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Automated cars on motorways: Active and passive safety aspects

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Gesamtverband der Deutschen Versicherungswirtschaft e.V.
Wilhelmstraße 43/43 G, D-10117 Berlin
Postfach 08 02 64, D-10002 Berlin
Phone +49 (0)30 20 20 – 58 21, Fax +49 (0)30 20 20 – 66 33
www.udv.de, www.gdv.de, unfallforschung@gdv.de

Content
Dr.-Ing. Matthias Kühn
Dipl. Ing. (FH) Jenö Bende

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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 very 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.

The German Insurers Accident Research has carried out a comprehensive study on motorway accidents involving cars. The aim of the study was to determine the overall safety effect of automated driving function. The study was performed by using the retrospective analysis of third party insurer claims. The methodology and its limitations will be discussed at first. The first part deals with potential active safety benefits. The second part of the study analysis the passive safety consequences. The third part finally concludes with the findings.

The aim of the first part of study was to determine the safety potential of advanced driver assistance and comfort systems (ADAS+) of today`s modern cars and, based on these benefits, to assess the additionally achievable safety potential of future automated driving functions. In the second part the injury outcome for the belted front seat passengers was assessed. When discussing the requirements for the design of car restraint systems in the context of automated driving the entire accident occurrence of a vehicle should be taken into account, regardless of the type of road the vehicle is using, although initially, automated Level 3 functions will be used on motorways only. When a car drives with an activated Level 3 automated function, the sitting position of the driver will change as a consequence of retracted steering wheel and pedals, which leads to a more comfortable position similar to the passenger position. This brings up the question if the requirements for the restraint systems will also change when the car uses an automated driving function?

Data base and methodology

German Insurers Accident Database (UDB)

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. 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.

Methodology and limitations

The methodology applied here is based on a retrospective case-by-case analysis of the third party claims of the German insurers and encompasses following parts:

- safety benefit estimation for advanced driver assistance and comfort systems (ADAS+) and automated driving functions (Level 3 and Level 4),
- injury predicition for belted front seat occupants in cars which are using an Level 3 driving function.

In the following, a short overview will be given in terms of describing the automated driving functions with their boundaries and major limitations of the methodology will be listed. Additional information can be found in [2] and [3].

For each motorway accident case 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 ADAS+ and two levels of automated driving. The cases were analysed using the "What would happen if..." method. In a first step, the safety benefits of automated driving functions were determined and in a second step, the injury mechanisms were analysed for belted front seat occupants in the case-car. Both analyses were made for different pools derived from motorway accidents involving a car.

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 ADAS+:

Advanced Driver Assistance Systems	Comfort System
Emergency braking assist	Adaptive cruise control (ACC)
Lane keeping assist	
Blind spot detection	

In simple terms, these four systems are pieces of a Level 1 and in combination a Level 2 automated driving mode. Even though these definitions deviate from current definitions established by BASt [4], these were found to be more applicable in this analysis. Additional two more levels were then defined by successively adding more attributes and capabilities [5, 6]. These levels were Level 3 and Level 4. Table 1 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 ADAS+, Level 1 and Level 2. In the following, the term ADAS+ will therefore be used for this group of systems.

It was possible to distinguish between these ADAS+, Level 3 and Level 4. The differences in the functionalities can be basically described by the situations that can be handled by the systems (see Table 1). But the most crucial difference between ADAS+ and Level 3 was that, for ADAS+, 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. 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]
- effects initiated by the automated ride that could lead to other accidents (e.g. fatigue) [8]
- different driver behavior due to mixed traffic.

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

Table 1

Description of the main system properties	ADAS +	Level 3	Level 4
	Driver can override or switch off the system		
	maintains longitudinal and lateral drive, but no lane change	System maintains longitudinal and lateral drive (incl. lane change and overtaking maneuvers)	
		operates up to 130 kph (not considered in this analysis)	
Critical situations on motorway derived from the accident analysis	**System can handle these situations**		
Construction sites	no	no	yes
Joining or leaving the motorway	no	no	yes
Steering mistake by driver	no	yes	yes
Fatique of the driver	no	yes	yes
Alcohol, severe physical issues of the driver	no	no	yes
Technical failure of the car	no	no	no
Extreme weather condition (strong rain)	no	no	no
Case car hit by another vehicle from behind or from the side	no	no	no

Active Safety Benefits

Motorway accidents involving cars in the UDB

Motorway accidents make up 11 percent of all car accidents in the UDB and contain n=346 accidents with a total of n=709 involved cars. These accidents were broken down into:

- 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).

Both accident groups were put into accident patterns which can be described by the parameters "Type of accident" [9] and "Kind of accident" [10]. In combination, both parameters were used first for a rough classification of the UDB accidents in scenarios. This was followed by a case-by-case analysis.

Motorway accidents where a car was responsible for the crash

Figure 1 shows the accident patterns that were derived from the accident analysis for accidents that were caused by a car. Two major scenarios were found to be predominant and they account for a total of 88 percent of all n=164 motorway accidents caused by a car. These scenarios are:

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

The share of 51 percent of typical rear-end accidents can be mostly characterized by the fact that the case-car was 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 (37%) are characterised by the fact that the case-car was 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, fatigue) its own driving lane. A closer look at the sub-scenarios shows that:

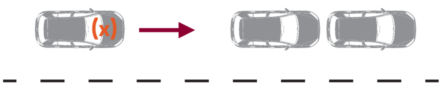
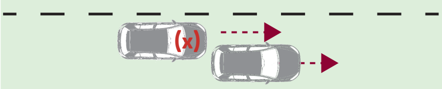
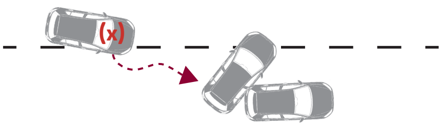
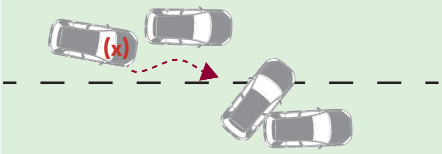
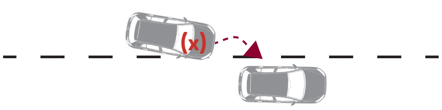
- Unintentional lane-changes of the case-car represent the most frequent sub-scenario and account for one third of all motorway accidents caused by a car.
- Rear-end conflicts with a stationary vehicle, as typical for congestion related situations, are the second most frequent sub-scenario and make up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

Motorway accidents where a car was not responsible for the crash

According to Figure 2, the accident occurrence for cars being involved but not responsible for the accident shows similar patterns to that of accidents where the car was responsible for the crash. Rear-end-collisions have the highest share, accounting for 51 percent of the cases where the car was not responsible for the crash. These are followed on second place by accidents caused by lane change of which share is remarkably high (41%).

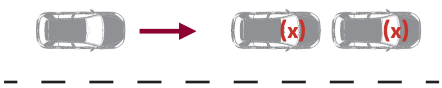
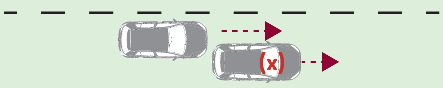
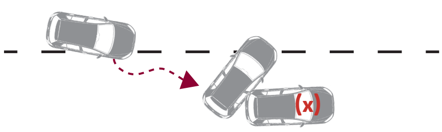
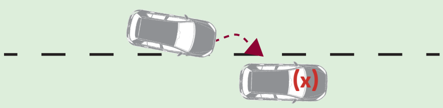
Scenarios and sub-scenarios for motorway accidents that were caused by a car

Figure 1

Motorway accidents that were caused by a car (n=164)			
Accident scenarios from the view of the car that was responsible for the accident (x)		n=164	100%
Rear-end collision		**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 the 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 the case-car and another vehicle caused by an **intentional** lane change of the case-car due to a vehicle in the same lane	6	4
Other conflicts		**21**	**13**
	Other conflicts (e.g. lane change of the case-car due to another lane changing vehicle of case-car being hit by a vehicle from the adjacent lane)	21	4

Main accident scenarios from the point of view of the case-car that was not responsible for the accident

Figure 2

Motorway accidents that were not caused by a car (n=244)			
Accident scenarios from the view of the car in Level 3 mode that was involved but not responsible for the accident (x)		n=244	100%
Rear-end collision			
	Another vehicle hits the rear-end of the case-car which itself is standing in traffic in the same lane	79	32
	Another vehicle hits the rear-end of the case-car which itself is moving ahead in the same lane	46	19
Lane change			
	Another vehicle collides after a lane-change with the case-car – various types of collisions are possible in this sub-scenario	99	41
Other conflicts			
	Other types of conflict (e.g. case-car is hit laterally by a vehicle using the adjacent lane)	20	8

Which are the safety benefits and which accidents will remain?

The case-by-case analysis of accidents where the car was responsible for the accident revealed that a modern car equipped with ADAS+ could achieve a safety potential of 21 percent on motorways (Table 2). This underlines the important part of driver assistance systems for road safety as we see it on today's cars. 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 especially for Level 2 when the driver monitors the driving task.

Related to all motorway accidents involving a car, an additional safety potential of +5% 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 1). And it has to be put in contrast to possible negative effects caused by a Level 3 system, e.g. take over request in a critical situation.

A nearly maximum safety potential of additional +18% can be achieved by a high automation level (Level 4), which requires no driver monitoring or driver intervention at all during the autonomous ride on the motorway. 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 involving a car would still remain unavoidable.

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 is 0.6 percent and even with a Level 4 maximum 2.1 percent more car accidents could be avoided.

Safety benefits for analysed levels of automated driving functions in relation to the different accident pools in the UDB

Table 2

Systems			Safety benefits [%] 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)
today	ADAS+		21%	45%	2.0%	4.0%
tomorrow	Level 3	additional	+5%	+11%	+0.6%	+1.0%
tomorrow	Level 4	additional	+18%	+38%	+2.1%	+3.4%

Achievable safety benefits for selected automation levels in the UDB broken down by the main accident scenarios

Table 3

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

For those accidents that were caused by a car on motorways, Table 3 gives a differentiated view of the achievable safety benefits for the two main accident scenarios. ADAS+ could avoid 80 percent of all rear-end accidents in the case material but only 10 percent of the lane-change accidents. This is not surprising because it reflects what ADAS+ in today's modern cars can already achieve today. Today's ADAS+ already overcome most rear-end conflict situations if ACC is always switched on. But most lane-change situations are still critical for them [11].

In comparison to ADAS+, the additional benefit of a Level 3 system can be derived from better performance in terms 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 ADAS+ (Table 3). For a Level 4 system there is almost no difference between the shares of the two scenarios. Due to the exclusion of the driver from monitoring and 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.

Passive Safety Consequences

Do we still need airbags and seat belts?

This chapter describes for motorway accidents the injury mechanisms of the belted front seat occupants in the case-car. More information on this part of the analysis can be found in [3]. In order to answer the initial question - which injuries can be expected for the driver in accidents during a Level 3 automated driving mode? - following approach was used: For each case-car the injuries of the front passenger were analyzed under the theoretical consideration that the passenger would be the driver riding in a Level 3 mode. Any differences between the originally sustained injuries by the driver and by the passenger would give an additional hint in terms of required adaptation of the current restraint systems towards restraint systems in a Level 3 automated mode. This is based on the assumption that a driver will act and sit like a passenger in a passenger-like environment during a Level 3 automated ride.

From all motorway accidents involving a car, two different pools with were analyzed [3]:

- accidents where the case-car was responsible but these were classified as unavoidable by an activated Level 3 driving function (RL3)
- accidents where the case-car with an activated Level 3 driving function was not responsible (NRL3)

All other accidents where the involved automated cars were driven manually are not affected by Level 3 - technology in terms of restraint systems and stay untouched. That's why there are not considered here.

Unavoidable accidents caused by the Level 3 car (RL3)

Under the assumption that during the automated ride the steering wheel and the pedals will change their position towards a more space saving, comfortable driver`s seating position, a look at the injury patterns of the passenger will help anticipating possible driver`s injuries, as described before. This part of the analysis was done for the pool of accidents that were initially caused by a car and that were evaluated as not avoidable by a Level 3 automated function (RL3).

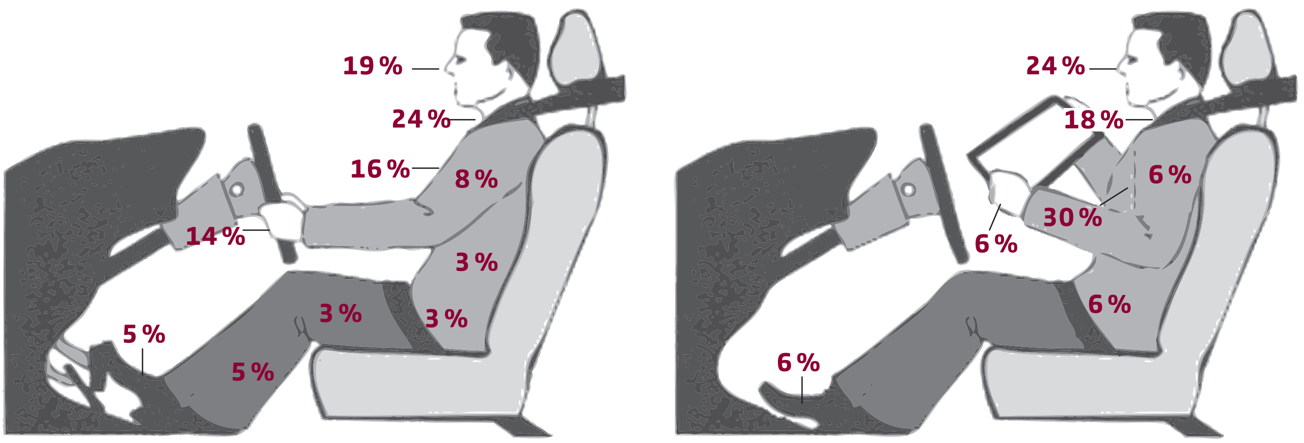
Figure 3 shows the distribution of the single AIS 1+ injuries (slight, severe and fatal injuries together) for the different body regions for driver and passenger in comparison.

An almost equal distribution of the single AIS 1+ injuries can be seen for nearly all body regions. When looking at those body regions in particular that are currently being addressed by restraint systems (head and thorax), the passenger was injured at least as often as the driver was. This means that the driver in automated mode will still have to be protected in these regions. Even foot injuries will remain during the Level 3 automated ride despite the assumption that these could be omitted due to the retraction of the pedals. But leg injuries will happen less.

With regard to future requirements for the restraint systems, following can be stated: In case of a RL3 accident the same body regions of the driver would be injured – except the legs - as if the same accident was caused during a manual drive. This means that the current protection level for passive safety systems must be kept in order to continue protecting the upper body regions.

Single AIS1+ injuries by body regions for driver and passenger in RL3 accidents (frontal, side and rear-end collisions)

Figure 3



Single AIS 1+ injuries – manual ride; n=37 (100%)

Single AIS 1+ injuries – automated ride; n=17 (100%)

Accidents involving a Level 3 car without its own fault (NRL3)

With the assumption that during the activated L 3 automated driving function an adjustment of the driver`s resting position will still take place, the injury analysis was done for this larger pool of accidents, as well. This accident pool accounts for 75 percent of all cars involved in motorway accidents.

The analyses showed that NRL3 accidents are in general not severe for the belted front seat occupants. There are no differences between driver and passenger. About 80 percent of all front seat occupants in case-cars sustained only minor injuries (AIS 1) or no injuries at all (AIS 0). Life threatening injuries (AIS 4+) were counted only two times (one each for driver and for front seat passenger).

The in-depth accident analysis led to following findings with regard to the expected injury patterns for the driver during an automated ride:

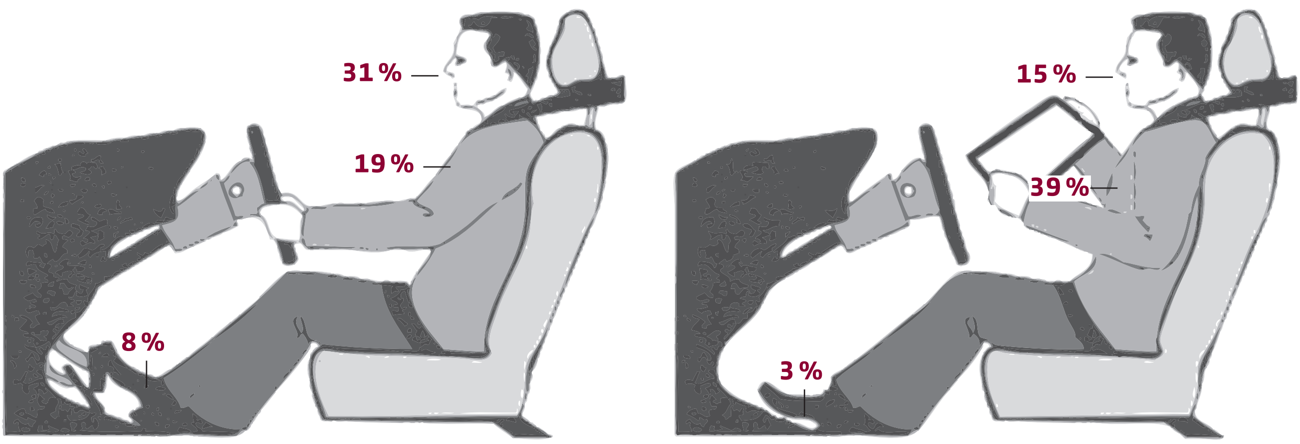
- no significant change in the overall frequency of AIS single injuries, however (Figure 4)
- a strong decrease in the share of severe head injuries (31% driver vs. 15% passenger).
- a strong increase in the share of severe thorax and abdomen injuries (19% driver vs. 39% passenger)
- a strong decrease in the share of severe foot injuries (8% driver vs. 3% passenger).

Another finding from the analyses was that in 59 percent of the cases, the first and most severe impact at the case-car occurred at the rear. It is striking though that only 25 percent of the belted front seat occupants were involved in a frontal impact but these frontal impacts account for 44 percent of all MAIS 2+ injured belted front seat occupants.

A closer look at the AIS 2+ single injuries of the belted front seat occupants reveals for frontal collisions a similar picture for the passenger as seen before: Thorax injuries increase leg and foot injuries decrease.

Share of the single AIS 2+ injuries by body region for belted front seat occupants in NRL3 accidents

Figure 4



Single AIS 2+ injuries – manual ride; n=48 (100%)

Single AIS 2+ injuries – automated ride; n=33 (100%)

Conclusions

The accident occurrence will not change compared to today's situation when cars with an automated driving function drive in manual mode. If, in comparison, cars are driven in an automated mode, active safety benefits and passive safety consequences can be expected.

The most substantial benefit in terms of 21 percent avoidable accidents can be expected from today's modern assistance and comfort systems (ADAS+) 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 ADAS+, an additional benefit of +5% could be expected for a Level 3 system in terms of avoidable accidents on motorways. Compared to the benefits of ADAS+, 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 safety 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 involved in accidents without their own fault. Lane-change accidents will make up the majority of those accidents that can`t be avoided. The most critical part for a Level 3 automated car in the future will still be the driver.

Only a Level 4 system will provide a high benefit in terms of additional 18 percent 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 of motorway accidents will still remain unavoidable. In this context, possible negative effects of mixed traffic are not considered here.

From the German Insurers point of view, highly automated vehicles (Level 4) could bring great benefits in terms of road safety if they functioned flawlessly under all conditions within their intended design domain. Until such time as these systems come onto the market, vehicles should be driven manually and benefit in terms of road safety from continual improvements in advanced driver assistance systems [12].

With regard to the requirements for the protection level of restraint systems in cars during the Level 3 automated ride, the analyses show that: Accidents caused during a Level 3 ride would lead to the same injury pattern for driver and passenger as if the accident was caused during a manual ride. In accidents that were not caused by a Level 3 car, the injury patterns of the driver will change slightly in terms of more thorax and abdomen injuries and less head and foot injuries.

In summary the current protection level of passive safety systems will have to stay at least the same for all accidents where the case-car was driven manually. The protection level will also stay at least the same for all accidents that were caused by the Level 3 car driven in automated mode. But it will have to change for accidents in which the case-car in Level 3 mode was only involved. During the activated automated ride it will have to be adjusted with more focus on protecting thorax and abdomen injuries of the driver.

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DIE DEUTSCHEN VERSICHERER

Wilhelmstraße 43 / 43G
10117 Berlin
Tel.: 030 / 20 20 – 58 21
Fax: 030 / 20 20 – 66 33

unfallforschung@gdv.de
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