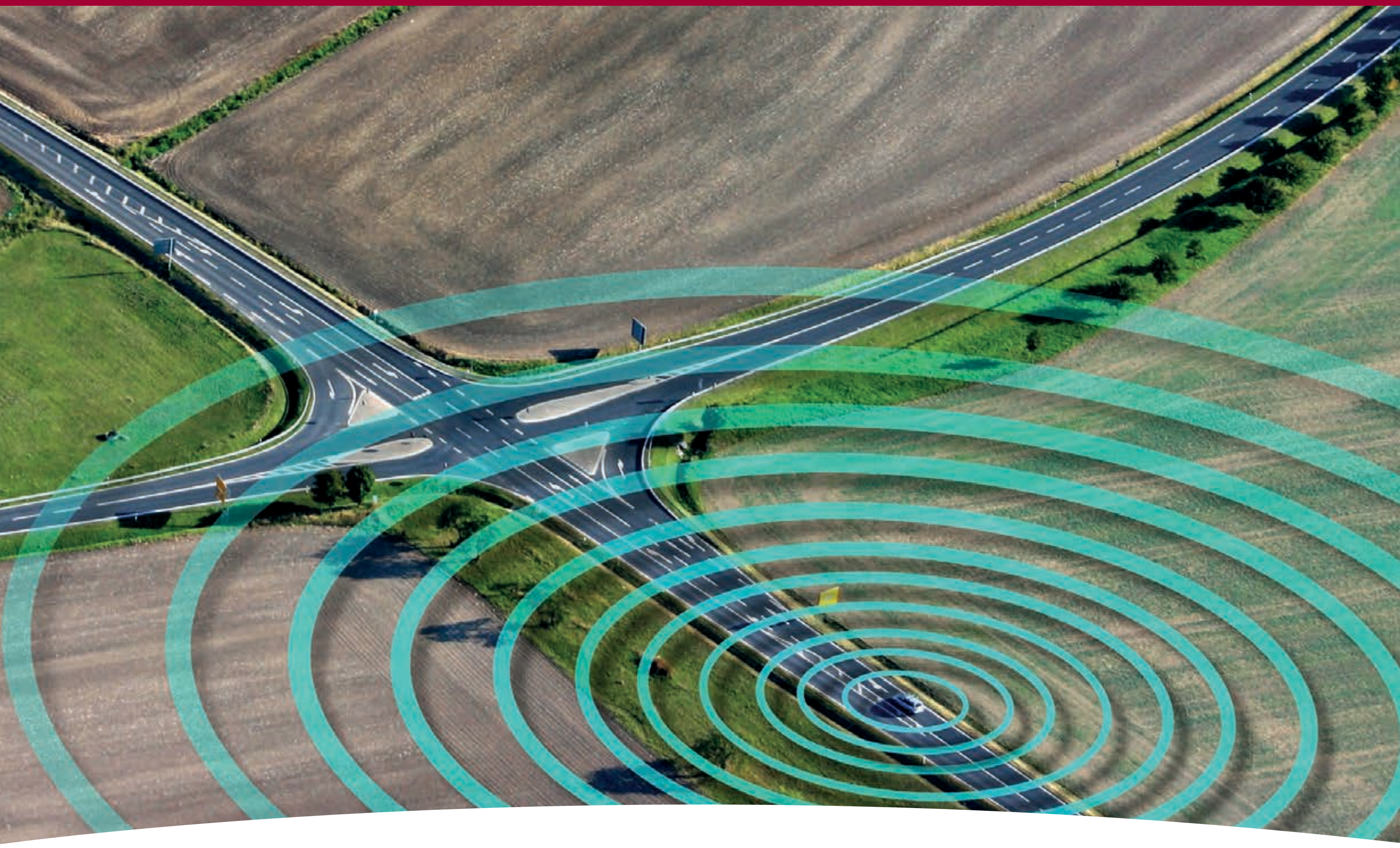
German Insurane Association No. 17



Compact accident research

Improving Safety through Communication between the Vehicle and the Road

Unfallforschung der Versicherer
GDV

Imprint

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Insurers Accident Research

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Preliminary remarks

The number of accidents with personal injuries and the number of fatalities and injuries on German roads have been falling since 1970. Due not least to improvements in vehicle safety, accident severity has decreased continuously in recent decades. Drivers are now assisted by numerous safety systems. In addition to the most well-known advanced driver assistance systems such as ABS and ESC, these include lane departure warning systems, brake assist systems and blind spot warning systems, for example. Engineers hope for further improvements to safety from systems that offer an effective vehicle-to-vehicle or vehicle-to-infrastructure communication which is enable to avoid the most number of collisions, in particular accidents with serious personal injuries on roads outside built-up areas. Their purpose is to provide early notification of dangers and to enable the driver or vehicle to react in good time.

But how and where do the relevant accidents happen? What do they have in common, and what information is required in order to indicate imminent danger?

To answer these questions, accidents on roads outside built-up areas were examined in this study, and the general requirements to be met by suitable assistance systems were identified. It was revealed that, due to the high level of investment these systems require, both in terms of technical input and finance, there are really only a few applications for which it makes sense to use infrastructure-based assistance systems.

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1 Introduction

The absolute numbers of fatalities and injuries on German roads have been falling since they reached a peak in 1970, despite increased vehicle numbers and mileage driven. This also applies to roads outside built-up areas. However, the consequences of accidents on roads outside built-up areas (as measured by serious personal injuries per 1000 accidents involving personal injury) are more serious than the consequences of accidents on freeways (autobahns) or in built-up areas (figure 1c).

Due to the high number of accidents on roads outside built-up areas, the serious nature of their consequences and thus their high costs, there is an urgent need for action. However, there is a limit to what the authorities can do because of financial constraints. Consequently, what is needed are solutions other than construction measures that are as inexpensive and effective as possible. Advanced driver assistance systems (ADASs) based on vehicle-to-infrastructure communication (V2I) are one possibility. These are not currently widespread both because most applications are still in the development phase and because many questions in relation to their effectiveness, standardization, operation and financing as well as questions of liability have yet to be answered.

The UDV (German Insurers Accident Research) therefore commissioned TRANSVER GmbH of Munich to investigate the extent to which V2I-based ADASs are suitable for improving safety on roads outside built-up areas. Self-sufficient in-vehicle ADASs and ADASs based on vehicle-to-vehicle (V2V) communication were considered as alternative solutions in the investigation.

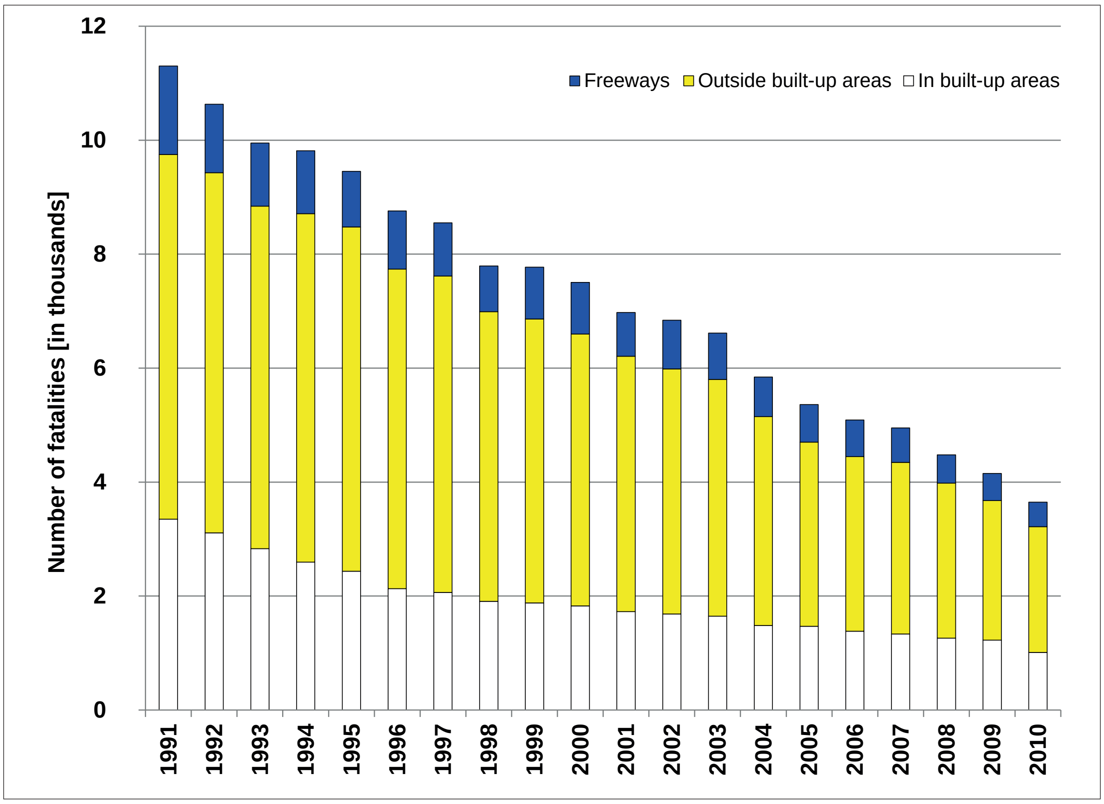


Figure 1 a:
Fatalities on different types of roads since 1991

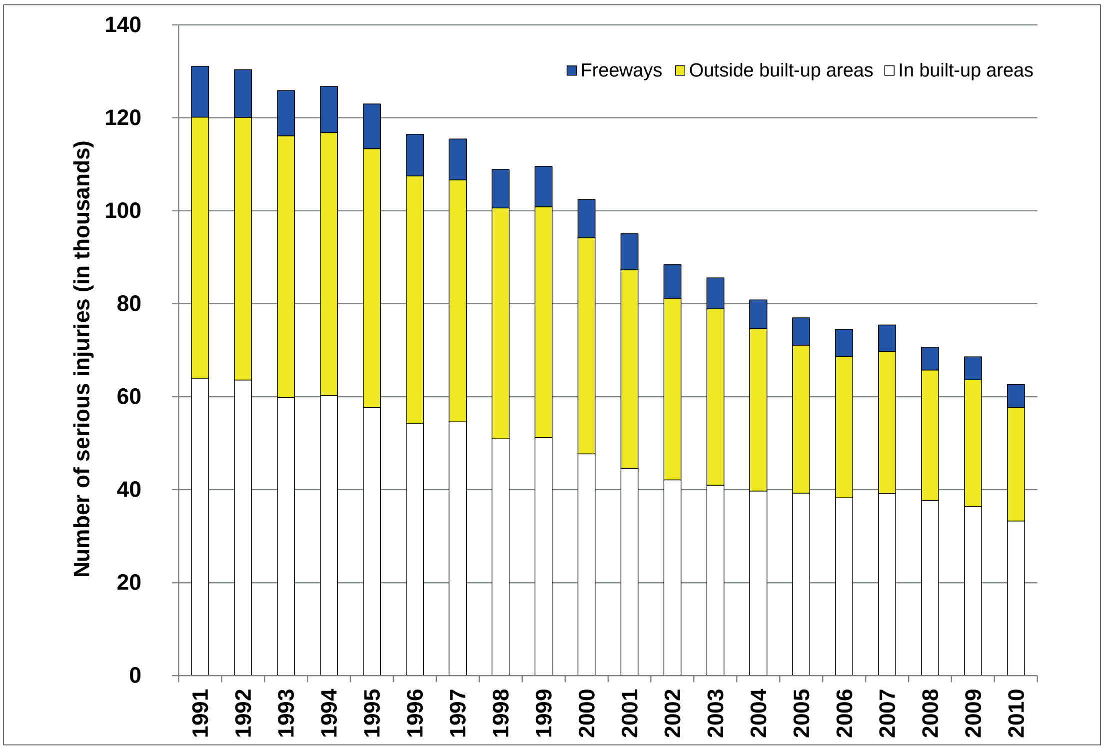


Figure 1 b:
Serious injuries on different types of roads since 1991

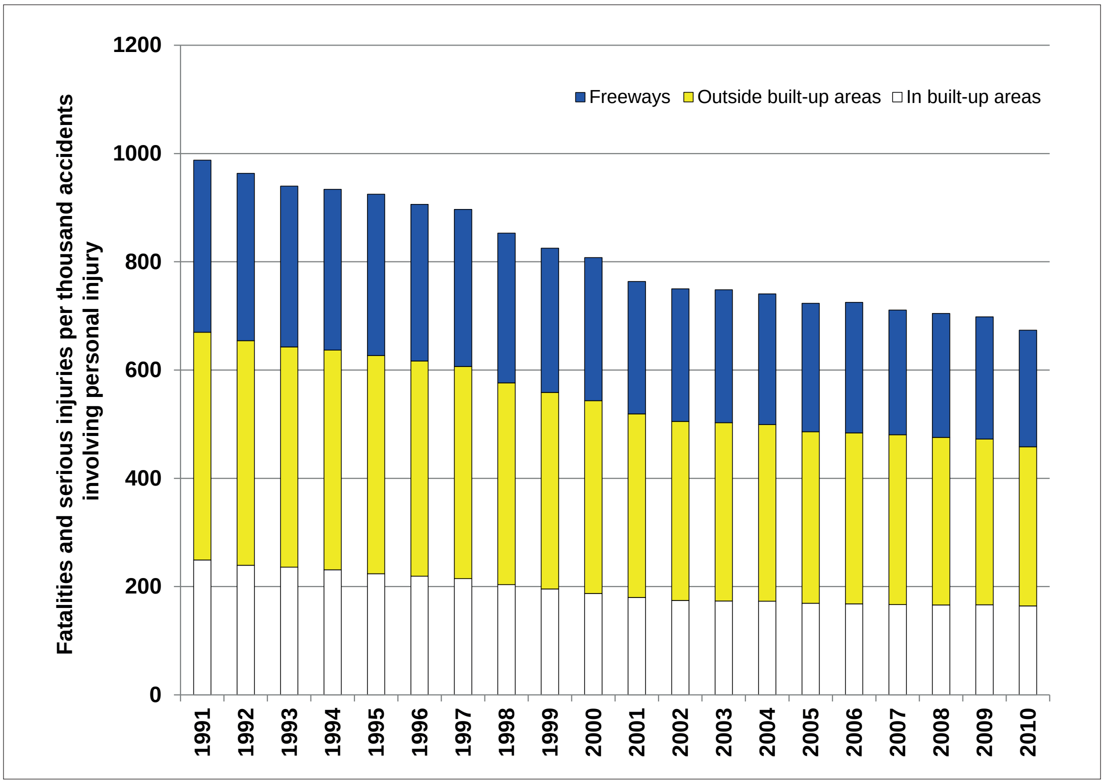


Figure 1 c:
Fatalities and serious injuries on different types of roads since 1991

Procedure and methodology

The procedure used in the study is shown in figure 2. The steps involved are outlined below.

Examination of the literature

In an extensive examination of the literature, the ADASs both available on the market and in development were analyzed, compared and examined with regard to their possible benefits for road safety. Distinctions were drawn between four different types of ADAS:

- Infrastructure-only systems (e.g. variable-message signs)
- Self-sufficient in-vehicle systems (e.g. ESC)
- V2V-based systems (vehicle to vehicle)
- V2I-based systems (vehicle to infrastructure and vice versa)

A cooperative V2I-based ADAS is characterized by bidirectional communication between vehicles and the infrastructure. Road users and dangers are detected by contactless sensors that can be fitted both to vehicles and the infrastructure.

Particular value was placed on the economic viability of V2I-based ADASs. The main criterion applied was the possibility of implementing self-sufficient in-vehicle ADASs and V2V-based ADASs as alternatives.

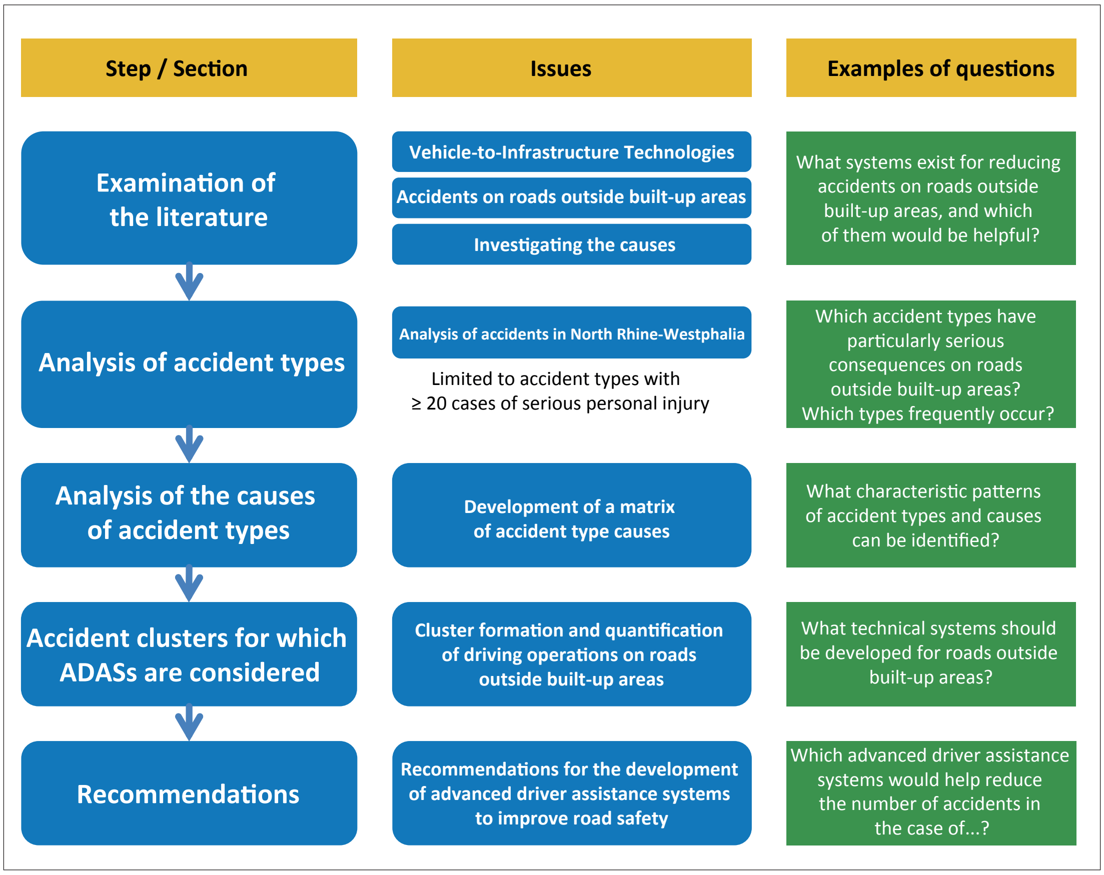


Figure 2:
Procedure of the project and key issues on which it focused

Analysis of accident types

Detailed accident statistics are a prerequisite for ascertaining the requirements to be met by technical systems in order to improve road safety. The German Federal Statistical Office publishes aggregated accident data broken down into seven accident types. However, the single-digit accident types used are not detailed enough to permit exhaustive conclusions to be drawn about how the accidents happen. For example, accidents involving vehicles turning left at a traffic light across oncoming traffic (in Germany, where vehicles drive on the right) are different from accidents involving vehicles turning right, yet they come under the same accident type (accident type 2: turning-off accident) in the accident data of the Federal Statistical Office.

The police in North Rhine-Westphalia have an accident data base that subdivides the seven accident types into a total of 295 different, three-digit accident types. Due to the level of detail thus offered, anonymized accident data from this database was used in this study. The study focused on the period from 2004 to 2008. 89,391 accidents on roads outside built-up areas in North Rhine-Westphalia were reported to the police in this period.

Analysis of the causes of accident types

To reduce the number of accident types to be taken into account, rare and/or less serious accident types with less than 20 cases of serious personal injury that occurred in this five-year period were excluded. The threshold was set after examining the curve for the total number of serious personal injuries of all accident types (sorted in descending order). The number of accident types was thus reduced from 295 to 78 (by 74%), whereas the number of accidents only decreased from 89,391 to 84,405 (by 6%). The causes of this large number of accidents were then examined. To this end, the 78 remaining accident types were combined with the reported accident causes, the accident variables were aggregated across all the associated accidents, and the 5,266 possible combinations of accident type and accident cause were sorted in descending order. The four most common combinations of accident type and accident cause are shown as examples in figure 4.

The requirements to be met by technical systems were then set against these accident type/cause combinations (see figure 4). In turning-off errors involving a collision (ranked 1), a suitable ADAS must be able to detect other vehicles, for example. In driving accidents in bends (ranked 2), the factors to be taken into account include the radius of the bend, the condition of the road surface and speed.

Accident clusters for advanced driver assistance systems

Based on the analysis of accident types/causes, accident clusters were formed. These group together accident type/cause combinations that are similar in terms of driving dynamics. One example would be a turning-off error (accident cause 35) of a driver turning off to the left across oncoming traffic (accident type 211) and a failure to observe the traffic sign indicating priority (accident cause 28) of a driver turning in to the left (accident type 302). In these two cases the driving operation is comparable because another vehicle has not been seen or incorrectly anticipated in a turn to the left. The requirements to be met by a technical system are thus the same.

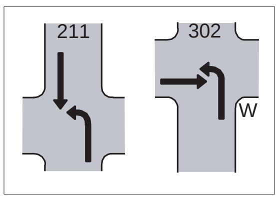


Figure 3:
Accident types 211 and 302

Ranking	Accident typ	Accident cause	Number of causes in this accident type/cause combination	Number of accidents of this accident type	Accident type/cause combinations as a percentage of all accident type/cause combinations	Cumulative accident type/cause combinations as a percentage of all accident type/cause combinations	Description of the accident cause	Ranking by accident costs for these accident type/cause combinations	Comparison with ranking by frequency (column 1)	Total accident costs of these accident type/cause combinations (in '000 euros)	Recognition of and warnings before															
											bends	Intersections														
											Speed, longitudinal or transverse gradient, radius of bend, state/ condition of road surface	Vehicles	other road users	Trafic signals	(excessive) speed	(Failure to keep a) safe distance from the vehicle in front	Lane departure	End of a tailback	Oncoming traffic	Overtaking vehicle	Turning vehicle	Wild animals	Alcohol	Slippery road surface	Wet road surface	
											yes	yes	yes	yes	–	–	in bends	Traffic bottlenecks	–	–	–	Where wild animals cross	–	Bridges, for example	Depressions, for example	Can the requirement be limited to certain locations?
											✓	✓	–		✓	✓	✓	✓	–	–		✓	✓	✓	✓	Possible implementation approach: In-vehicle
											–	–	✓	✓	✓	✓	✓	✓	–	–		✓	–	✓	✓	Infrastructur only
												✓		–			–	✓	✓	✓	✓	✓	–	✓	✓	C2C / V2V
											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	✓	✓	C2I / V2I
																										Degree of implementation in C2I/V2I: already on the market
											✓	✓	✓	✓	✓		✓	✓						✓	✓	in development
																✓			✓	✓	✓	✓				unknown
1	**211**	**35**	6860	8114	6,2	6,2	 *Error when turning off*	4	↘	365.721		●														
2	**101**	**13**	5848	8158	5,2	11,4	 *Inappropriate speed in other cases*	1	↗	506.555	●				●											
3	**102**	**13**	5845	7796	5,2	16,6	 *Inappropriate speed in other cases*	2	↗	462.384	●				●											
4	**302**	**28**	4802	5743	4,3	20,9	 *Failure to heed traffic signs indicating priority*	6	↘	247.662		●														

Figure 4:
Most common combinations of accident type and cause

2 Results of the accident clusters for advanced driver assistance systems

2.1 Overview of the accident clusters for ADASs

A total of 20 different accident clusters were examined in detail. Accident types that are similar in terms of driving dynamics and driving activities were grouped together to form the clusters. The clusters identified are broken down below by location and accident causes. These are shown in table 1.

In terms of location, a distinction was drawn between accidents on the open road (on a straight or in a bend) and accidents at intersections. In addition, a variety of environmental conditions were examined in detail. For the sake of completeness, drivers under the influence of alcohol (accident cause 1) and other driver errors (accident cause 49) were also dealt with.

It should be pointed out that the same accident can be included in different accident clusters. For example, an accident that occurred in a traffic jam on a wet road is included under both "accidents in traffic jams" and "accidents on wet roads".

Particularly important accident clusters are described in detail below.

2.2 Selected accident clusters for ADASs

2.2.1 Accidents at intersections

Description of the accident cluster

This accident cluster combines conflict situations at intersections with and without traffic signals

Table 1:
Overview of the accident clusters investigated for ADASs

Short designation		Description	Ranking by A	F	SPI	SPI/ 1000 A	C
Inter-section	IS1	Accidents as a result of priority violations	1	3	2	17	2
	IS2	Accidents at signal-controlled intersections	4	13	9	19	9
	IS3	Accidents involving pedestrians and cyclists	8	5	7	5	7
Open road	OR1	Driving accidents in bends	3	2	3	8	3
	OR2	Driving accidents on straight roads	11	10	10	6	10
	OR3	Accidents in traffic jams	15	20	18	20	18
	OR4	Accidents involving overtaking vehicles	17	14	15	15	15
	OR5	Accidents involving oncoming vehicles	7	4	4	2	6
	OR6	Accidents involving turning vehicles	14	16	16	18	16
	OR7	Accidents involving pedestrians and cyclists	13	9	13	1	13
	OR8	Accidents involving animals	16	17	14	12	14
	OR9	Accidents involving temporary obstacles	10	6	8	3	8
Environmental conditions	EC1	Accidents on wet roads	12	12	12	16	12
	EC2	Accidents involving ice and snow	9	11	11	13	11
	EC3	Accidents on a road surface with reduced skid resistance	5	8	6	14	4
	EC4	Accidents in fog	19	18	19	11	19
	EC5	Accidents in crosswinds	20	19	20	4	20
	EC6	Accidents in dazzling sunshine	18	15	17	10	17
Other	AC1	Accidents involving road users under the influence of alcohol	6	7	5	9	5
	AC49	Accidents involving "other driver errors"	2	1	1	7	1

A: accidents; F: fatalities; SPI: serious personal injury; C: accident costs

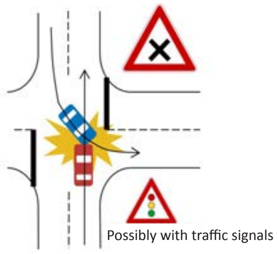
involving vehicles from the left (accident types 301, 302 and 303), vehicles from the right (accident types 321 and 322) and oncoming traffic with vehicles turning left (accident type 211). The selected conflicting traffic streams could be separated in principle by providing the turning-off streams with dedicated traffic signals. The following accident causes are considered: violation of the rules of the road (including traffic signals) (accident causes 27, 28 and 31), failure to take into account oncoming vehicles (accident cause 32) and turning-off errors (accident cause 35).

The statistics shown in table 2 are for all forms of this accident cluster. When the accident cluster was additionally limited to accidents at signal-controlled intersections, it was found that the accident severity (serious personal injuries per 1000 accidents involving personal injury) decreased significantly.

The relative details allow a comparison to be made of the severity of the consequences of the different accident clusters. In this particular example of accidents at intersections, it means that 29.2% of all accidents account for “only” 19.6% of all accidents involving fatalities (accident category 1). The consequences of this accident cluster are thus less serious than the average for all accident clusters considered. In terms of those involved, the difference between

Table 2:
Statistical profile of the accident cluster of „accidents resulting from priority violations“ with and without traffic signals

	Conditions	
Accident types	211, 281, 301, 302, 303, 321, 322	7 of 77 accident types
Accident causes	27, 28, 31, 32, 35	5 of 69 accident causes
Further Conditions	none	



Cluster statistics

In relation to the people involved

	Number	Percentage
People involved	50788	33.9%
Fatalities	360	18.8%
People with serious injuries	5416	24.5%
People with minor injuries	18466	28.7%

Modes of transport	Number	Percentage
Car	42141	37.1%
Bus	191	27.1%
Truck	3189	32.5%
Motorcycle	3518	25.9%
Pedestrian	18	0.9%
Bicycle	1222	16.6%
Other	509	21.0%

In relation to the accidents

	Number	Percentage	Accident costs
Accidents	24613	29.2%	1,539,561,000 €
Accident category 1	344	19.6%	92,880,000 €
Accident category 2	4202	23.4%	1,134,540,000 €
Accident category 3	10254	24.4%	184,572,000 €
Accident category 4	9813	43.1%	127,569,000 €

Accidents on:	Number	Percentage	Accident costs
Federal highways	6987	30.0%	437,284,000 €
State highways	11946	31.3%	745,821,000 €
District highways	3478	25.5%	231,783,000 €
Other roads	2202	23.6%	124,673,000 €

the numbers involved and the numbers of fatalities is even more marked. The percentage of people involved is about twice as high, which can be explained by the fact that accidents without third-party involvement were excluded by definition (an accident without third-party involvement would be categorized as an accident of type 121, 122 or 123).

Requirements to be met by a technical system

An intersection assistant requires information that is as accurate as possible on the position (e.g. lane), movement (direction of travel, speed, acceleration/deceleration) and other status information (e.g. direction indicator lamps) of, wherever possible, all road users on the approach to and in the immediate vicinity of the intersection as well as status data on traffic signals in order to calculate a probability-based forecast of future movements on a dynamic map. If the calculated probability of a dangerous conflict situation exceeds a set threshold, the affected vehicles are warned. Automated interventions are also technically conceivable.

Recommendation

V2I-based ADASs are recommended at signal-controlled intersections where accidents are likely. Because they can be adapted to suit local circumstances (e.g. impaired visibility due to buildings) and they permit hierarchical management of complex traffic situations, they are superior to self-sufficient in-vehicle ADASs and V2V-based ADASs.

2.2.2 Driving accidents in bends and on straight roads caused by driving at inappropriate speeds

Description of the accident cluster

Driving accidents in bends generally have particularly serious consequences. As can be seen in table 3, driving accidents in bends at inappropriate or excessive speeds led to about a quarter of all fatalities and over a fifth of all serious injuries on roads outside built-up areas.

Driving accidents on straight roads happened less often but were similar in terms of the seriousness of their consequences (table 4). A great many accidents on straight roads come under the cause category "other driver errors". These are not included in the accident cluster shown in table 4.

Requirements to be met by a technical system

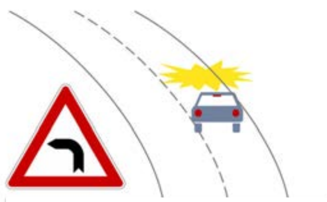
An ADAS must recognize when vehicles are travelling at inappropriate speeds (simply by detecting that they are exceeding the speed limit or, in more complex cases, by taking into account circumstances such as the weather conditions, tire adhesion, skid resistance of the road surface, etc.) and warn the driver in order to prevent accidents.

Recommendation

Self-sufficient in-vehicle ADASs are to be preferred here, since they could potentially be

Table 3:
Statistical profile for driving accidents in bends

	Conditions	
Accident types	101, 102, 121, 122, 123, 131, 132, 151, 152	9 of 99 accident types
Accident causes	12, 13	2 of 69 accident causes
Further Conditions	None	



Driving accidents in bends (including gradients etc.) involving inappropriate speeds

Cluster Statistics

In relation to the people involved

	Number	Percentage
People involved	18910	12.6%
Fatalities	482	25.2%
People with serious injuries	4776	21.6%
People with minor injuries	9466	14.7%

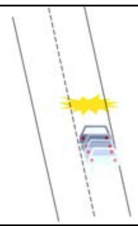
Modes of transport	Number	Percentage
Car	15203	13.4%
Bus	53	7.5%
Trucks	849	8.6%
Motorcycle	2470	18.2%
Pedestrian	61	2.9%
Bicycle	127	1.7%
Other	147	6.1%

In relation to the accidents

	Number	Percentage	Accident costs
Accidents	15907	18.8%	1,357,966,000 €
Accident category 1	435	24.7%	117,450,000 €
Accident category 2	3915	21.8%	1,057,050,000 €
Accident category 3	6645	15.8%	119,610,000 €
Accident category 4	4912	21.6%	63,856,000 €

Accidents on:	Number	Percentage	Accident costs
Federal highways	3221	13.8%	249,601,000 €
State highways	7584	19.9%	653,309,000 €
District highways	3299	24.2%	312,454,000 €
Other roads	1803	19.4%	142,602,000 €

Table 4:
Statistical profile for driving accidents on straight roads

	Conditions		
Accident types	141, 153, 163, 183, 761	5 of 77 accident types	
Accident causes	12, 13	2 of 69 accident causes	
Further conditions	none		

Cluster statistics

In relation to the people involved

	Number	Percentage
People involved	4350	2.9%
Fatalities	127	6.6%
People with serious injuries	1219	5.5%
People with minor injuries	2305	3.6%

Modes of transport	Number	Percentage
Car	3601	3.2%
Bus	10	1.4%
Truck	240	2.4%
Motorcycle	352	2.6%
Pedestrian	19	0.9%
Bicycle	92	1.2%
Other	36	1.5%

In relation to the accidents

	Number	Percentage	Accident costs
Accidents	3804	4.5%	345,752,000 €
Accident category 1	110	6.3%	29,700,000 €
Accident category 2	1010	5.6%	272,700,000 €
Accident category 3	1692	4.0%	30,456,000 €
Accident category 4	992	4.4%	12,896,000 €

Accidents on:	Number	Percentage	Accident costs
Federal highways	1086	4.7%	95,097,000 €
State highways	1474	3.9%	137,426,000 €
District highways	722	5.3%	68,160,000 €
Other roads	522	5.6%	45,069,000 €

effective in all bends and on all straight roads if vehicles were equipped with them. Since the most important input parameters are structural (e.g. road geometry) or relatively easy to capture (e.g. speed), to achieve faster market penetration the warning could be integrated in mobile applications such as pocket navigation systems or smartphones.

Infrastructure-only driver assistance systems with speed measurement and variable-message signs before hazardous bends could warn drivers of non-equipped vehicles when they were driving at inappropriate speeds.

V2I-based ADASs are not very useful in this accident cluster, since they only work in certain cases and for drivers of vehicles that are equipped with the technology.

2.2.3 Accidents involving oncoming traffic

Description of the accident cluster

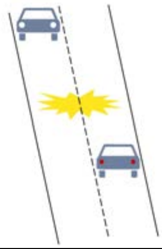
The accident cluster outlined in table 5 consists of accidents involving oncoming traffic: both accidents involving overtaking (accident type 661) and accidents on straight sections of road (accident type 681) and in bends (accident type 682). Since the three accident types used are very clearly differentiated, no specific selection of accident causes was made.

Requirements to be met by a technical system

The minimum requirement to be met by a suitable ADAS is that it should warn drivers when they are inadvertently leaving their lane.

Table 5:
Statistical profile for the accident cluster for accidents involving oncoming traffic

	Conditions	
Accident types	661, 681, 682	3 of 77 accident types
Accident causes	all	69 of 69 accident causes
Further conditions	none	



Cluster Statistics

In relation to the people involved

	Number	Percentage
People involved	11572	7.7%
Fatalities	265	13.9%
People with serious injuries	2121	9.6%
People with minor injuries	4512	7.0%

Modes of transport	Number	Percentage
Car	8371	7.4%
Bus	121	17.1%
Truck	1251	12.7%
Motorcycle	741	5.4%
Pedestrian	20	1.0%
Bicycle	738	10.0%
Other	330	13.6%

In relation to the accidents

	Number	Percentage	Accident costs
Accidents	5339	6,3%	486,985,000 €
Accident category 1	232	13,2%	62,640,000 €
Accident category 2	1347	7,5%	363,690,000 €
Accident category 3	2355	5,6%	42,390,000 €
Accident category 4	1405	6,2%	18,265,000 €

Accidents on:	Number	Percentage	Accident costs
Federal highways	1258	5,4%	143,122,000 €
State highways	2285	6,0%	207,519,000 €
District highways	923	6,8%	83,142,000 €
Other roads	873	9,4%	53,202,000 €

This is easiest to implement through recognition of lane markings, as already happens with lane departure warning systems in vehicles.

Much more complex would be an ADAS that captures with a high degree of precision the positions, directions of travel and speeds of all the relevant vehicles in order to forecast their future movements (trajectories) and thus to detect possible collisions in good time.

Recommendations

Self-sufficient in-vehicle lane departure warning systems can reduce accidents involving collisions with oncoming vehicles. A further development of this incorporating V2V communication could warn drivers about oncoming vehicles even when they are not visible, provided these vehicles were also equipped with the technology. V2I-based ADASs would be very costly to implement and their impact would be limited to very specific locations. They are therefore unlikely to be suitable for reducing accidents involving collisions with oncoming vehicles.

2.2.4 Accidents involving non-motorized road users in longitudinal traffic

Description of the accident cluster

This accident cluster focuses on non-motorized road users killed or injured in longitudinal traffic on roads outside built-up areas. There are some explicit accident types for accidents with pedestrians. Since there is not a separate accident type for accidents involving cyclists, most accidents involving pedestrians and cyclists were included. Accident types such as driving accidents on straight roads (accident type 141) are therefore also included.

The accidents in this accident cluster therefore tend to have very serious consequences (see table 6).

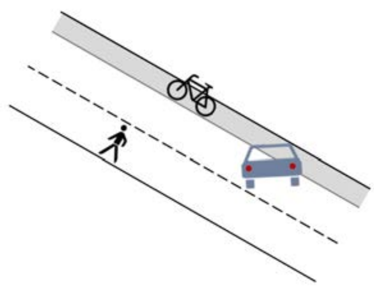
When light conditions were taken into account, it was found that, although accidents often happen in daylight, the percentage of fatalities for accidents occurring in the dark is particularly high.

Requirements to be met by a technical system

Although there are already self-sufficient in-vehicle ADASs on the market that can detect non-motorized road users in the dark, the study shows that a suitable ADAS should also work in daylight. The ADAS should thus be able to detect the positions of pedestrians and cyclists both in daylight and in the dark and identify them accordingly (visually).

Table 6:
Statistical profile for the accident cluster for non-motorized road users in longitudinal traffic

	Conditions	
Accident types	**Cyclists**: 101, 102, 141, 151, 152, 153, 199, 601, 651, 652, 661, 681, 682, 699 **Pedestrians**: 101, 141, 671, 672, 699	5 to 14 of 77 accident types
Accident causes	all	69 of 69 accident causes
Further Conditions	Every accident type has to show more than 25 accidents for cyclists and for pedestrians.	



Cluster statistics

In relation to the people involved

	Number	Percentage
People involved	6446	4.3%
Fatalities	188	9.8%
People with serious injuries	1285	5.8%
People with minor injuries	2612	4.1%

Modes of transport	Number	Percentage
Car	1635	1.4%
Bus	38	5.4%
Truck	148	1.5%
Motorcycle	271	2.0%
Pedestrian	1604	76.7%
bicycle	2659	36.0%
Other	91	3.8%

In relation to the accidents

	Number	Percentage	Accident costs
Accidents	3385	4.0%	408,540,000 €
Accident category 1	182	10.3%	49,140,000 €
Accident category 2	1198	6.7%	323,460,000 €
Accident category 3	1975	4.7%	35,550,000 €
Accident category 4	30	0.1%	390,000 €

Accidents on:	Number	Percentage	Accident costs
Federal highways	592	2.5%	77,416,000 €
State highways	1213	3.2%	156,322,000 €
District highways	549	4.0%	71,582,000 €
Other roads	1031	11.1%	103,220,000 €

Recommendations

Infrastructure-only systems that detect pedestrians and cyclists in longitudinal traffic and make drivers aware of them by means of variable-message signs could be installed on sections of roads outside built-up areas where accidents frequently occur.

The existing self-sufficient in-vehicle ADASs should also be able to detect pedestrians and cyclists in daylight. V2V communication can only be expected to bring minor benefits over self-sufficient in-vehicle systems. V2I-based ADASs also offer little promise, since the accidents occur in many different places, and installation costs would therefore be high.

Due to the distribution and severity of the accidents, the further development and distribution of self-sufficient in-vehicle systems should be encouraged because they are effective in all locations.

2.3 Effective approaches for advanced driver assistance systems

Table 7 shows which approaches were found in the study to be promising and which

Table 7:
Overview of promising approaches for advanced driver assistance systems in order to improve road safety

Accident Cluster type	Accident cluster		SP/1000 acc.	Advanced driver assistance systems			
				Infrastructure only	Autonomous in-vehicle	V2V	V2I
Inter-section	IS1	Accidents as a result of priority violations	234.7	×	●	●	✓
	IS2	Accidents at signal-controlled intersections	161.9	×	●	●	✓
	IS3	Accidents involving pedestrians and cyclists	369.6	●	●	●	✓
Open road	OR1	Driving accidents in bends	338.0	✓	✓	×	●
	OR2	Driving accidents on straight roads	352.3	×	✓	×	×
	OR3	Accidents in traffic jams	112.2	×	●	✓	×
	OR4	Accidents involving overtaking vehicles	250.0	×	●	✓	×
	OR5	Accidents involving oncoming vehicles	446.9	×	●	✓	×
	OR6	Accidents involving turning vehicles	213.4	×	●	✓	×
	OR7	Accidents involving pedestrians and cyclists	523.8	×	✓		×
	OR8	Accidents involving animals	268.3	✓	✓		●
	OR9	Accidents involving temporary obstacles	435.2	×	✓	×	×
Environ-mental conditions	EC	Accidents due to rain, ice, wet roads, etc.	257.6	●	✓	●	×
Other	AC1	Accidents involving road users the influence of alcohol	328.5	×	✓	×	×

✓ recommended approach ● alternative approach × approach with little promise were found to be less promising in terms of improving road safety. The study shows that the benefits of V2I-based ADASs can be exploited effectively particularly in complex traffic situations in certain limited locations, such as at intersections.

Incidents that occur suddenly and can occur in a wide variety of locations, such as trucks losing their loads or vehicles turning in the road, can best be covered by vehicle-based ADASs.

3 Results and summary

Table 8 shows the various dependencies and types of driver assistance system. Today's infrastructure-only driver assistance systems (e.g. traffic signals and other traffic management systems) are financed from the public purse and can be used by all drivers. Self-sufficient in-vehicle driver assistance systems (e.g. lane departure warning systems, adaptive cruise control systems) are financed through the purchase of a car and can "only" be used by the drivers of the vehicles equipped with them. V2I-based ADASs are a special case because they are "only" effective in the vehicles in which they are installed, yet, as things stand, to a large extent they have to be financed with public money.

It should be pointed out here that how the technical functionality is financed is not necessarily the issue, but the costs do have an important influence on the extent to which these systems become widely distributed and thus on their effectiveness. One possible approach would be a permanent or time-limited V2I-based solution financed by the private sector to achieve suitably high levels of coverage and effectiveness.

Recommendations

The conclusion of the study is that driver assistance systems can make a significant contribution to improving road safety. However, due to the costly technical systems that have to be installed, the V2I-based alternative can only be used in a limited number of locations, which thus restricts its potential for improving road safety.

Overall, in order to improve road safety, the recommended approach is to push for the introduction and spread of those driver assistance systems that have an impact against the following frequently occurring accidents with serious consequences:

- accidents on straight roads that occur as a result of inappropriate speeds,
- accidents in bends that occur as a result of inappropriate speeds,
- accidents that occur as a result of the driver being distracted,
- accidents that occur as a result of the driver being under the influence of alcohol.

Some driver assistance systems were found to be rarely effective in that they only have an

Table 8:
Comparison of the different types of driver assistance systems

	Responsible party	Communication required	Effectiveness/Visibility	
			Collectiv	Individual
Infrastructur - only systems	Public-sector bodies		✓	
Self-sufficient in vehicle systems	Automotive industrie			✓
V2I-based systems	Primarily public-sector bodies	✓		✓
V2V-based systems	Automotive industrie	✓		✓

impact on accidents that occur rarely or do not have serious consequences:

- accidents in fog,
- accidents resulting from trucks losing their load,
- accidents caused by a stationary vehicle.

V2I-based driver assistance systems could be used particularly at intersections. Recently concluded research projects such as SAFESPOT and InterSafe2 have shown that the technical implementation of these systems is already possible today. However, the effectiveness, standardization, operation and, in particular, the financing of the technical systems on the infrastructure side, as well as questions of liability, have yet to be clarified.

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