Prediction of the expected accident scenario of future Level 2 and Level 3 cars on German motorways

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Abstract According to the SAE J3016 definitions, modern vehicles already include functionalities, which fulfill the criteria of Level 2 automation. The first applications of Level 3 automation in vehicles will probably include motorway scenarios only. The research question of this paper is an analysis of the current accident scenario on German motorways and its potential change due to Level 2 and Level 3 automation. Beside the field of effect, possible blind spots of automated cars can be identified. As the traffic behavior on motorways is depending on the vehicle fleet, modal split, traffic densities, and maybe legislative decisions, several scenarios are evaluated.

The study uses more than 1.000 motorway accidents out of database of the German In-depth Accident Study (GIDAS) that happened between 2005 and 2018 involving a passenger car. The results are extrapolated to the German national accident situation (approx. 19.000 accidents, 31.000 casualties, 270 fatalities).

The results show that systems in Level 2 cars already address most motorway scenarios. Level 3 functionalities will lead to still more safety in terms of reduced accidents. However, even Level 3 cars will be involved in accidents. The study shows which requirements for passive safety systems can be expected for these cars on motorways. The first Level 3 applications lead to more safety on motorways by mainly reducing rear-end collisions and accidents in lane change maneuvers. Current Level 2 systems will already address many critical situations.

Keywords Accident research, Automated driving, GIDAS, Motorway assistance, Scenarios

I. INTRODUCTION

Highly automated driving is a field of vehicle safety to which a large potential for the reduction of accidents and accident victims is attributed. The first vehicles with a high degree of automation are expected in a few years. The functionality to introduce these vehicles (level 3 automation) mainly addresses maneuvers on motorways. The necessary functions for roads in urban areas or on rural roads are too complex to be mastered with current technologies.

The use of Level 3 vehicles in public road traffic is accompanied by mixed traffic of older vehicles and highly automated vehicles. Due to this, Level 3 vehicles can still be involved in serious traffic accidents with personal injury. For this reason, secondary safety measures must not be reduced even for more highly automated vehicles. In order to estimate the safety benefit from the introduction of highly automated vehicles, a number of questions still need to be answered. In this study, the following research questions will be dealt with:

- Which market penetration scenarios of Level 2 and Level 3 vehicles are realistic?
- How many motorway accidents could be avoided by introducing Level 2 and Level 3 functions in M1/N1 vehicles?
- What types of accidents will still occur on Germany's motorways in the future?

II. METHODS

The study is divided into three main parts. The first part deals with the retrospective analysis of historical accident data. It is based on police-recorded accidents on all German motorways (provided by the Federal Bureau of Statistics) and motorway accidents out of the GIDAS database. This is followed by the definition of

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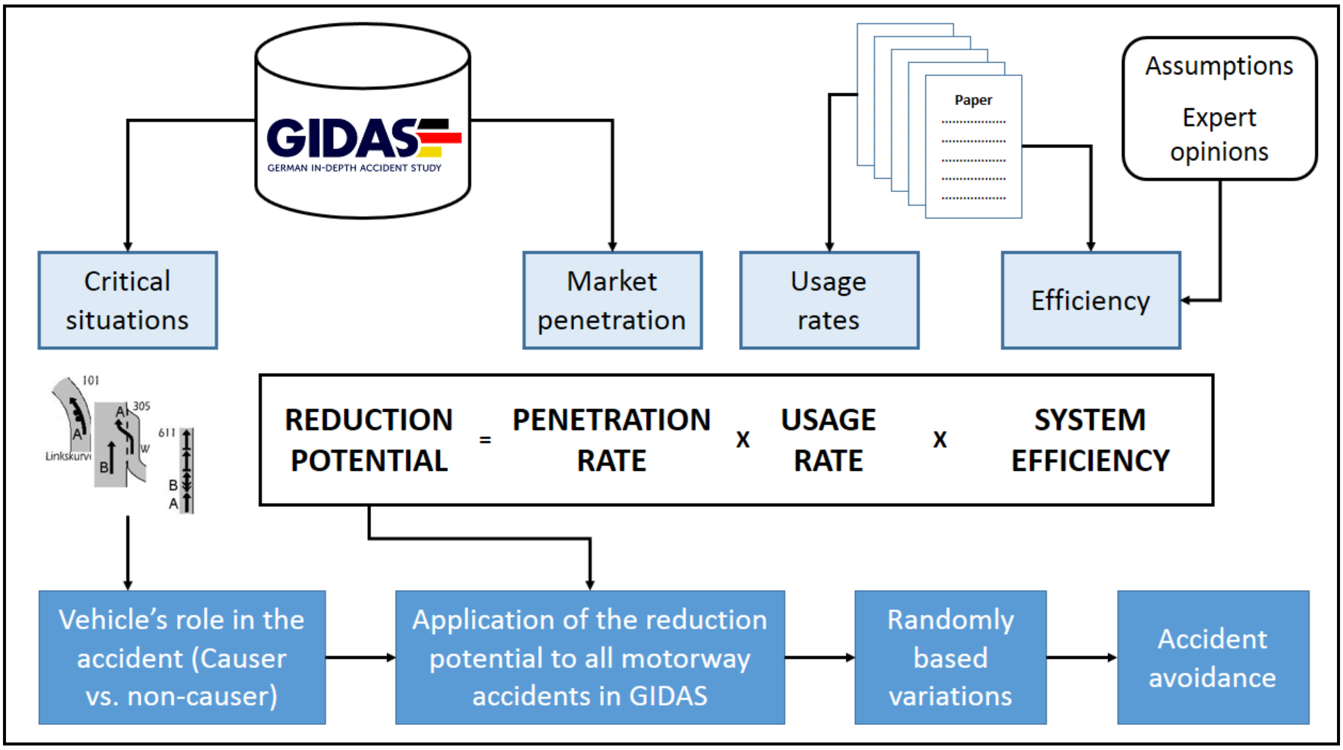
Level 2 and Level 3 vehicles and related usage/activation rates of systems. Afterwards, the expected future accident incidence is modelled by using the market penetrations of various safety systems for passenger cars involved in current accidents as well as assumptions regarding the system efficiencies. The effect on the German motorway accident scenario is then estimated. Finally, the potentially remaining accidents are analysed in a descriptive statistics.



Weighting and descriptive statistics of current accident data

In the first part of the study, the current accident situation on German motorways is analysed using the in-depth accident database GIDAS. This is necessary for the understanding and description of the current accident scenario on German motorways. It is the basis for modelling and predicting the future scenarios on highways.

GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive and serves as a basis of knowledge for different groups of interest. Due to a well defined statistical sampling plan, representative statements for the German accident scenario are possible after the application of weighting processes. Since July 1999, accidents have been investigated on the spot in the areas of Hanover and Dresden. GIDAS collects data from all kinds and types of accidents with personal damage. Approx. 3.500 information (about vehicles, persons, injuries, infrastructure, environment etc.) per accident are coded in the database on average. Finally, every accident is reconstructed.

The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT e.V.), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the consortium members. However, to allow interested parties the use of GIDAS data, several models of participation exist. Further information can be found at www.gidas.org.

To ensure representative results, the GIDAS dataset is weighted towards the German national statistics. This is necessary due to slightly biased data. The investigation teams are not thoroughly informed about all accidents and information about injuries cannot always be obtained immediately after the accident respectively after the investigation shift. Therefore, it is necessary to weight the data. After the application of the weighting process the derived conclusions can be used for statements that can be considered as representative for the German accident scenario.

For this study on motorway accidents with personal damage, all motorway accidents in GIDAS are weighted towards all motorway accidents in Germany that happened in 2017. The weighting uses two criteria:

- accident category (accident with slightly / seriously / fatally injured persons)
- kind of accident (ten different categories)

Due to the use of weighting factors it is possible that the total sum of accidents (or persons, vehicles etc.) gives non-natural numbers. Some analyses may present unweighted data (e.g. all chronological analyses of equipment rates) as the use of weighted data would distort the results. If unweighted data was used this is described in the diagram and/or related text.

The creation of the master-dataset for the study was done by applying the following filter criteria to the GIDAS dataset:

- fully completed and reconstructed cases only
- accident location: motorway / controlled-access highway ("Autobahn" in German)
  - roads with several lanes per direction and a structural separation between the driving directions
  - including acceleration lane and deceleration lanes
  - excluding rest areas and junctions/crossings at end of motorway exit
- accident year: 2005 – 2018 (to use the most current accidents only)
- accident involving one vehicle of the EC classes M1 or N1 according to [1]

Afterwards, missing data (e.g. variables that were introduced into the GIDAS coding scheme later than 2005) was coded in a single case analysis. However, accident databases with such a high level of detail will always have some fields with unknown data. Unknown information are kept in the dataset and will be excluded later in the single queries/diagrams.

The analysis is done on vehicle (i.e. participant) level as several vehicles/cars may be involved in one accident and each participant may have different options in terms of accident mitigation / avoidance.

Definition of Level 2 and Level 3 vehicles

Generally, the different automation levels of vehicles are categorized into six levels (0 to 5) according to [2]. For the evaluation of Level 2 resp. Level 3 vehicles a definition of the capabilities of these vehicles is necessary. Therefore, current state-of-the-art cars with Level 2 functions have been checked regarding their functions and available Advanced Driver Assistance Systems (ADAS) that are relevant for driving on motorways. As a result, the following assumptions have been used for a "typical" Level 2 car. This is assumed to be a good average out of several current models of different car manufacturers.

- standard (mandatory) features: Antilock Braking System (ABS), Brake Assist System (BAS), Electronic Stability Control (ESC)
- Automatic headlamps
- Traffic sign recognition
- Full speed range Adaptive Cruise Control (ACC) with Stop & Go function
- Forward Collision Warning System (FCW)
- Autonomous Emergency Braking (AEB) system → detecting driving and standing vehicles in front
- Lane Keeping Assist (LKA) with lane centering function
- Blind Spot Detection (BSD), Blind Spot Information System (BLIS)
- Tire Pressure Monitoring System (TPMS) (information/warning only)

As there are no Level 3 production vehicles available on the German / European market today (March 2019), the "Level 3 motorway function" has to be defined by assumptions. Therefore, current publications about Level 3 functions as well as regulations, consumer rating protocols or legislation documents have been used. Basically, a Level 3 function for motorway scenarios consists of all Level 2 features (as described above) with the following additional functions / features:

- Lane Change System (LCS) (Assumption: vehicle performs lane changes autonomously; backwards looking sensors are able to do safe lane changes according to the minimum requirements [6])
- AEB for pedestrian and bicyclists (VRU) with an operating speed range of 0 to 60kph [7]

- Detection of friction coefficient resp. road condition
  (vehicle detects low friction values, e.g. due to snow or ice on the road)
- No Autonomous Emergency Steering System → hard to evaluate with current accident databases as there is hardly any information about the surrounding traffic available)
- Intelligent Speed Adaption (ISA) → assumption: 100% correct speed information available
  (based on updated map data and traffic sign recognition)
- System avoiding Wrong Way Driving (WWDA)
- Speed limitation to 130 kph in autonomous mode

There is another crucial aspect when it comes to ADAS and their benefit in terms of accident mitigation and avoidance: the usage/activation rates. Nearly all current ADAS can be switched off manually by the driver. Thus, assumptions must be made regarding the usage rate of systems, especially the ones that may significantly influence the driving behavior on motorways (like ACC, LKA, BSD). As the paper aims to indicate the (maximum) potential of Level 2 and Level 3 systems, rather optimistic assumptions are made. Based on a literature review a constant value of 80% for all ADAS was assumed [4][5][9]. This is of course a simplification as the actual usage rate often varies, depending on the system itself, the age of the driver, the situation, and other influences.

Prediction of the future accident scenario on motorways

The main part of the study is the prediction of the future accident scenario on motorways when L2 and L3 vehicles are present in the vehicle fleet. Several steps are necessary for the prediction. At first, the market penetration for already existing ADAS is analysed to create a basis for assumptions about realistic market penetration scenarios of L2 and L3 motorway functions.

For the study, market penetration information is derived from the GIDAS database. Here, all M1/N1 cars (in all types of accident as well as in urban, rural, and motorway scenarios) are considered that were involved in an accident as non-causers (i.e. these cars were not the main causer of the accident). These vehicles are considered to be involved by chance and thus, represent the average vehicle fleet. Fig. 1 shows the market penetration rates of different ADAS for the accident years 1999 to 2017.

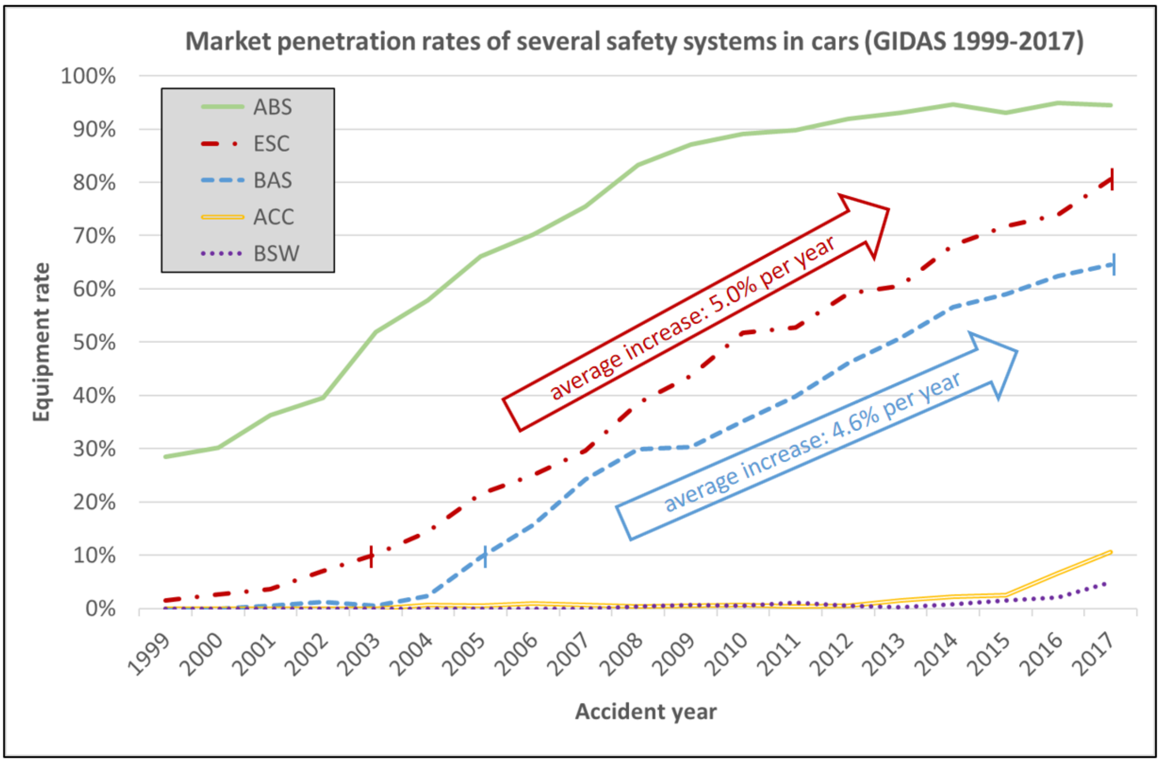


Fig. 1. Market penetration of several safety systems in Germany (source: GIDAS)

The equipment rates derived from cars out of GIDAS show a very slow increase in the first years. Around 10 years are necessary to become present in 5% of the fleet. Then, an average annual increase of 4 – 5% can be obtained from the data. This is especially true for those systems which are mandatory for passenger cars from a certain point in time (e.g. ESC, BAS). Other systems, on the other hand, take a very long time to be installed in vehicles in significant numbers (e.g. BSD). The average age of a vehicle fleet has an additional influence. In Germany, for example, the age of registered passenger cars rises continuously over the years [3]. As a consequence, the introduction of new systems on the market will also be delayed.

Although autonomous driving functions will most likely not become mandatory for the next decades, a very optimistic market penetration scenario is assumed for the L3 motorway function. After the initial market introduction phase (five years with an annual increase of 0.5% meaning that around 7% of the annual new registrations must have this function) the market penetration will steadily increase by one additional percent annually until 4.5% per year are reached (Fig. 2).

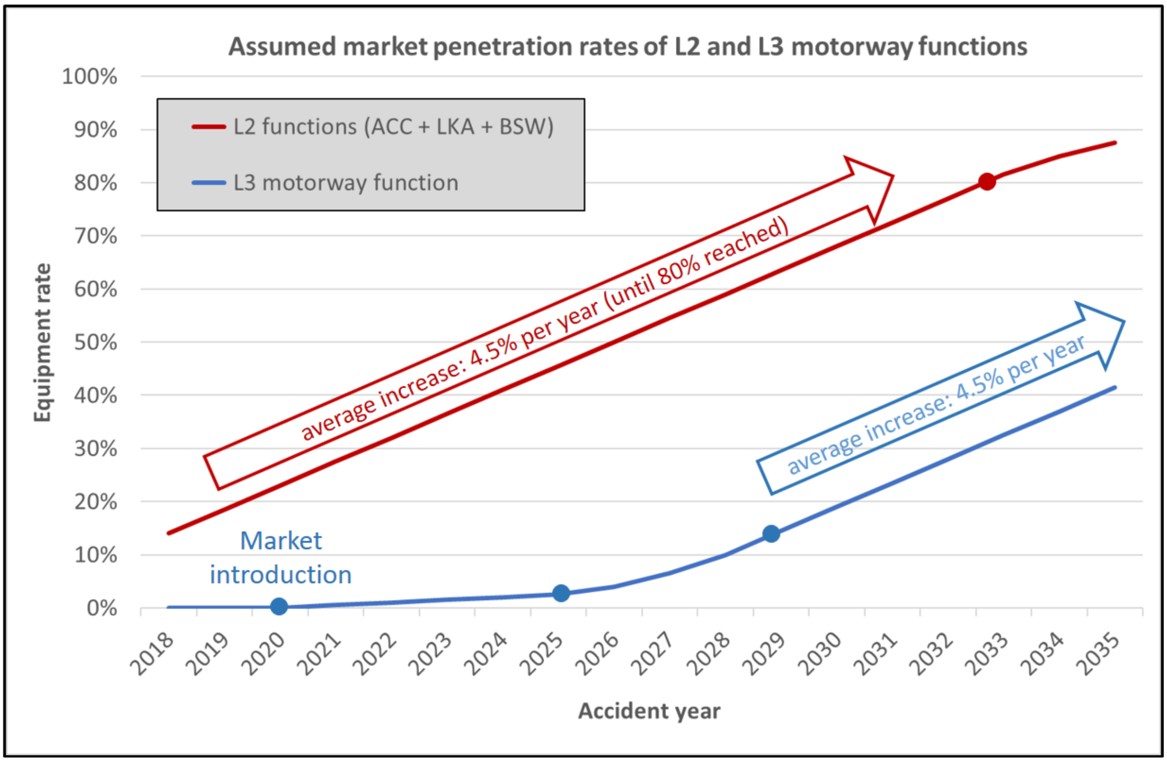


Fig. 2. Assumed market penetration for the considered L2 and L3 motorway functions

The assumptions made for Level 2 and Level 3 vehicles in the reduction rate calculation are shown in Tables 1 and 2. For Level 3 vehicles, for example, it is assumed that 90% of the journeys are made by using the Motorway-Assistant and only 10% of the journeys are made manually. The manual journeys can be caused, for example, by weather conditions (snow on the carriageway, construction site areas).

The assumed reduction rates have been determined depending on the accident type and the role of the vehicle in the crash (car was the main causer or not). The accident type plays a crucial role as they describe the initial conflict situation which resulted in the accident. The accident type represents the phase in the traffic situation where the further course of events could no longer be controlled because of improper action or some other cause. However, it does not describe the actual collision but indicates how the conflict was touched off before this possible collision [8]. Seven (main) accident types have been defined. Additionally, there are further distinctions available with more detailed sub-categories having a 3 digit number. If more than one accident type is addressed, the corresponding digits are replaced by an “x”. So, “1xx” stands for all accident types with numbers between 101 and 199, “30x” for all types between 301 and 309.

Assisted driver							
Level 2 vehicle							
	Type of accident	**Main Causer Efficiency (integrated Systems)**	**Usage Rate Estimation, based on [13]**	**Remarks**	**Other Participants Efficiency (integrated Systems)**	**Usage Rate Estimation, based on [13]**	**Remarks**
Loss of control accidents	**1xx**	80% [10] [11] [12]	90%	LKA, ESC, Traffic Sign recognition	35% front collision [10] 0% other	75%	front crashes (AEB)
Accident caused by turning into a road or by crossing it	**30x**	30% [10]	90%	BSD + high speed differences	35% front collision [10] 0% other	75%	front crashes (AEB)
Accident caused by crossing the road	**40x**	0%	95%	AEB VRU at high speeds	0%	0%	AEB VRU at high speeds
Accident involving stationary vehicles	**50x**	35% [10]	75%	AEB, ACC, LKA	0%	0%	
Accident between vehicles moving along in carriageway	**60x - 62x**	35% [10]	75%	AEB & ACC	0%	0%	
	63x - 64x	50% [10]	90%	BSD System	35% [10]	75%	AEB & ACC
	65x	90% [10]	90%	LKA & BSD	0%	0%	no avoidance within own lane
	68x	0%	90%	Wrong Way Driving possible	0%	75%	no avoidance
	69x	25%	90%	unclear situation, but 25% addressed by AEB, ACC, LKA	0	90	
Other accidents	**71x**	0%	0%	backwards driving still possible	35% front collision [10] 0% other	75%	front crashes (AEB)
	73x	35% [10]	75%	AEB w/o fixed object detection	0%	75%	AEB w/o fixed object detection
	74x	50%	90%	AEB, ACC, LKA (objects out of lane)	0%	0%	
	75x	0%	0%	no animal detection	35% front collision [10] 0% other	75%	front crashes (AEB)
	76x	0%	0%		35% front collision [10] 0% other	75%	front crashes (AEB)
	771	50%	100%	TPMS w/ warning	35% front collision [10] 0% other	75%	front crashes (AEB)
	772-775	0%	0%	no detection of other suden technical defects	35% front collision [10] 0% other	75%	front crashes (AEB)
	79x	0%	0%		35% front collision [10] 0% other	75%	front crashes (AEB)

Table 1: Assumptions for Level 2 vehicles

Highly automated driving							
Level 3 vehicle							
	Type of accident	**Main Causer Efficiency (integrated Systems)**	**Usage Rate**	**Remarks**	**Other Participants Efficiency (integrated Systems)**	**Usage Rate**	**Remarks**
Loss of control accident	**1xx**	100%	90%	no loss of control	50%	90%	front crashes (AEB)
Accident caused by turning into a road or by crossing it	**30x**	100%	90%	cut-in assist	50%	90%	front crashes (AEB)
Accident caused by crossing the road	**40x**	50% [10]	90%	AEB VRU at high speeds	0%	90%	
Accident involving stationary vehicles	**50x**	100%	90%	L3 drives not backwards on motorway	100%	90%	AEB w/ stationary vehicle detection
Accident between vehicles moving along in carriageway	**60x - 62x**	100%	90%	AEB	0%	90%	
	63x - 64x	90%	90%	Lane change assist (v_diff not considered)	50%	90%	front crashes (AEB)
	65x	100%	90%	Lane change assist	25%	90%	avoidance of 25% with side sensors
	68x	100%	90%	Wrong Way Driving Assist	50%	90%	front crashes (AEB)
	69x	80%	90%	unclear situation, but 80% addressed by AEB, ACC, LKA	0%	90%	
Other accidents	**71x**	100%	90%	no backwards driving possible	50%	90%	front crashes (AEB)
	73x	75%	90%	AEB w/ object detection	50%	90%	front crashes (AEB)
	74x	100%	90%	front crashes (AEB)	0%	90%	
	75x	50%	90%	comparable to AEB VRU	50%	90%	front crashes (AEB)
	76x	100%	90%		50%	90%	front crashes (AEB)
	771	80%	90%	TPMS w/ speed reduction	50%	90%	front crashes (AEB)
	772-775	0%	90%		50%	90%	front crashes (AEB)
	79x	0%	90%		50%	90%	front crashes (AEB)

Table 2: Assumptions for Level 3 vehicles

It has to be mentioned that most of the assumptions are the result of a combined literature review and expert opinions, as no experience is available for L3 vehicles at all. Sometimes, the boundary conditions of the reviewed studies do no match perfectly to the motorway situations that are analysed here.

However, some scenarios like “pedestrian crossing” (accident types 4xx), animal accidents (accident types

75x), backwards driving (e.g. accident types 71x), or accidents with stationary vehicles (accident types 50x) occur very seldom and thus, will hardly influence the final results.

The last step of the prediction is the randomly based variation of accident avoidance probabilities to all vehicles in the dataset. Here, the assumption was used that an accident can be avoided by the main causer but also by other road users. To address the different market penetration scenarios, random variations were applied (50 times each) to all evaluated scenarios.

III. RESULTS

At first, some characteristics of the current accident scenario on German motorways is presented. These figures are derived from Germany's national road traffic accident statistics [8] and are valid for the year 2017.

In Germany, 20,928 accidents with personal damage happened on motorways representing 6.9% of all police-recorded accidents with personal damage. 356 accidents (1.7%) were fatal accidents (resulting in 409 fatalities), nearly 4.400 accidents (21.0%) caused at least one serious injury and approx. 16.200 accidents (77.3%) ended up slight injuries. Fig. 3 shows the kind of accident of all motorway accidents in Germany.

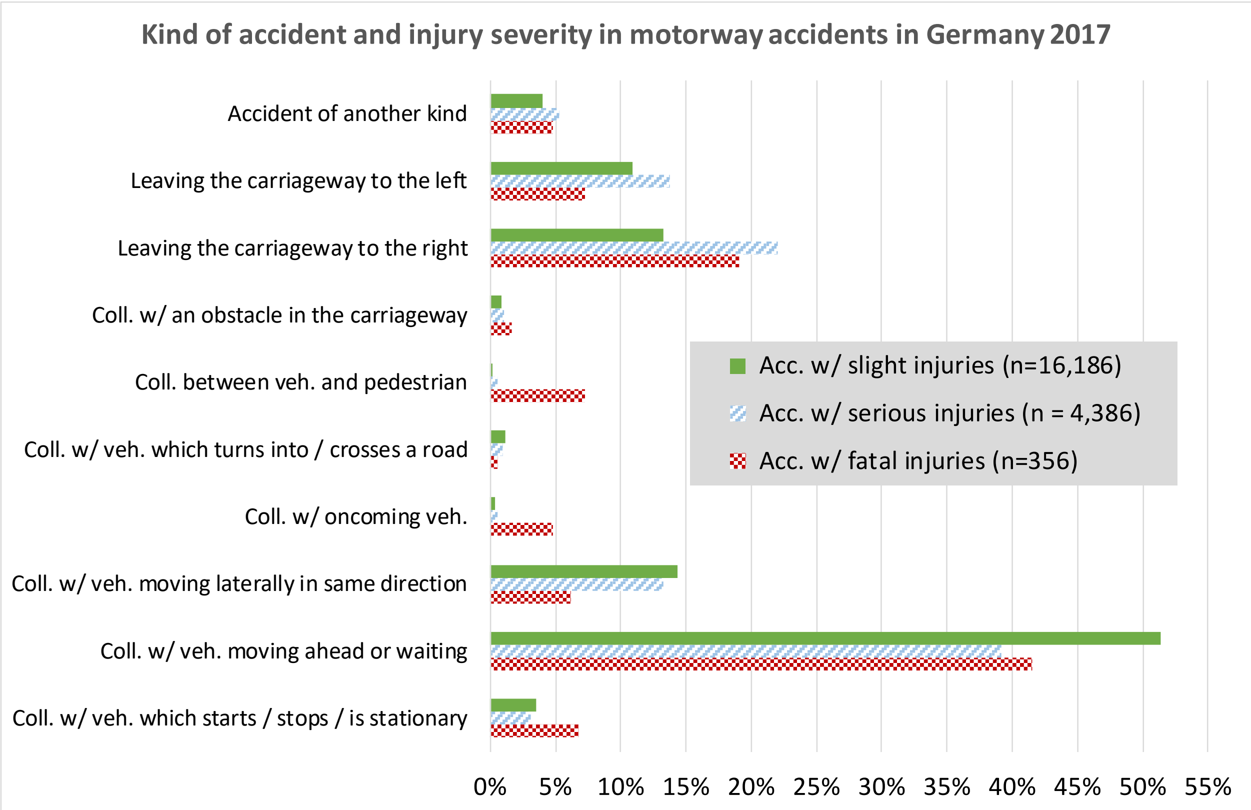


Fig. 3: Kind of accident in motorway accidents in Germany in 2017 [8]

As expected, the vast majority of accidents with personal damage is dominated by accidents where one vehicle collides with another vehicle that is moving ahead or waiting (at the end of a traffic jam). This kind of accident makes up around 40% of severe and even more than 50% of slight accidents. Loss of control accidents (mostly resulting in accidents where a vehicle leaves the carriageway to the right or left) are the second most frequent group. These accidents are usually more severe. However, the highest share of fatal accidents comes from the (rare) groups of pedestrian collisions and wrong way driving (collision with oncoming vehicle).

Another particularity of motorway accidents is the fact that more road users are involved in one accident. Compared to urban accidents (1.96 road users per accident) and accidents on rural roads (1.76) the number of involved road users is higher on motorways (2.16 participants per accident). This is a result of higher speeds (leading to more multiple collision accidents) and the occurrence of accidents in longitudinal traffic (rear-end collisions).

Looking on the type of road users also gives a clear picture. About four out of five involved road users are passenger cars (78.5%), followed by goods vehicles (incl. light commercials and heavy goods vehicles) with 18.3%. Other road users like powered two-wheelers (2.0%), busses (0.3%) or pedestrians (0.3%) do not play an important role.

In the next step, the described modeling process and the defined assumptions were applied to 998 GIDAS accidents on motorways involving 1,843 M1/N1 vehicles. The weighting process towards the German national statistics results in a master-dataset of 18,318 accidents involving 35,382 M1/N1 vehicles.

The following table shows the final results of the study. The accident avoidance potential has been calculated for several market penetration scenarios (10% / 20% / 50%) of L2 and L3 vehicles separately.

	L2 motorway functions			**L3 motorway functions**		
Market penetration scenario	10.0%	20.0%	50.0%	10.0%	20.0%	50.0%
Integrated efficiency	depending on acident type / critical situation according to assumptions					
Usage rate	depending on single systems according to literature and assumptions			90%		
Motorway accidents involving M1/N1 cars [2017, 100%]	18318			18318		
Avoided accidents due to L2 functions [result of 50 randomly based variations]	653 ± 70	1,308 ± 112	3,271 ± 126	1,425 ± 156	2,804 ± 216	6.962 ± 215
Potential effect (acident avoidance)	3.6% ± 0.4%	7.1% ± 0.6%	17.9% ± 0.7%	7.8% ± 0.8%	15.3% ± 1.2%	38.0% ± 1.2%

Table 3: Results of the estimations

IV. Discussion

There is an increasing availability of Level 2 cars on the market. System combinations (e.g. ACC with stop and go function plus lane keeping systems) help car drivers to stay in their lane and to maintain the appropriate speed and distance. However, the driver is responsible at any time although most of the functions manage to drive longer distances without any driver action (except of touching the steering wheel). The traffic scenario on motorways is less complex than traffic on rural or urban roads due to the one-directional traffic flow, missing crossing/turning traffic and the absence of pedestrians and bicyclists. Thus, Level 2 systems address many of the typical motorway situations. Beside the slow increase of the market penetration of such systems, the usage rate is one crucial factor that has a strong influence on the enhanced vehicle safety.

The study aims to answer the question which potential benefit can be expected from introducing these L2 functions into the passenger car fleet when realistic assumptions are made for the efficiency, usage rate and market penetration of such functions. As expected, current Level 2 functions are already able to address many accident situations on motorways. If every fifth passenger car would be equipped with the combination of the above mentioned systems (mainly ACC with stop and go, LKA, BSD, ESC, AEB front) and the drivers will use them often this would lead to a reduction of around 7% of all motorway accidents where a passenger car involved. However, some accident types will not be addressed by current Level 2 functions. Remaining accidents are for example:

- pedestrian accidents (very rare but very severe, often fatal)
- lane change accidents with a speed difference that cannot be covered by BSD)
- accidents during entering the motorway on the acceleration lane
- collisions with animals or objects (e.g. lost loading) on the road

Generally, many current accidents cannot be addressed by L2 systems if the equipped car is standing or driving slowly and gets involved in a rear-end collision. Here, higher equipment rates are helpful as well as the introduction of Level 3 systems so that many vehicles are technically able to avoid rear-end collisions. As a side effect, the more frequent observance of the safety distance between two consecutive vehicles and thus, a harmonization of traffic flow and less emergency braking maneuvers can be expected.

The next step towards more automation and possibly more safety is the (fast) introduction of Level 3 functions for motorway scenarios. Here, the study figured out which benefit can be expected from such functions. The assumed usage rate of 90% is of course a rather optimistic assumption. Here, a 20% market penetration will already avoid 15% of the accidents. If every second passenger car in the current motorway traffic scenario would be equipped with the defined Level 3 functions and the usage rate would be 90%, nearly 40% of accidents could be avoided.

One important aspect is the fact that passenger cars with Level 2 and Level 3 functions are also able to avoid collisions although they are not the causer of the critical situations. This is especially true for lane change and cutting-in maneuvers as well as driving side by side. Thus, the potential avoidance rate will not increase linearly with the market introduction. A progressive increase is expected as one vehicle with an L3 function is probably able to compensate the mistakes of the own vehicle (with a human driver) as well as other road users.

Another fact that is not covered in this study is the positive effect of vehicles using Level 2 and Level 3 functions on the traffic flow [14]. As accident database like GIDAS do not include much information about the surrounding traffic of the collision partners, analyses about the harmonization effect of L2 and L3 vehicles are hardly possible. However, it can be expected that even a small number of cars with Level 2 and Level 3 functions will lead to more safety distances, less speed differences and less critical lane changes. This will result in a more harmonized traffic flow as well as less critical situations for standard (Level 0 or Level 1) cars.

The presented study is mainly based on current knowledge about Level 2 and potential Level 3 systems as well as on current accident data out of the GIDAS database. Thus, the future effect of L2 and L3 functions is an estimation assuming that there are no other crucial changes (e.g. legislation, modal split, etc.). Here, further research is needed where such additional aspects are taken into account. Additionally, the presented approach could be compared to model based approaches in the future. Therefore, combined traffic and pre-crash simulations using actual/real system configurations could be carried out.

V. LIMITATIONS

A major limitation of the study is that the assumptions made did not take into account any change in traffic flow or the emergence of critical situations. The assumption here suggests itself that already with a share of 10-15% Level 3 vehicles in the fleet, clear positive effects in the traffic flow are to be expected. For example, traffic jams and rear-end collisions can be significantly reduced.

A very important factor of the calculations is the usage rate of the systems. A uniform usage rate of 90% was assumed for Level 3 vehicles. This might be rather optimistic but especially the first buyers/users of innovative technologies usually show high usage rates.

Due to changes in mobility behavior, traffic characteristics will probably change in the next decades. This was not taken into account in the study as it is very hard to estimate how car-sharing services, long-distance busses, and other transport modes (train, plane) will develop and the modal split on motorways will change.

In Germany, 70% of motorways have no fixed speed limit. In the GIDAS survey area this proportion is not equivalent, but in the present study this was formulated as an assumption.

In order to provide a more accurate estimate of possible reductions in the number of road accidents, further extensive randomized simulations of the individual cases (several participants, cascading of avoidance) must be carried out. This represents the next appropriate step in the research activities.

VI. CONCLUSIONS

As a summary of this study it can be stated that a significant safety benefit can already be achieved with Level 2 vehicles when the corresponding functions (like ACC and Lane Keeping Systems) reach significant market penetration rates and if they are used frequently. Highly automated vehicles (L3 or more) have an even higher potential but here, again, market penetration and usage rates will play a crucial role on effectiveness.

Due to the currently limited availability of systems and functionalities of Level 2 and Level 3 vehicles on the roads, many assumptions still have to be made for the efficiency of the systems. They should be proved and/or validates regularly when corresponding vehicles are available in the fleet.

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