ACCIDENTS INVOLVING CARS IN AUTOMATED MODE – WHICH ACCIDENT SCENARIOS WILL (NOT) BE AVOIDED BY LEVEL 3 SYSTEMS?

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ABSTRACT

In the coming years systems will become available that will be able to drive in automated mode for certain periods of time but will only be able to handle selected situations. This is referred to as conditional automation (level 3), whereby the driver no longer has to monitor the vehicle continuously but does have to take control on request when the limits of the automation driving system are reached. What we can say today is that vehicles with different levels of automation will be sharing the roads with manually driven vehicles in the foreseeable future. It is still unclear whether automated vehicles sharing the road with manually driven vehicles will lead to additional road safety risks (mixed traffic). With the presumption that vehicles will still be involved in accidents while they are driving in automated mode, following question arises: how will these accidents look like in the future? The German Insurers Accident Research therefore analyzed the impact of automated driving on motorway accidents. For this study, the UDV used its own accident database (referred to as the UDB) which contains a representative cross-section of all third-party vehicle claim files of the insurers involving personal injury and at least € 15,000 total claim value. The analyzed pool consists of accidents which occurred between 2007 and 2013. In a first step, relevant accident scenarios were determined based on all motorway accidents involving cars in the data pool. In a second step, generic automated driving functions and their characteristics were defined. Thereby, starting with driver assistance and comfort systems (DACS), automation Level 3 and 4 were defined and analyzed. By means of a case-by-case analysis the theoretical benefit potential of these systems was evaluated. Results of the analyses are: It can be expected for the future that cars driving in automated mode will still be involved in accidents. An active Level 3 function as described above could prevent up to 6% more motorway accidents than modern cars equipped with DACS. But negative effects that haven't been quantified up to know may decrease this potential significantly. With these systems it can anticipated that the frequency of rear-end accidents will decrease. But accidents caused by lane change will remain a big challenge for the automated driving systems. With a Level 4 system which drives in automated mode a total of 21% of all motorway accidents were considered as avoidable. The approach used in the study is based on limited knowledge on automated driving available today. It can be stated that the driver is the most critical part up to Level 4 automated driving. Starting with Level 4 this uncertainty will be nearly eliminated. A significant change in the accident situation can be expected only from systems with a very high level of automation (Level 4+) which exclude the driver from the driving task completely. But even with a Level 4 system, accidents will still happen in the future, e.g. due to mixed traffic.

INTRODUCTION

Automated driving is regarded as the future of mobility. It is expected to make traffic flow more efficiently and reduce the number of road accident victims as well as emissions and traffic jams. This will be more of a multi-dimensional, gradual transition than a rapid change. The new technology will be available in both cars and commercial vehicles. Currently, these vehicles offer either Level 2 (partial) or, in the near future, Level 3 (conditional) driving automation, which is typically active only on motorways [1]. As the development of the technology continues, vehicles with higher levels of automation that are also suitable for use in other situations, not just on motorways, will gradually become available. The situation is somewhat different with parking functions. Here, development may proceed more quickly toward highly automated functions. What we can say today is that vehicles with different levels of automation will be sharing the roads with manually driven vehicles in the foreseeable future. This development will affect both cars and commercial vehicles.

GERMAN INSURERS ACCIDENT DATABASE

The accident database of the German Insurers Accident Research (referred to as the UDB) is a database that was set up for accident research purposes. The data collected is conditioned for interdisciplinary purposes for the fields of vehicle safety, transport infrastructure and traffic behavior. The contents of the claim files from the insurers form the basis of the UDB. Only third-party vehicle claims involving personal injury and at least € 15,000 damage costs have been taken into account for the GDV accident database. Cases involving only damage to property and less serious accidents involving personal injury (damage costs < € 15,000) are not included in the UDB

The data sample used in this analysis consists of a total of 3,029 accidents that occurred between the years 2007 and 2013 and involved at least one passenger car. A total of 4,845 cars excluding vans were involved in these accidents. Motorway accidents make up 11% (n=346 relevant cases with n=709 involved cars) of these accidents. All types of traffic involvement were taken into account as the collision parties for the car (cars, trucks, buses, motorcycles, bicycles and pedestrians) as well as single car accidents. Single car accidents are, however, underrepresented, as cases in which there is no injury or damage to a third party are not brought to the attention of GDV.

MOTORWAY ACCIDENTS INVOLVING CARS IN THE UDB

The n=346 motorway accidents in the UDB were broken down in:

- accidents where a car was responsible for the crash (which make up 25% of all involved cars)
- accidents where at least one car was involved but not responsible for the crash (which make up 75% of all involved cars).

Out of these 346 accidents, a total of 146 cases where the car was responsible for the crash and 244 cases where the car was not responsible for the crash have been analyzed. The fact that more than one car may be involved in an accident led to multiple counting, i.e. the same case can be counted more than once.

Motorway accidents where the car was the main responsible

Motorway accidents can be described in different ways. The most common method is by using the parameters "Type of accident" [2] and "Kind of accident" [3]. In this study, a combination of both parameters was used first for a rough classification of the UDB accidents in scenarios and, in addition, a case-by-case analysis was performed in order to break them down in sub-scenarios. The type of first conflict between the case-car and another vehicle was the decisive factor in this matter.

Two major scenarios were found to be predominating and these acount for a total of 88% of all n=164 motorway accidents caused by a car. These are:

- "rear-end accidents" (51%) and
- "lane change accidents" (37%).

There is also a small group of "other" accidents (13%) which can not be put in patterns. These are conflicts with crossing animals, for instance, or rear-end collisions where the case-car was hit from behind after a lane change. Since the vehicle coming from behind was very fast and/or far away at time of lane change, these accidents were not assorted to the group of lane change accidents.

Rear-end accidents are characterized by the fact that the case-car is involved in one or multiple collisions after a conflict with a moving or stationary vehicle in front of it in the same lane. In most of the cases the driver of the case-car oversaw the vehicle ahead or failed reacting properly when approaching it.

Lane change accidents are characterized by the fact that the case-car is involved in one or multiple collisions after having left either intentionally (lane change in order to avoid a rear-end collision with the vehicle ahead) or unintentionally (e.g. due to driver distraction, fatique) its own driving lane.

A closer look at the sub-scenarios shows that:

- Unintentional lane changes of the case-car represent the most frequent sub-scenario and account for one third of all all motorway accidents caused by a car.
- Rear-end conflicts with a stationary vehicle, as typical for congestion related situations, are the second most frequent sub-scenario and make up 31% of all mtorway accidents caused by a car.

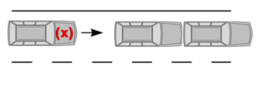
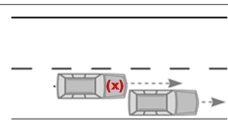
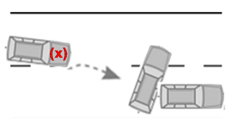
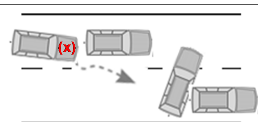
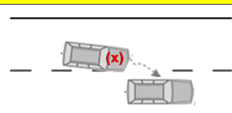
Motorway accidents that were caused by a car (n=164)			
Accident scenarios from the view of the case-car that caused the accident (x)		n	%
Total accidents		164	100
Rear-end		83	51
	Conflict between the case-car and a stationary vehicle in front in the same lane	51	31
	Conflict between the case-car and a vehicle moving ahead in the same lane	32	20
Lane change		60	37
	Conflict between case-car and another vehicle in the same or another lane caused by an unintentional lane change of the case-car	54	33
	Conflict between case-car and another vehicle caused by an intentional lane change of the case-car due to a vehicle on the same lane	6	4
Others		21	13
	Other conflicts (e.g. lane change of the case-car due to another lane changing vehicle or case-car being hit by a vehicle from the adjacent lane)	21	13

Figure 1. Motorways accidents caused by a car and their classification in scenarios and sub-scenarios

Motorway accidents where the car was involved but not responsible

The groupf of accidents where the car was involved but not responsible for the crash build the second pool. It contains 244 accidents and makes up a larger proportion within all motorway accidents invoving a car in the UDB (n=346).

A short overview of the main and sub-scenarios (Figure 2) reveals a picture which is similar to that observed for accidents with the car being responsible. Rear-end-collisions have the highest share, accounting for 51% of the cases being followed by the group of lane change accidents with a share of 41%.

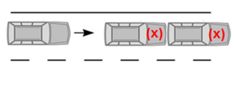
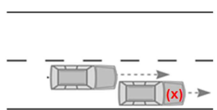
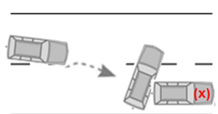
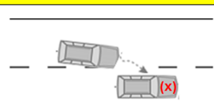
Motorway accidents that were not caused by a car (n=244)			
Accident scenarios from the view of the case-cars that were invovled but not responsible for the accident (x)		n	%
Total accidents		164	100
Rear-end			
	Another vehicle collides with the case-car which is standing in the traffic in the same lane	79	32
	Another vehicle collides with the case-car which is moving ahead in the same lane	46	19
Lane change			
	Another vehicle collides with the case-car after a lane-change (different collision constellations possible)	99	41
Others			
	Other conflicts (e.g. case-car is hit by a vehicle that is moving on the adjacent lane)	20	8

Figure 2. Motorways accidents caused by a car and their classification in scenarios and sub-scenarios

CATEGORIZING AND DISTINGUISHING BETWEEN MODERN ASSISTANCE AND AUTOMATED FUNCTIONS

The discussion around automated driving requires a clear understanding of the attributes and capabilities of the functions involved. Driving can be subdivided into navigation, vehicle control and stabilization tasks [4]. According to this model, the navigation level is about route planning, the vehicle control level involves the driver comparing the goal with the current situation (i.e. dynamic driving), and the stabilization level is about controlling deviations in a closed loop system.

Assistance and automation functions operate on the vehicle control level. There are three different modes of action here [5]: informative and warning functions, continuously automating functions and temporarily intervening systems (see table 1). This approach has the advantage that a distinction can be drawn between advanced driver assistance systems and automated driving functions. Even among advanced driver assistance systems, there are differences that are clearly based on their mode of action. Mode of action B describes the levels of automation under discussion (see table 2). Level 1 covers only advanced driver assistance systems that handle longitudinal and lateral control. These are the proximity control system and the lane-keeping assist system. The lane-departure warning system, on the other hand, comes under mode of action A/2.

Mode of action A Informative and warning functions	Mode of action B Functions offering continuous automation	Mode of action C Systems that intervene temporarily in accident-prone situations
Take effect exclusively and "indirectly" through the driver: 1. Status information, e.g. traffic-sign recognition 2. Abstract warning, e.g. lane-departure warning system 3. Concrete warning, e.g. • Blind-spot detection system or • Collision warning system	Have a direct effect on vehicle control, can always be overriden. Definition according to SAE J3016 [1] or VDA/BASt [4]	Preventive machine intervention with a negative situation forecast, e.g. • Emergency brake assist system • Emergency steering assist system

Table 1. Assistance and automation functions on the vehicle control level [4]

Nomenclature	Driving tasks of the driver by level of automation
Full automation **Level 5**	The system takes full control of driving on all road types and in all speed ranges and environmental conditions
High automation **Level 4**	The system takes over full lateral and longitudinal control in a defined application
Conditional automation **Level 3**	The system takes over lateral and longitudinal control for a certain period in specific situations
Partial automation **Level 2**	The system takes over lateral and longitudinal control (for a certain period and/or in specific situations)
Driver assistance **Level 1**	The driver has constant lateral or longitudinal control. The other driving task is handled by the system within certain limits (e.g. adaptive cruise control (ACC) system, lane-keeping assist system).
No automation **Level 0**	The driver drives constantly (for the whole journey) with both longitudinal control (acceleration and breaking) and lateral control (steering).

Table 2. Levels of automation in accordance with SAE J3016 and VDA/BASt [1,6]

METHOD DESCRIPTION

An overview of the analysis method and some specifications related to the automated driving systems will be given in the following.

For each motorway accident in the UDB, the car that caused the accident was defined as the case-car. In a case-by-case analysis, the safety potential was estimated for driver assistance and comfort systems (DACS) and two levels of automated driving. The cases were analyzed using the "What would happen if..." method. The prerequisite for this is the assumption that none of the analyzed case-cars involved was using an automated function or any DACS at that time. This approach considers the course of the accident as it happened in reality and contrasts it with the course of the accident as it would have been with the case-car driving in automated mode or with DACS. This makes it possible to determine the influence an automated ride would have had on the course of the accident. The original driver behaviour was taken into consideration, as far as it was possible. For each case it was assumed that during the automated ride the driver of the case-car would have behaved in the same way as he did before the original accident.

The challenging part was to define the automated driving functions and implement them in the analyses. An attempt was made to use the knowledge on the system definitions gained from the previous chapter. However, this could not be done in that detail as described in Table 1 and Table 2. When speaking of retrospective accident analysis, a clear distinction between DACS and automation systems is almost impossible. It could not always be determined which system would have intervended first in case of an accident: DACS or the automated system. The "What would happen if..." method uses the assumption that the case-car was driving in automated mode right before the accident, but does not consider earlier traffic events that could have been influenced by the automated ride.

With this limitations and being aware of the fact that we were not exactly in line with the definitions in Table 2, three degrees of systems were defined and their boundary conditions were set. It was assumed that every case-car (and no other vehicle involved) was equipped with following driver assistance and comfort systems (DACS):

- Adaptive cruise control (ACC),
- Emergency braking assist,
- Lane keeping assist and
- Blind spot detection system.

In simply terms spoken, these four DACS are pieces of a Level 1 and in combination a Level 2 automated driving mode. Additonal two more levels were then defined by succesively adding more attributes and capabilities. These levels were Level 3 and Level 4. Table 3 gives a short description of the systems with their boundary conditions.

It has to be underlined that with this method no differentiation could be made between DACS, Level 1 and Level 2. These differences lie mostly in the Human-Machine-Interface – with the full responsibility of the driver - and not in technical details of the systems. These human based differences can also not be adressed with the tool of a retrospective accident analysis. In the following parts of this paper, the term DACS will therefore be used for this group of systems.

It was possible to distinguish between these DACS, Level 3 and Level 4. The differences in the functionalities can be basically described by the situations that can be handled by the systems. But the most crucial difference between DACS and Level 3 was that, for DACS, the driver behaviour"overwrote" the system functionality in certain situations. This was not done for a Level 3 system because, according to the definitions, the driver was not monitoring during the automated ride. Following aspects were essential when declaring no safety potential to the systems:

- System reaches its technical boundaries (see Table 3)
- System is not activated or manually switched off by the driver
- Unforseen environmental or car related events (aquaplaning, tire blow, technical failure of the car).

The analyses did also not consider following aspects that could lead to negative effects for road safety but which are not quantified yet:

- Take-over request to the driver [7]
- Negative effects initiated by the automated ride that could lead to other accidents (e.g. fatique) [8]
- Different driver behaviour due to mixed traffic.

<table>
<tr>
<td>Assumptions for DACS:

o System maintains longitudinal and lateral drive, but no lane change
o Driver can override or switch off the system
o Driver acts / monitors the system continuously (hands on the steering wheel)
o System performs braking manoeuvers but no evasive steering manouvers (only warning)
o System has no safety potential in following cases:
▪ Construction sites
▪ Joining or leaving the motorway
▪ Steering mistake by the driver
▪ Alcohol, fatigue and physical issues of the driver
▪ Technical failure of the car
▪ Extreme weather conditions (strong rain, aquaplaning).</td>
<td>Assumptions for a Level 3 automated driving function:

o System operates up to 130 kph (not considered in this analysis)
o System maintains longitudinal and lateral drive (except: entering and leaving the motorway)
o Driver can override or switch off the system
o System performs braking, lane change (evasive) and overtaking manouvers
o Driver is not required to monitor the system
o Driver receives a take-over-request in critical situations
o System has no safety potential in following cases:
▪ Construction sites
▪ Joining or leaving the motorway
▪ Alcohol and severe physical issues of the driver
▪ Technical failure of the car
▪ Extreme weather conditions (strong rain, aquaplaning).</td>
</tr>
<tr>
<td colspan="2">Assumptions for a Level 4 automated driving function:

o System operates up to 130 kph (not considered in this analysis)
o System maintains longitudinal and lateral drive (incl. entering or leaving the motorway)
o Driver can override or switch off the system
o System performs braking, lane change and overtaking manouvers
o Driver is not required to monitor the system
o System performs braking and evasive manouvers
o In critical situations, the system initiates a minimal risk manouver
o Systems has no safety potential in following cases:
▪ Technical failure of the car
▪ Extreme weather conditions (strong rain, aquaplaning).
▪ Collisions with other vehicles that approach from the site or from behind</td>
</tr>
</table>

Table 3. Boundary conditions for the three defined levels of automation in the UDB analysis

SAFETY POTENTIAL FOR SELECTED LEVELS OF AUTOMATION

The safety benefits were calculated for each of the systems separately and were then put in relation to the different accident pools (see Table 4).

A modern car equipped with DACS could achieve a safety potential of 21% on motorways. This underlines the important part of driver assistance systems for road safety. As already mentioned before, with this method, this equals the safety benefit of a Level 1 and Level 2 system. That means that no additional safety benefits can be expected for Level 1 and Level 2 but negative effects might lead to less benefit at this point (see Figure 3).

Related to all motorway accidents involving a car, an additional safety potential of +6% could be achieved by a Level 3 system. This "ad on" is small and can be explained by the fact that a Level 3 system still has to rely on the driver as a back-up when the technical boundaries of the system are reached (see also Table 3). And it has to be put in contrast to possible negative effcts caused by a Level 3 system.

A nearly maximum safety potential of additional +21% can be achieved by a high automation level (Level 4), which requires no driver monitoring or driver intervention at all during the autonomous ride. Even here, possible negative effects (mixed traffic) must be considered. According to the analyses, with a Level 4 system, more than half of all motorway accidents caused by a car would still remain unavoidable, for instance.

If these benefits are put in relation to the larger accident pools, their amount will decrease. Related to all accidents involving a car in the UDB, for instance, the achievable safety potential for a Level 3 system system is 0.7% and even with a Level 4 maximum 2.4% more car accidents could be avoided.

Systems		Safety benefit [%] in terms of avoidable accidents as an "ad-on" to the achievable benefits by ADAS			
		Motorway accidents involving a car (n=346)	Motorway accidents caused by a car (n=164)	All accidents involving a car (n=3,029)	All accidents caused by a car (1,834)
DACS		**21%**	**45%**	**2.5%**	**4.0%**
Level 3	additional	**6%**	**12%**	**0.7%**	**1.1%**
Level 4		**21%**	**45%**	**2.4%**	**4%**

Table 4. Achievable safety benefits for analyzed levels of automated driving functions in relation to the different accident pools – the numbers for Level 3 and 4 represent the additional benefits in comparison with DACS

For those accidents that were caused by a car on motorways, Table 5 gives a differentiated view of the achievable safety benefits for the two main accident scenarios. DACS could avoid 80% of all rear-end accidents in the case material but only 10% of the lane change accidents. This is not surprizing because it reflects what DACS in modern cars can already achieve. Todays DACS already overcome most rear-end conflict situations. But most lane change situations are still critical for them [9].

In comparison to DACS, the additional benefit of a Level 3 system can be derived from better skills in the form of dealing with lane change situations. In the analyzed case material, a Level 3 system could avoid only few more rear-end accidents (factor 1.1) but nearly three times more lane change accidents than DACS (see Table 4). For a Level 4 system there is almost no difference between the share of the two scenarios. Due to the exclusion of the driver from monitoring/intervening during the automated ride, a Level 4 system will be able to overcome all types of conflicts in longitudinal traffic properly, i.e. a lane change will be also no problem anymore for self-caused accidents.

Motorway accidents that were caused by a car (n=164)					
Accident scenarios	n	%	avoidable accidents [%]		
			DACS	**Level 3**	**Level 4**
	164	100	**35**	**49**	**91**
Rear-end	83	51	**80**	**87**	**98**
Lane change	60	37	**10**	**27**	**97**

Table 5. Achievable safety benefits for selected automation levels in the UDB

DISCUSSION - ACCIDENTS AND AUTOMATED DRIVING?

One major outcome of the analyses is that there still will be accidents caused by the car during a Level 3 automated ride in the future, regardless the achievable safety benefits of the system. The main reason is that an automated ride with a Level 3 system will still need the driver in terms of intervening in the event of critical situations.

The fundamental problem in connection with constant monitoring coupled with intervention in the event of critical situations is based on a human characteristic investigated by psychologists over 100 years ago [10]. The resulting Yerkes-Dodson law describes the general relationship between a person's ability to perform well and their state of physiological and mental arousal. When a person has a low level of arousal, their performance remains at a minimum level. As the person becomes more aroused, their performance increases up to a maximum level. If arousal increases beyond that, performance starts to drop again until it reaches a similar minimum level to the level at low arousal (Figure 3). Put simply, this means that people perform demanding tasks best with a moderate level of arousal. Driving a car is such a task. Monotonous tasks, like driving down a perfectly straight road with no traffic, can result in a low level of performance or failure. Monitoring a Level 2 system is one such task. Equally, if a driver is overtaxed, the result will be poor performance and even failure. Suddenly being requested to take over control from a Level 3 system would be an example of this.

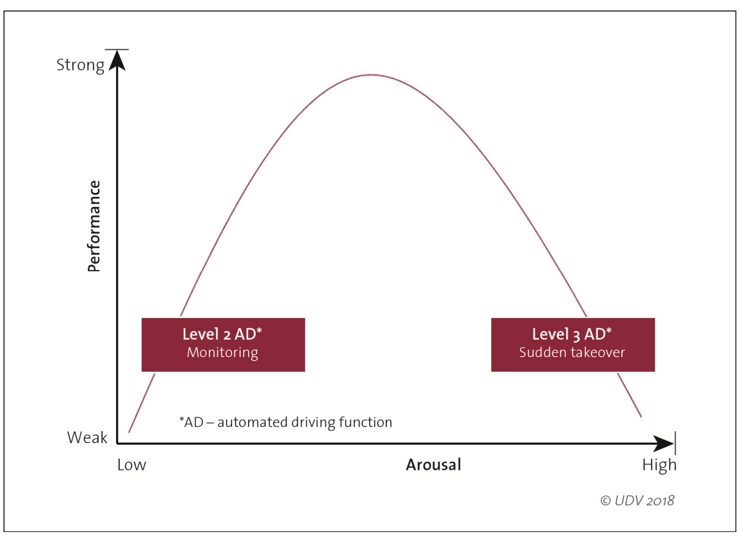


Figure 3. Simplified representation of the Yerkes-Dodson law in connection with automated driving [10]

CONCLUSIONS

The analyses revealed that 11% of all accidents involving a car occur on motorways. For accidents that were caused by a car, safety benefits were determined based on two levels of automated driving. The most substantial benefit in terms of 21% avoidable acidents can be expected from modern assistance and comfort systems (DACS) if these consist of an emergency breaking assist, a lane change assist, a blind spot detection system and an adaptive cruise control.

In comparison to modern cars equipped with DACS, an additional benefit of +6% could be expected for a Level 3 system in terms of avoidable accidents on motorways. Compared to the benefits of DACS, this level of automation might have a higher benefit because it will be able to avoid more lane change accidents. Nevertheless it has to be considered that there could be negative effects on road safety caused by a Level 3 system. Up to know, these effects have not been quantified yet. But studies indicate that they should not be underestimated and that these negative effects might reduce the additional positive benefits. In total, Level 3 systems might have no additional positive effects at all.

It can be predicted that cars driving in a Level 3 automated mode will still cause accidents on motorways in the near future. And they will also be even more often involved in accidents without their own fault. The most critical part for a Level 3 in the future will still be the driver. The majority of those accidents that can not be avoided by a Level 3 system will be lane change accidents.

Only a Level 4 system will provide a high benefit in terms of additional 21% avoidable accidents compared to a Level 3 system. This is because a Level 4 system will be able to handle almost all traffic situations properly but most importantly, the critical part "driver" will be nearly eliminated during the automated ride. Nonetheless, even with a Level 4 system, a large proportion motorway accidents involvoing a car will still remain unavoidable. In this context, possible negative effects of mixed traffic are not considered here.

From the view of the German Insurers, highly automated vehicles (Level 4) could bring great benefits in terms of road safety if they functioned flawlessly under all conditions within their intended scope. Until such time as these systems come onto the market, drivers of manually controlled vehicles should benefit in terms of road safety from continual improvements in driver assistance systems.

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