the figure of killed road users.

Still, the biggest portion of killed road users are car occupants: 2,368 persons (53%) out of all 4,447 killed road users were in this sub group in 2008. As indicated by the relative figure of killed car occupants referred to 100,000 cars registered in the national circulating fleet of the corresponding year, it is obvious that the most effective efforts in vehicle and road safety related to car occupants occurred in the years before 1990, see **Figure 2**.

Amongst these is the introduction of the resistant passenger cell with a so called "crumple zone" in front as well as the fitting of safety belts as standard equipment starting in the year 1959. The use of safety belts became mandatory on January 1st, 1974. A fine for unbelted occupants in a car has been introduced on August 1st, 1984. In parallel, the OEMs did improve the protection of car occupants model year by model year. In 1980, the market-introduction of airbags began to additionally protect car drivers in the event of a frontal impact (later on for the additional protection of front passengers as well).

During the 1990ies special structural measures to the car body were introduced to protect car occupants in the event of a lateral impact. In the year 1995 the first car equipped with a side airbag entered the marked. The electronic stability control system (ESP) to prevent cars from sideslips was sold for the first time in 1995. In 1997 the so called “elk test” was a catalyst to push this safety technique to large sales figures as the standard equipment for cars.

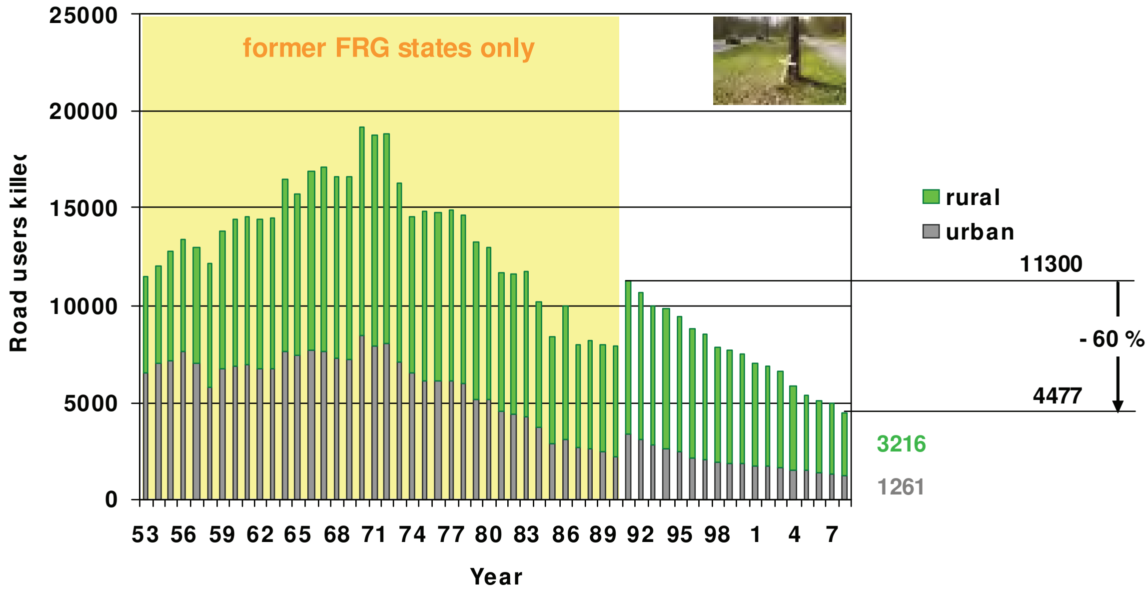
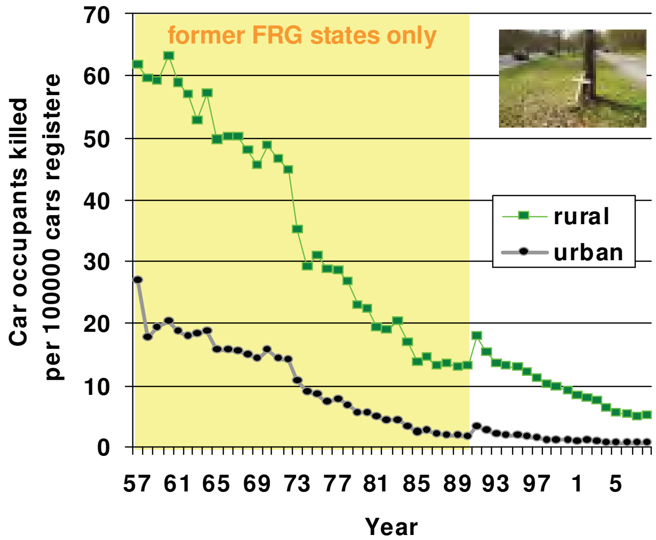


Figure 1. Historical evolution of the figures of road users killed in the Federal Republic of Germany (FRG) on urban and rural roads (data source: DESTATIS [1])



Year	1957	2008
Car occupants killed urban	695	269
Car occupants killed rural*	1598	2099
Cars registered	2583656	40840**
Car occupants killed urban per 100000 cars registered	26.9	0.7
Car occupants killed rural per 100000 cars registered	61.9	5.1

* including the Autobahn

** since 2008 without vehicles temporarily out of service

Figure 2. Historical evolution of the figure of killed car occupants referred to 100,000 cars registered in the national circulating fleet of the corresponding year for the Federal Republic of Germany from 1957 to 2008 (data source: DESTATIS [1])

2 STATISTICS ON REAL-WORLD CRASHES ON TREES

2.1 Current situation in Germany

To further reduce the absolute and relative figures of fatalities, existing potentials have to be tapped as effective as possible. In this context it is of interest that the federal statistics for 2008 report that out of the total of 4,117 fatal crashes, 838 crashes (38%) involved an impact on a tree alongside the carriageway.

Considering the site of these crashes it can be recognised that from the 1,222 fatal crashes on urban roads 98 crashes (8%) have been impacts on trees, **see Figure 3**. From 2,461 fatal crashes outside urban area (without the Autobahn) 696 crashes (28%) involved an impact on a tree. From 434 fatal crashes on the autobahn 44 crashes (10%) were crashes on trees.

These figures demonstrate that the impact on a tree alongside the carriageway is a prominent focal point within the current situation of fatal accidents on the federal highways, state roads and district roads outside urban area. But even for fatal crashes inside urban area and on the Autobahn this kind of accident plays quite an important role.

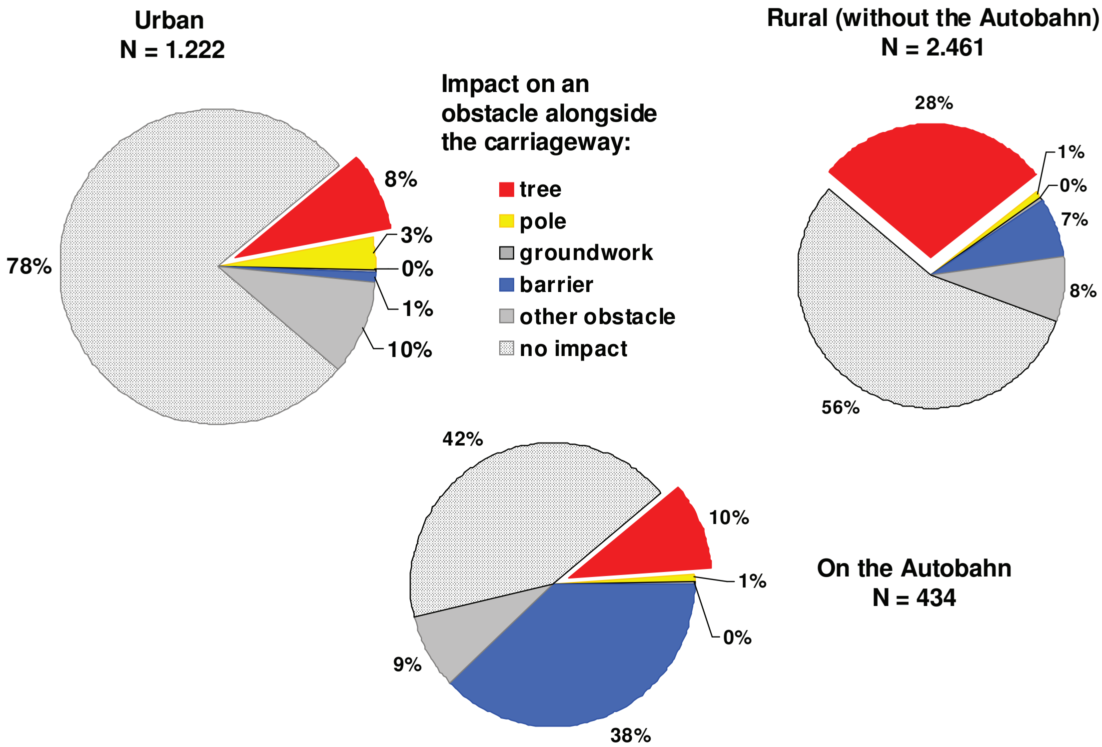


Figure 3. Portion of fatal crashes involving impacts on trees alongside the carriageway for the year 2008 in Germany separated by their sites (data source: DESTATIS [1])

2.2 Evolution in Germany since 1995

Starting with the year 1995 the published German federal statistics display some detailed figures for crashes on trees alongside the carriageway. Therefore the chronological evolution can be displayed and analysed for 14 sequent years up to 2008. In 1995 of all casualties (crashes with killed and injured persons) the portion of fatalities was about 2.2%. For the year 2008 this portion is reduced to 1.3%, see **Figure 4**. This leads to the general finding that the risk of being killed for all crashes involving killed and injured persons has clearly decreased.

For casualties involving impacts on trees alongside the carriageway the portion of fatal crashes was 8.1% in 1995. Hence, in 1995 the risk of being involved in a fatal crash was 3.7 times greater for crashes involving impacts on trees than for all casualties (8.1% : 2.2%).

6.0% of the crashes with killed or injured persons and impacts on trees were fatal crashes in 2008. Referred to 1995 in the considered period of 14 years the portion of fatal crashes amongst these crashes decreased as well. But referred to the portion of 1.4% fatal crashes for all crashes with killed or injured persons recently the risk of being involved in a fatal crash is 4.6 times higher for crashes involving impacts on trees than in all crashes with killed or injured persons (6.0% : 1.4%). Thus, the increased risk mentioned here is still extensive and was even higher in 2008 than in 1995.

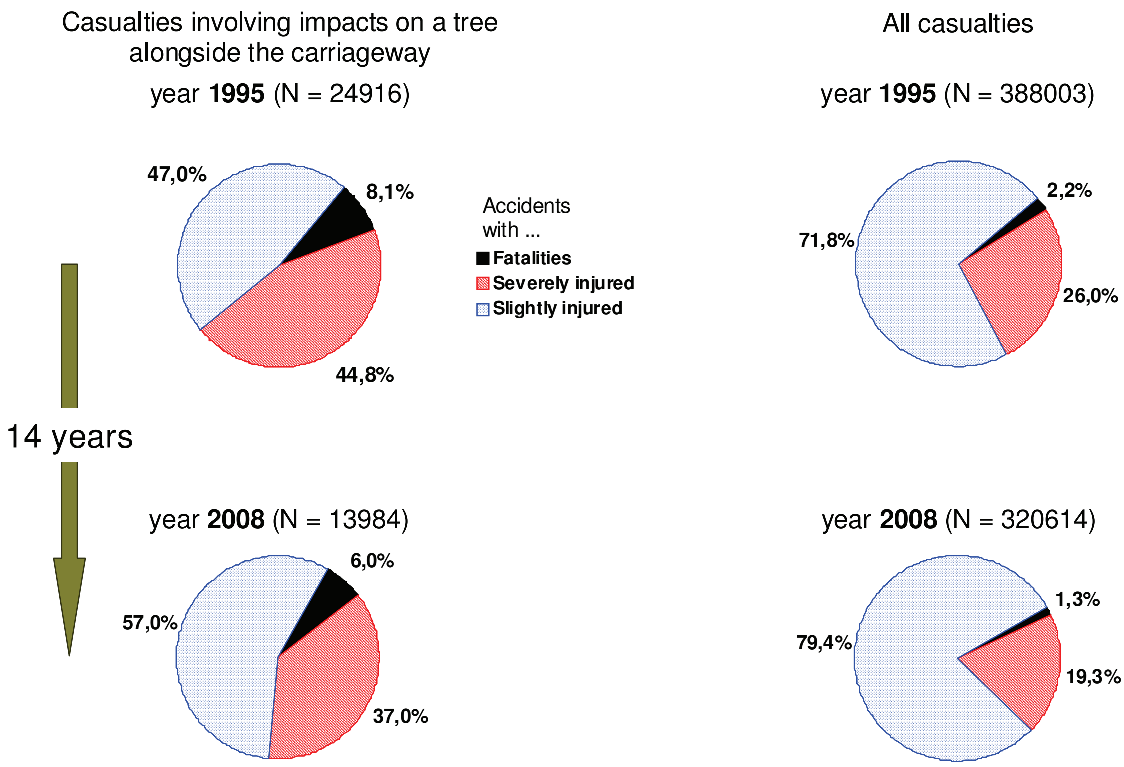
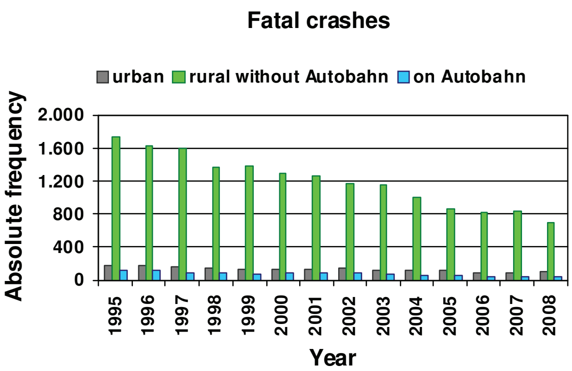
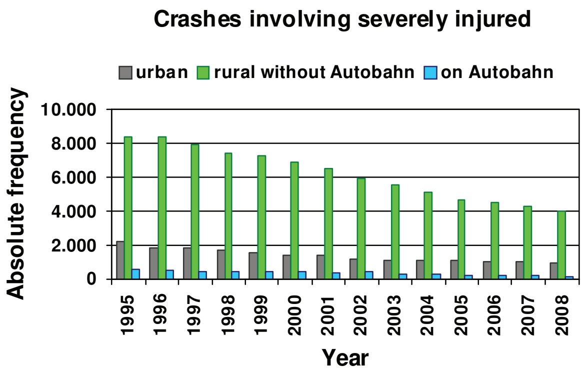


Figure 4: Portions of fatal crashes, crashes with severe injured persons and crashes with slightly injured persons involving impacts on a tree alongside the carriageway and of all casualties in Germany for the years 1995 and 2008 (data source: DESTATIS [1])

As displayed with **Figure 5**, the absolute figures of fatal crashes as well as the absolute figures of crashes involving severely injured persons, both involving impacts on a tree alongside the carriageway, decreased from 1995 to 2008 for all sites in Germany. In this process the figure of fatal crashes on rural roads (except the Autobahn) decreased by 60% (from 1,737 to 696). In parallel, the figure of fatal crashes inside urban area decreased by 45% (from 177 to 98) and in fatal crashes on the Autobahn by 60% (from 115 to 44 crashes) which is very remarkable respectively the same proportion of 60%.

Similar relations can be seen for the evolution of the figures of crashes involving severely injured persons and impacts on trees. For the period under discussion on rural roads (except the Autobahn) a reduction of 52% (from 8,387 to 4,010 crashes) occurred. Inside urban area this figure decreased by 56% (from 2,228 to 981) and on the Autobahn by 66% (from 555 to 190).





Year Crashes involving tree impacts ...	1995	2008	Δ abs.	Δ rel.
... urban	177	98	-79	-45 %
... rural without Autobahn	1.737	696	-1.041	-60 %
... on Autobahn	115	44	-71	-62 %

Year Crashes involving tree impacts ...	1995	2008	Δ abs.	Δ rel.
... urban	2.228	981	-1.247	-56 %
... rural without Autobahn	8.387	4.010	-4.377	-52 %
... on Autobahn	555	190	-365	-66 %

Figure 5. Evaluation of the figures of fatal crashes respectively crashes involving severely injured persons and impacts on trees alongside the carriageway in Germany from 1995 to 2008 separated to their sites (data source: DESTATIS [1])

For the accident occurrence in Germany a consistent and sustainable evolution towards reduced figures of fatal crashes on trees and crashes on trees with severely injured persons can be determined. With the background that typically severe impacts on trees occur predominantly outside urban area (that means on district roads, state roads and federal highways) it has to be asked for the reason of this positive evolution. Special measures to avoid crashes on trees alongside the carriageway outside urban area should have led to a decrease above the average for this type of accidents on such roads.

Obviously this is not the case. Therefore, a nearby assumption is that the reduction of severe crashes involving impacts on trees is mainly due to the general trend of the reduction of fatal and severe accidents in Germany. This involves, amongst others, the steady improvement of the safety of traffic participants by technical measures related to the vehicle itself and by improvements of the rescue services. This topic cannot be elaborated in detail in this paper, but in the context of the accident statistics discussed here, it should not be unmentioned.

2.3 Evolutions in the German states since 1995

The official German Statistics deliver also regional figures for crashes and for killed and injured traffic participants in the respective states of the Federal Republic. With these figures the evolution of traffic participants killed in crashes on trees alongside the carriageway can be displayed an analysed for each of the 16 states.

For the year 1995 it is reported that Brandenburg with 412 killed persons had the greatest figure (inside and outside urban area) of fatalities for crashes on trees, see **Figure 6**. Until 2008 this figure decreased to 79. For the considered period, no other state had a similar reduction of the absolute figure of killed road users (-333) for this kind of accidents than Brandenburg. This is equivalent to a relative reduction of -81%, see **Table 1**.

From 1995 to 2008 not only in Brandenburg but in all other German states the figures of road users killed in crashes involving impacts on trees decreased. Similar to Brandenburg the relative reduction of theses figures was more than -70% in Mecklenburg West-Pomerania (-78.9%), Hesse (-73.8%) and Saxony-Anhalt (-73.6%).

In 2008 most of the fatalities of accidents involving impacts on trees alongside the carriageway have been registered in Lower Saxony (209), Bavaria (129) and North Rhine-Westphalia (120). On rank 5 with 79 fatalities is Brandenburg as the first of all eastern German states. Baden-Württemberg with 80 fatalities in 2008 is on rank 4 and nearly on the same level as Brandenburg.

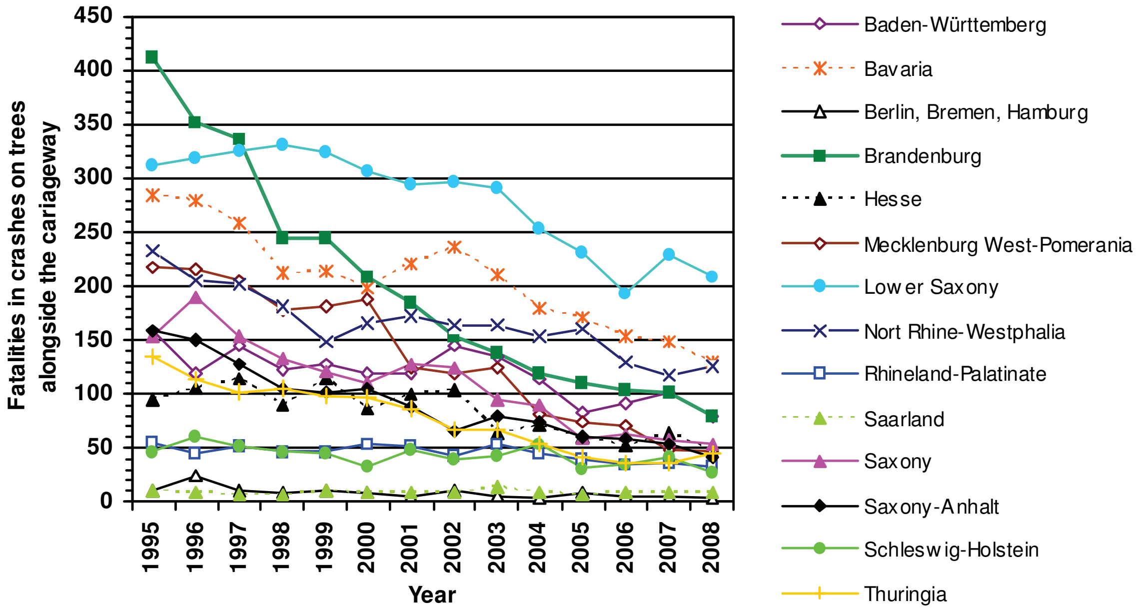


Figure 6. Evolution of the figures of fatalities in crashes on trees alongside the carriageway for the respective states of the Federal Republic of Germany from 1995 to 2008 (all sites, data source: DESTATIS [2])

Table 1. Absolute frequency of fatalities in crashes involving impacts on trees alongside the carriageway for the respective states of the Federal Republic of Germany in the years 1995 and 2008 with its absolute change Δ abs. and relative change Δ rel. (all sites, data source: DESTATIS [2])

State Year	Baden-Württemberg	Bavaria	Berlin, Bremen and Hamburg	Brandenburg	Hesse	Mecklenburg West-Pomerania	Lower Saxony
1995	159	284	11	412	95	218	312
2008	80	129	4	79	47	46	209
Δ abs.	-79	-155	-7	-333	-48	-172	-103
Δ rel.	-49.6%	-54.6%	-63.6%	-80.8%	-73.8%	-78.9%	-33.0%
State Year	Nord Rhine-Westphalia	Rhineland-Palatinate	Saarland	Saxony	Saxony-Anhalt	Schleswig-Holstein	Thuringia
1995	232	56	10	154	159	47	135
2008	126	33	9	54	42	28	45
Δ abs.	-106	-23	-1	-100	-117	-19	-90
Δ rel.	-45.7%	-41.1%	-10.0%	-64.9%	-73.6%	-40.4%	-66.7%

For further interpretation and assessment of these regional figures, also the figures of the circulating vehicle fleet and of the population as well as their alterations have to be considered for the respective states. However, by means of the absolute figures it can be stated that the accident occurrence for road users killed in crashes involving impacts on trees alongside the carriageway is not only a problem for the new states of the German Federal Republic. Already in 1995 this was not the case. In general, the fatal accidents considered here may be understood as a problem which is evident especially for the (greater) territorial states. This is obvious because in these states the number and the length of rural roads which are especially concerned are relatively large.

The evolution of the portion of road users killed in crashes involving impacts on trees related to all killed road users for the respective German states is displayed in **Figure 7**. Here too, for Brandenburg a convenient evolution can be diagnosed. For this state the portion of road users killed in tree impacts decreased from 54% in 1995 down to 36% in 2008. In contrast to this, for Lower Saxony this portion was 30% in 1995 and increased up to 35% in 2008. Recently, Brandenburg and Lower Saxony as well as Mecklenburg West-Pomerania (35% portion as well) are the three states with the greatest portion of killed road users in crashes on trees alongside the carriageway related to all fatalities.

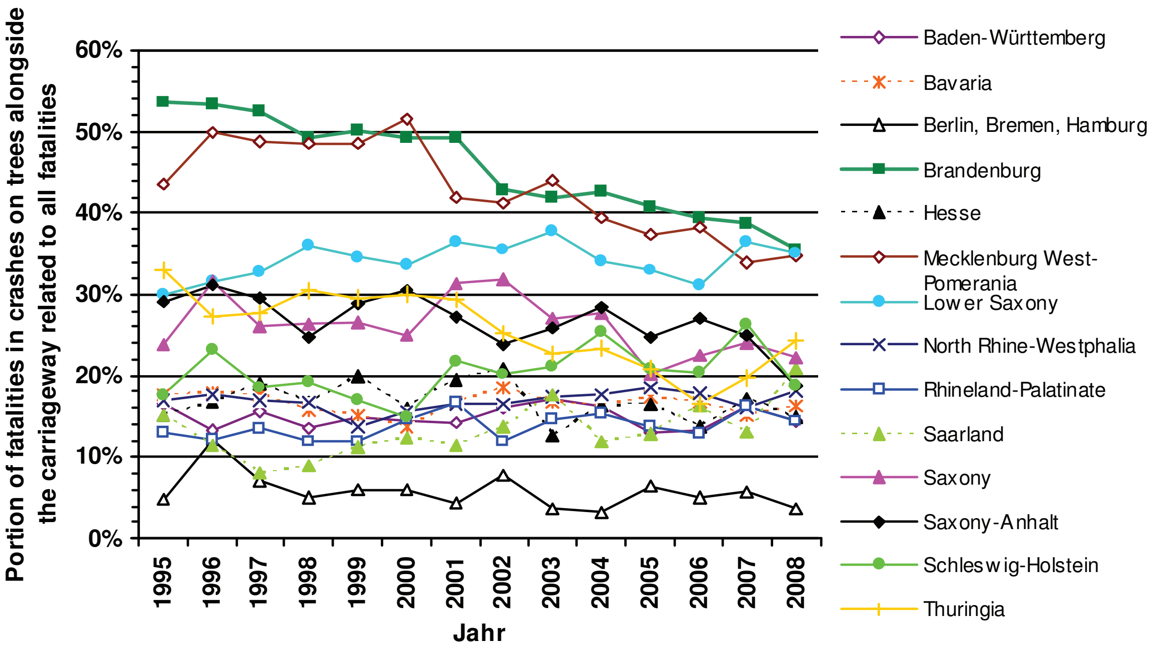


Figure 7. Evolution of the portion of fatalities in crashes on trees alongside the carriageway related to all fatalities for the respective states of the Federal Republic of Germany from 1995 to 2008 (all sites, data source: DESTATIS [2])

3 EXAMPLE OF AN ACCIDENT

Using data from the federal statistics it is impossible to ascertain how many of the crashes which are discussed here occur with impacts on trees standing in a row alongside the carriageway of typical avenues or with impacts on single trees respectively on trees at the border of a forest. The latter is likewise often the case and is displayed with many single crashes reconstructed by experts. The speed of the vehicle involved when impacting a tree also is not recorded in the federal statistics. To gather more detailed and updated knowledge on such parameters it is necessary to analyse samples of in-depth descriptions of such accidents as part of new accident research projects.

An example of a crash with a car involved is described in **Figure 8**. This accident happened in August 2007 on a rural road. Prior to the accident the car was driven at a speed of approx. 120 km/h in a drawn-out right-turning curve and slightly left the carriageway on the right. The driver was able to steer the car back on paved road. But he was not able to stabilise the car’s movement afterwards. Instead the skidding car got on the opposite side of the carriageway where it left the roadway again and crashed with its right-hand side on a tree. The impact velocity was that high that the structure of the vehicle was damaged severely and the trunk of the tree intruded deeply into the passenger compartment with fatal consequences.

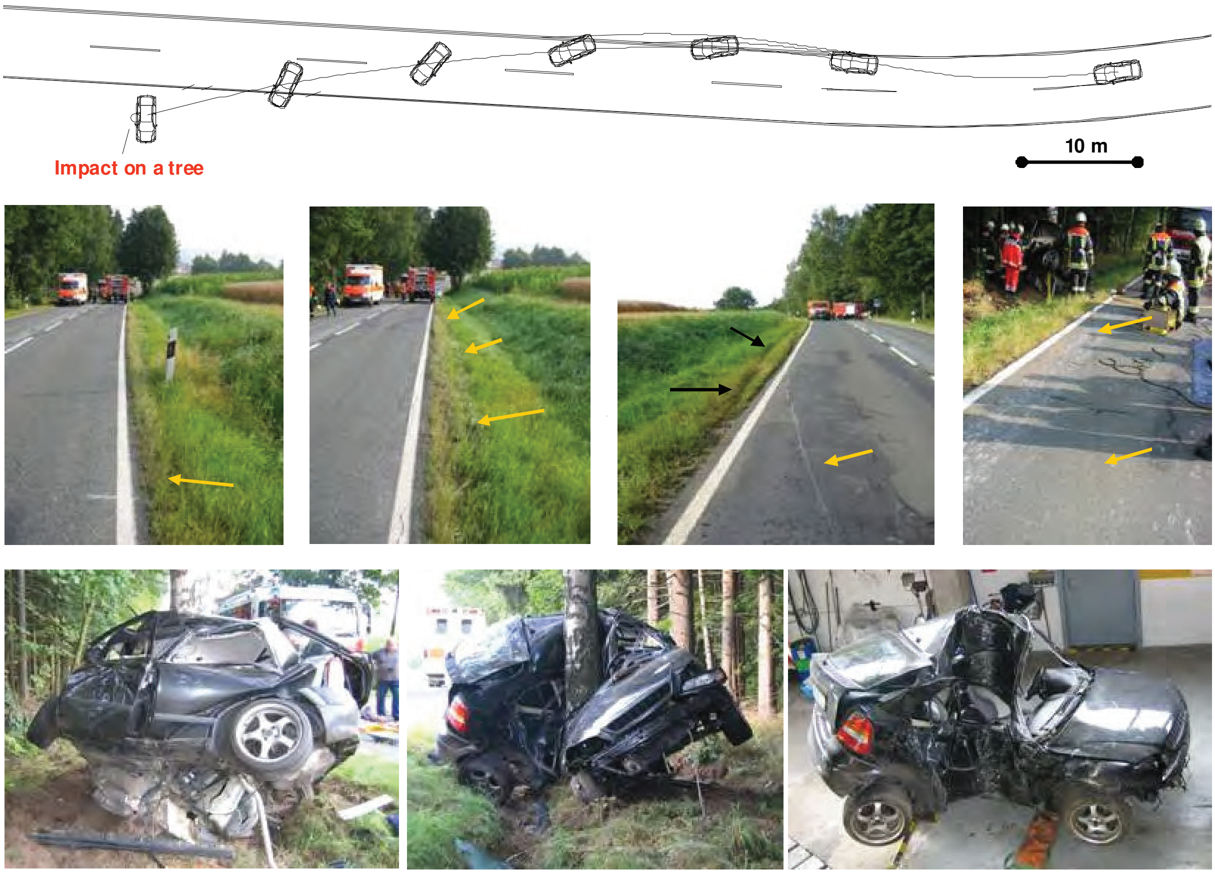


Figure 8. Accident example

4 POTENTIALS AND LIMITS OF VEHICLE SAFETY

As far as occupants are involved, the structure of the vehicle's body, the bolstering of the compartment interior as well as the restraint systems, which are mandatory seat belts since the 1970ies and supplemented by front and side airbags since the 1990ies, may recently give an "all-around protection". But, compared to the front, at the side band of the compartment there are only little possibilities to implement so called "crumple zones" to transform kinetic energy into deformation during the impact. However, the vehicle designers take this into account within the framework of the corresponding guidelines and under consideration of the technical feasibility measures regarding the side impact on trees and on smaller obstacles shaped like poles.

Amongst the crash tests executed with this regard is the 29-km/h side impact onto a fixed rigid pole having a diameter of 254mm as per Euro NCAP [3]. Particularly the results of such "pole tests" show remarkable efforts at recent car models compared to older ones which came into traffic as new models in the 1980ies and 1990ies (for examples see test results published at www.euronacp.com.).

However, it has to be expected that in real-world crashes with a side impact onto a tree at velocities which are higher than used in the Euro-NCAP test (29 km/h) the limits of the secondary (passive) safety will be reached soon or even exceeded drastically, see **Figure 9**. With this background it can be recognized that in the field of secondary (passive) safety the potentials of occupant protection are limited for severe impacts on trees which mostly occur at far higher speeds.

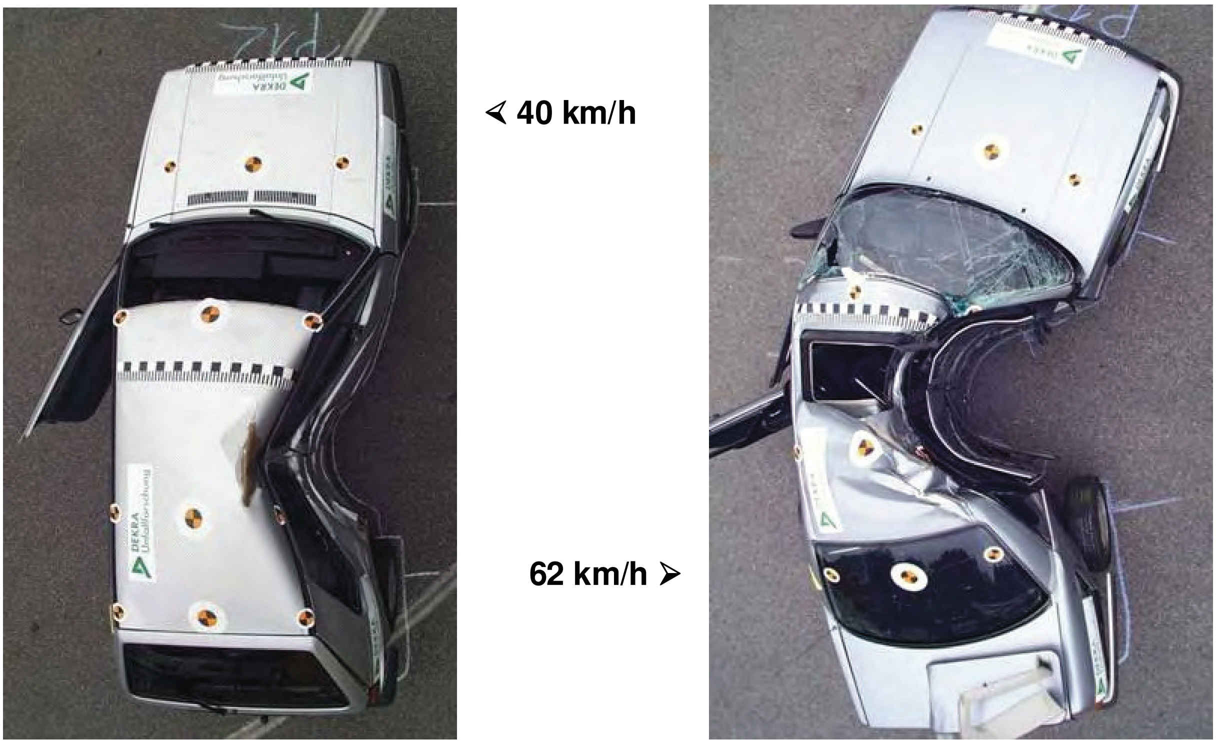


Figure 9. Deformations on cars after crash tests carried out to simulate real-world accidents with side impacts into a pole at velocities of 40 km/h and 62 km/h.

To further reduce the figures and consequences of accidents involving impacts on trees alongside the carriageway the implementation and propagation of driver assistance systems represent a much higher potential. In this context, the electronic stability programme ESP principally has a high potential to avoid accidents in which the vehicle leaves the roadway and impacting a tree - or to lower the consequences of such accidents. For example ESP may help to stabilize a vehicle after having entered a curve at too high speed so that it will not leave the roadway. But this is only possible within the physical limits of the driving dynamics. In particular for high-speed accidents the potential of ESP to avoid the accident may be limited vigorously respectively it may no longer exist.

Leaving the road as a consequence of driver inattention can be avoided by a so called "lane-departure warning device" LDW. Furthermore, driver assistance systems that help to recognize obstacles on the road and the course of the roadway in front are also helpful to avoid accidents in which the vehicle leaves the carriageway – for example as the consequence of a too late and panic reaction of the driver. Latest systems enter the market these days which help to detect road signs (speed limit, danger warning) have further potentials as well.

In the past, these safety devices were first implemented into cars for the market segment of the upper and luxury class. Meanwhile ESP is serial equipment in most cars in the medium-class as well as in a lot of cheaper cars. The portion of ESP equipment for new cars sold in the German market was around 69% in the year 2008 [4]. Advanced driver assistance systems like for example adaptive headlamps and LDW are predominantly introduced for luxury cars and in the upper class recently. For smaller and cheaper vehicles such safety systems are extra equipment – or not available so far.

In Germany, the mean value of the car age in the circulating fleet was 8.1 years on January 1^{st} 2010. That means that approx. half of the cars in the fleet are 8 years old or older. Therefore it takes a relatively long time until the latest safety technology is implemented in a noteworthy portion of vehicles which take part in traffic and are involved in accidents. Regarding the further reduction of the figures and consequences of accidents involving impacts on trees alongside the carriageway the advanced safety of vehicles may give additional contributions. This will – as hitherto – in the mid and long term contribute to a sustainable reduction of the figure of casualties on our roads.

Within the physical limits there are still potentials to avoid crashes utilizing the latest safety technology for vehicles today and in the future. Nevertheless even with state-of-the-art vehicles fatal accidents occur when leaving the road and impacting trees or other massive obstacles alongside the carriageway at higher speeds. Not only car occupants but also other road users, for example motorcycle riders, are involved.

5 HOLISTIC PERCEPTION, MEASURES AND RESTRICTIONS

In general a holistic assignment of traffic safety covers the fields of combat against the causes of accidents and the mitigation of crash consequences. However, most of the accidents are caused by more than one initial single failure. The predominant majority of accident causes is assigned to human beings as drivers of vehicles. In this context risky driver behaviour amongst others combined with high speed, inattention, distraction or the influence of alcohol often plays an important role.

The "failure forgiving vehicle" and its equipment are designed to assist the imperfect driver who is coping with his operating tasks and with the avoidance of accidents (primary safety). The "failure forgiving vehicle" may also mitigate the consequences for the driver and the passengers (secondary safety) in accidents which nevertheless occur. In the context of a holistic assignment this should also be true for the road and for the surrounding environment. This can be summarized with the term "failure forgiving road".

Measures addressed to the road and the environment to improve the traffic safety can often be implemented in relatively short terms (neglecting that the forming of opinions, making of decisions and the planning may sometimes take a long time). Such measures often give benefits to all road users (i.e. occupants in older cars or motorcycle riders). In addition, forceful implementations of relevant rules of the road traffic regulations and corresponding administrating instructions may have significant impacts to the local accident occurrence and its consequences.

Already in the year 2001 DEKRA and the Winterthur Insurance Company conducted an information event in the Swiss town Wildhaus dealing with "leaving-the-road accidents". Accidents involving impacts on trees had been at focus and "failure forgiving roads" were a central demand [5].

Regarding the road and its surrounding some technical solutions are possible:

- For new road designs and constructions a sidewise safety zone should be implemented. This is already in practice on rural roads in Scandinavia. In this side area roadside restraint systems like steel barriers or adequate bushes can be placed.
- To perform at a high protection level, steel barriers need a greater distance to the obstacles (trees). Providing this, a barrier is able to absorb energy by deformation. But even with restricted space for deformation a steel barrier (or a barrier made of concrete) can avoid a small impact location at the side of a car (as occur due to an impact on a tree) with the consequence of a collapsing compartment and a fatal reduction of the survival space for he occupants.
- Optical guidance systems on the lane or directly at the kerbside may improve the orientation on the roadway. This is also possible using reflecting (and yieldable) guide posts.
- Bushes or shrubbery could be a reasonable ecological and safety-related option for the design of the road space. Herewith an impacting vehicle can be restrained relatively soft on a larger contact area. By a crash test it has been demonstrated that the loadings to the occupants during an impact into a bush are approx. eight times lower than for an adequate impact onto a tree. However, bushes and shrubbery are naturally growing objects providing different

performance in terms of impact damping and alter over the time. To cope with this, additional analyses and fostering advices will be necessary.

- The replacement of trees which are marred or destroyed at the kerbside by new trees should be omitted. If ever possible, trees should be removed from the kerbside and newly implanted with a sufficiently greater distance to the road. At single spots which are known to be endangered by trees at the kerbside and where the trees are not removable, special impact dampers can be an appropriate measure. Such dampers can enlarge the contact area of an impacting vehicle and absorb supplementary energy.
- On hazardous roads adequate speed limits and bans of passing can contribute to improve the traffic safety. Traffic control (speed check) is an additional measure to support such acts and interdictions.

A pioneer in fighting against severe crashes involving impacts on trees was the German Insurance Association (GDV). Some fundamental research resulting in practical suggestions were published in the early 2000s [6]. Via the internet an updated package of measures is available [7]. Primarily addressed are persons in charge for transport policy and responsible for roadwork.

The implementations of some proposals are clearly recommendable from the point of view of accident research but meet with refusals or are partially impossible in daily practice. This is particularly true in terms of removing or displacing trees alongside the carriageway. Following a judgement of the Higher Regional Court (OLG) Hamm (see VersR 1995, 1206) there is a general interest in the conservation of the tree population even at the kerbside of public roads. Therefore, it must be balanced between the issues of traffic safety and the ecological interest on the conservation of the existing tree population.

A statement of the Federation of the German Landscape Architects (BDLA) concerning the draft of the "German guideline for protection against tree accidents" (RSB) mentioned that the character of an avenue with its typical space perception is in fact associated with a closed roof formed by the treetops [8]. As per clause 31 of the law on nature conservation of the state of Brandenburg (BbgNatSchG) avenues are particularly protected and therefore it is illegal to eliminate, to destroy, to damage or to negatively affect in any way such roads with their typical trees alongside the carriageway. For Brandenburg it is an explicit objective of policy to conserve avenues which are formative for the natural scenery of this state. This is true not only for side roads or country lanes but also for highly frequented streets [9].

Bearing in mind these socially and politically determined factors, a special significance can be recognised for measures with no need for felling or replacing trees.

6 NEED FOR FURTHER RESEARCH

To solve the problems described above and to eliminate tree impacts as one of the most important focal points of road safety, there still is a need for further research. So far, no science-based information is known about the site of accidents involving impacts on trees alongside the carriageway. What is the figure of the accidents registered in the federal statistics which occur with impacts on trees alongside avenues (which are protected) or at the border of a forest or on single trees (which could be removed and replaced more easily)?

The figures published in the federal statistics do not specify the kind of the vehicles (cars, light and heavy trucks, motorcycles, bicycles) involved in tree-impact accidents. For cars and light trucks it is additionally of interest what percentage of these vehicles is equipped with ESP respectively other advanced driver assistance systems. As far as these vehicles are involved it is of high interest whether such accidents will decrease in the future when the portion of vehicles which are equipped with ESP (or other driver assistance systems) in the entire circulating fleet will be significantly higher than today.

To cope with this and to find new and updated answers to the relevant questions, further research by the OEM's accident-research departments and by the accident-research institutions in Germany is necessary.

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