ADAPTIVE DISTANCE CONTROL – ROAD SAFETY POTENTIALS OF AN EXCITING NEW FEATURE IN EXISTING E/E ARCHITECTURE

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ABSTRACT

The list of driver assistance features is getting longer and longer. All this assistance raises the question: Will driving still be fun in future? Adaptive cruise control (ACC) as SAE Level 1 system adds safety and comfort to the driver. Per definition, ACC takes over driving tasks and offers limited self-determination in terms of driving experience and enjoyment. On the other hand, Automatic Emergency Braking (AEB) systems are designed to prevent a potential collision at latest. Yet, an AEB system has operational constraints depending on its system capabilities and the type and complexity of the sensors used.

To expand SAE Level 0 safety systems like AEB, Bosch develops the feature Adaptive Distance Control (ADC). It transfers an early and comfortable distance control to self-driving situations. And it adapts to personal driving style to enable a natural driving experience with a comfortable and noticeable safety benefit. Thus, ADC links between ACC and AEB to relax traffic flow and to prevent incidents at an early stage.

The present study evaluates the effectivity of ADC in terms of the above-mentioned safety benefits. It is comprised of a thorough analysis of road traffic observation data (drone data) and the analysis of rear-end collisions involving M1-vehicles on German roads.

In the first part of the study, real-world traffic observation data (highD dataset) from six motorways in North Rhine-Westphalia in Germany was used to determine the time headway (THW) among cars. THW equals the ACC time gap between two vehicles. In the second part, data from the German in-depth accident study (GIDAS) was used to identify the number of relevant crashes which can potentially being positively influenced, i.e., the field of effect (FoE) for ADC.

The analysis of 89,139 passenger car observations reveals that ADC could support 1 out of 12 drivers to keep a THW ≥ 0.6s if lane changes are neglected. Furthermore, the FoE for ADC was estimated up to 5.3% of all crashes with casualties in Germany, depending on its system capabilities. This corresponds to about 16,100 addressable collisions annually if each car would be equipped with the ADC feature.

The present study reveals that ADC can prevent crashes. Moreover, the system maintains the balance between safety and comfortable driving experience and could support a relaxation of the traffic flow. All this in a standard E/E architecture without adaptations.

INTRODUCTION AND MOTIVATION

Feel safe, be comfortable, stay in control – these are the working principles of Adaptive Distance Control (ADC). It conveys a comfortable distance control and adapts it to personal driving styles enabling a natural driving experience with a comfortable and noticeable safety benefit. ADC is always on and works in the background. In other words, ADC links between an Adaptive Cruise Control (ACC) and an Automatic Emergency Braking (AEB) system.

The well-known and established Adaptive Cruise Control (ACC) system automatically adapts the vehicle speed to the current traffic environment by controlling the longitudinal distance to a preceding vehicle travelling in the same lane and direction. Without a preceding vehicle, the ACC system will keep its set cruise control speed. Its functionality allows the ACC to automatically slow down and speed up in accordance with the current traffic without intervention from the driver (SAE Level 1). ACC is deactivated once the driver brakes. From a hardware perspective, the ACC needs a reliable system to detect the lead vehicle's distance and speed, typically achieved by a radar sensor. Given all features and limitations, ACC adds some safety elements but is mainly a comfort system supporting the driver in their longitudinal control.

On the other hand, Automatic Emergency Braking (AEB) systems are designed to avoid or mitigate potential collisions. Consequently, the AEB system is a safety feature (SAE Level 0) and not a comfort system. Typically, the AEB system is adapted to different opponents, ranging from cars and trucks to cyclists and pedestrians. It observes the distance to potential collision opponents and continuously calculates the degree of vehicle deceleration required to avoid a collision. If the system detects that the driver has failed to apply a sufficient brake force, it may automatically initiate full braking. As a result, the collision is avoided or, in adverse conditions, mitigated due to a reduced collision speed. As the AEB system is constantly monitoring its environment, it is always active within its functional scope. In-fleet AEB system studies of indicate an avoidance rate (effectiveness) for rear-end injury crashes of 56 - 64% [1][2].

ADC offers functions linking ACC and AEB: at a first glance it is an ACC system where the driver is controlling the vehicle speed. The ADC system is keeping the longitudinal distance to a preceding vehicle, and it is always active, even after a braking intervention by the driver. It performs moderate braking maneuvers, de-escalating critical situations before they may become dangerous. To maintain the driver experience of actively controlling the vehicle, the driver may temporarily decrease the ADC inherent distance to the preceding vehicle, limited to a certain minimum (see Figure 1). Thus, the driver is in control and, at the same time, can rely on the system at times of comfortable cruises. Due to its capabilities of moderate braking maneuvers, the ADC system ensures a time gap to the preceding vehicle and may hand over to the driver or the AEB system in case of an imminent collision. Consequently, the ADC system adds some safety aspects, too.

This study aims to give an introduction of the ADC system and its working principles as well as an estimate of the potential comfort and safety benefit. In the following chapter, ADC will be introduced as well as its technological requirements and functional limitations. Thereafter, we share more insights about the comfort and safety benefit assessment, in particular for Germany. For the comfort aspects of ADC, we evaluate traffic observation data whereas for the safety benefit estimation we analyze German crash data. We close with a detailed discussion of the results and pointing out its limitations.

ADAPTIVE DISTANCE CONTROL

Description

The Adaptive Distance Control (ADC) system controls the longitudinal distance to the preceding vehicle while driving manually. The ADC system is designed to support the driver when driving on frequented roads, in normal traffic or within traffic jams.

As the ADC system keeps the distance to the preceding vehicle it acts as safety angel in the background and supports AEB interventions in advance or even avoids them. The system increases safety due to early distance control and supports the driver if necessary to avoid critical distances to a preceding vehicle. The driver is in full responsibility of the vehicle and can override the system.

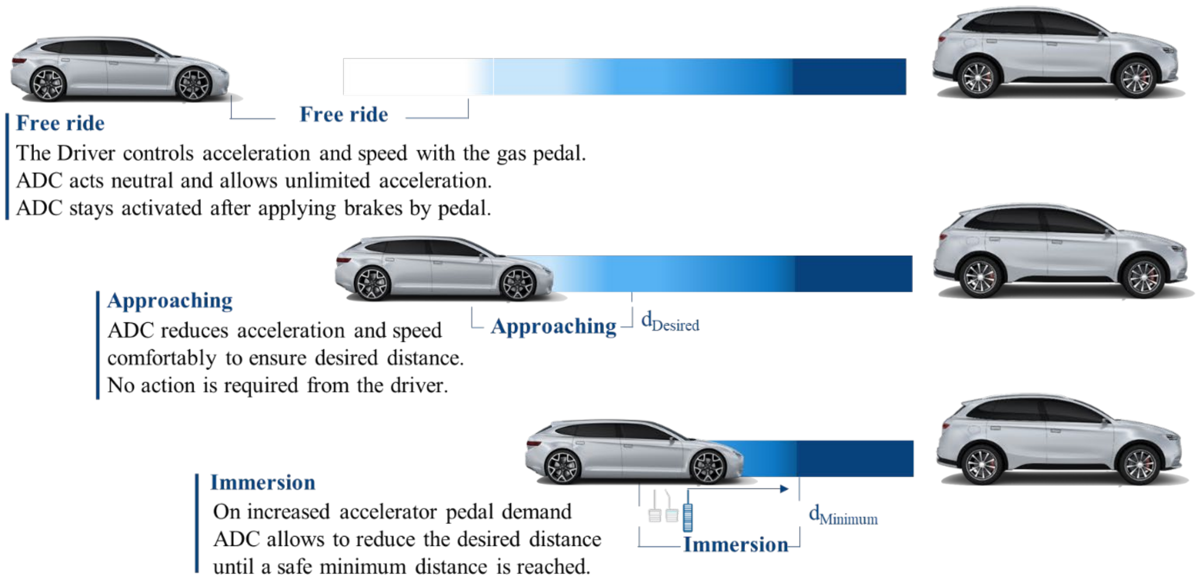
The system is active on any road including urban area, rural area and motorway. The driver has the following adjustment possibilities:

- The initial distance with a safety margin to the preceding vehicle in form of a so-called time gap or time headway (THW). It can be set in the Human-Machine Interface (HMI).
- The desired distance can be adjusted by a changed accelerator pedal positioning. The adjustment is limited to a minimum safety distance.
- ADC can be deactivated manually by the driver via the HMI.

The initially set distance with a safety margin is a time featuring values between 1.0s and 2.5s. It is offered to the driver in e.g., three selectable steps. The ADC system is automatically active when the ignition is switched on. If the driver brakes, the system stays active. If the driver strongly pushes the accelerator pedal (e.g., kick-down), the ADC system is temporarily deactivated.

ADC can decelerate the vehicle down to standstill when the vehicle in front stops. ADC can automatically drive off, if the vehicle has stopped for less than 3s and if the driver still pushes the accelerator pedal. For safety reasons, the driver has to drive-off after longer stopping time periods by additionally increasing the accelerator pedal positioning.

Figure 1 visualizes the functional principle of ADC. If during free ride mode a slower preceding vehicle is detected, the ego vehicle adapts its speed to maintain the set THW (approaching mode). In case the preceding vehicle changes or leaves the lane, the ego vehicle accelerates to the speed requested by the accelerator positioning. If there is still a vehicle in front and the driver requests a higher acceleration by pushing the accelerator pedal, the system will reduce the longitudinal distance to the preceding vehicle until a safe minimum distance is reached (immersion mode). If a small distance is driven for a longer time, the driver is warned visually.



Free ride

The Driver controls acceleration and speed with the gas pedal.
ADC acts neutral and allows unlimited acceleration.
ADC stays activated after applying brakes by pedal.

Approaching

ADC reduces acceleration and speed comfortably to ensure desired distance.
No action is required from the driver.

Immersion

On increased accelerator pedal demand ADC allows to reduce the desired distance until a safe minimum distance is reached.

Figure 1: Functional principle of Adaptive Distance Control (ADC)

The availability of the ADC system depends on several conditions, which may deactivate or suppress an active system.

- Deactivation: The ADC system permanently monitors the operation parameter and will deactivate in certain situations. Depending on the situation the system will choose one of the following deactivation types:
  - Immediate deactivation: ADC will cancel immediately any engine or brake control without consideration of any comfort criteria. This applies in particular for fault entries in corresponding vehicle or transmission control units, if AEB or Evasive Steering Assist (ESA) are activated or either

    Electronic Stability Control (ESC) or Antilock Braking System (ABS) are active for a longer time period.
  - Soft deactivation: ADC will gradually release engine torque limit or release brake pressure to provide as much comfort as possible before cancelling. This applies for an ADC deactivation in the HMI or if object detection sensors are temporarily not available.

- Suppression: The ADC system permanently monitors the operation parameter and will be suppressed in several situations. For instance, if vehicle systems like, e.g., ABS, ESC, Parking Assist or Hill Descent Control are active. ADC is also suppressed if the engine is not ready or not running, if no forward gear is applied, if the vehicle is rolling backwards or driving faster than 250 km/h or if the slope is too steep.

E/E Architecture

The ADC system is a flexible and customizable software module which is responsible for managing the current values of time gap (THW). It allows changes to the value of THW through driver commands. These commands can be given using a suitable HMI, e.g., buttons and switches on the steering wheel or with a separate lever. The driver command is sent via the vehicle bus, which are then taken as an input for the ADC system. The buttons and switches are called driver input elements. Depending on the specific configuration, pressing these input elements causes changes in the time gap setting. These changes are managed and executed by corresponding ADC controllers.

Additional hardware elements of the E/E architecture required for the ADC system are a Vehicle Control Unit (VCU), Transmission Control Unit (TCU), Electronic Stability Control (ESC), and sensors like radar and video. All hardware elements and their respective tasks are displayed in Figure 2 and Table 1.

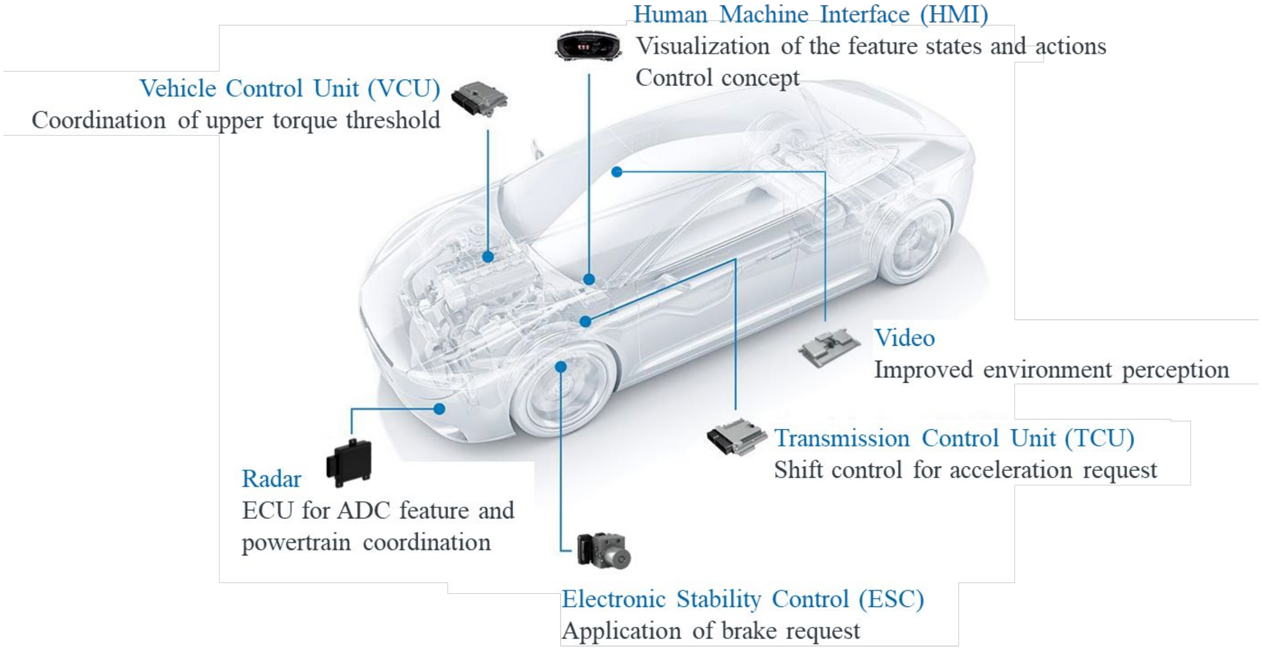


Figure 2: Overview of the E/E architecture for ADC

Table 1: Required technology elements

System/ Component	Function
Driver assistance system, e.g., front radar	Object detection and environment for ADC system
Brake system, e.g., ESC	Support of standstill management based on braking system e.g., Automatic parking brake for stop & go
Powertrain, e.g., VCU	Combustion engine or electric motor
Transmission, e.g., TCU	Automatic (for stop & go)
Human-Machine Interface (HMI)	Operation: Using existing driver assistance control elements or separate button (cp. operation concept) Visualization: No separate hardware needed

Functional limitations

The ADC system is parameterized according to ISO 15622 for ACC [3]. This addresses in particular to the maximum decelerations, the maximum change of deceleration, and the minimal time gap. All ADC characteristics are shown in the following Table 2.

Table 2: ADC functional parametrizations according to ISO 15622

Maximum ADC deceleration		
Vehicle speed	**ISO 15622**	**Implemented**
< 5.5 m/s	5.0 m/s²	4.5 m/s²
> 19.44 m/s	3.5 m/s²	3.5 m/s²
Maximum ADC change of deceleration		
Vehicle speed	**ISO 15622**	**Implemented**
< 5 m/s	5.0 m/s³	4.0 m/s³
> 20 m/s	2.5 m/s³	2.5 m/s³
Minimal ADC time gap without driver requested distance reduction		
Vehicle speed	**ISO 15622**	**Implemented**
all	1.0 s	1.0 s

Limitations by sensor technology performance results directly in a limitation of the ADC system. A non-availability of the ADC system is displayed to the driver.

SAFETY AND COMFORT EVALUATION APPROACH

Data sources

The data sources for our safety and comfort evaluations are two-fold: in the first part of the study, we use traffic observations from German motorways while for the second part of the study we use German crash data.

The traffic observations are based on the highD dataset which recorded naturalistic vehicle trajectories on six motorways in North Rhine-Westphalia in Germany in 2019 with an aerial drone. The dataset stores for each vehicle the trajectory, vehicle type, size, and maneuver. In addition, it was enriched with a lane-based time gap or time headway (THW) between two consecutive vehicles and a lane-based and simplified time-to-collision (TTC). In total, the dataset covers more than 110,500 vehicles (80.6% cars and 19.4% trucks). Further information can be found in Krajewski et al [4].

The crash data for this study is based on the data from German in-depth accident study (GIDAS) project. GIDAS records real traffic crashes with personal injuries and death and provides a reconstructed pre-crash sequence. Each recording contains detailed on-spot information of each participant including vehicle data, injury information, a scaled sketch of the accident site, and all environmental and road conditions [5]. For the present study, we use a subsample of the GIDAS database with more than 40,000 crashes. These data are weighted by type of crash, location, and injury severity to German national statistics of the year 2019 using additional data from the German Federal Statistical Office (DESTATIS) [6][7].

Methods

ADC comfort evaluation

For the ADC comfort evaluation, we analyze the number of vehicles that are affected in their regular driving by the ADC system. ADC controls the distance to the preceding vehicle based on time-headway (THW). The enriched highD traffic data directly provides for each vehicle and time step a THW in case there was a preceding vehicle in the same lane. Based on the functional limitations described earlier, we analyzed the highD dataset with the following requirements:

- Vehicle under investigation: passenger car (vehicle class “car”)
- Preceding vehicle: all other motorized vehicles
- Maneuver: No lane change

For the analyses below, we investigated the share of affected vehicles as a function of the minimal THW. As a standard application, we assumed a minimal THW = 0.6 s.

ADC safety evaluation: field of effect in crashes

To cover the safety aspect of ADC, GIDAS data was assessed to estimate the ADC field of effect (FoE). The FoE regarding crashes describes the number of crashes which potentially can be positively influenced (mitigation or avoidance of the original crash) by the ADC system. In general, the ADC system addresses the same crash scenarios as an AEB system: a vehicle hits with its front another vehicle in the back (front-to-rear-end crash). Based on the functional limitations of the ADC and AEB systems, we analyzed the GIDAS data with the following criteria:

- Vehicle under investigation:
    - passenger car (M1 vehicle)
    - crash triggering vehicle (main causer)
    - no skidding before primary impact
    - first contact at vehicle front
- Preceding vehicle:
    - all motorized vehicles
    - first contact at vehicle rear-end
- Front-to-rear end crash relevant type of accident

All crashes fulfilling these criteria are analyzed by location (urban, rural, motorway) separately.

An AEB system has operational constraints, mostly to ensure an intervention only in an imminent crash situation. As a result, some crashes may still occur with an AEB system, partially with reduced collision speed. All crashes that have not been avoided by an AEB system could be positively influenced by the ADC system, i.e., are within the ADC field of effect. Consequently, within the AEB field of effect, we looked for crashes with adverse conditions for AEB that could be further addressed by the ADC system. We used the following criteria:

- The lateral overlap (offset) between both vehicles is less than 50%
- Road surfaces with a low friction coefficient, i.e., wet, snowy or icy roads
- Speed difference between both vehicles above 60 km/h

A symbolic representation to identify the ADC field of effect within the AEB field of effect is shown in Figure 3. Basically, we assume for ideal conditions for AEB that an imminent rear-end crash will be avoided by the AEB system. All other remaining cases due to adverse conditions for AEB – estimated by the three main criteria above – are in the field of effect of the ADC system.

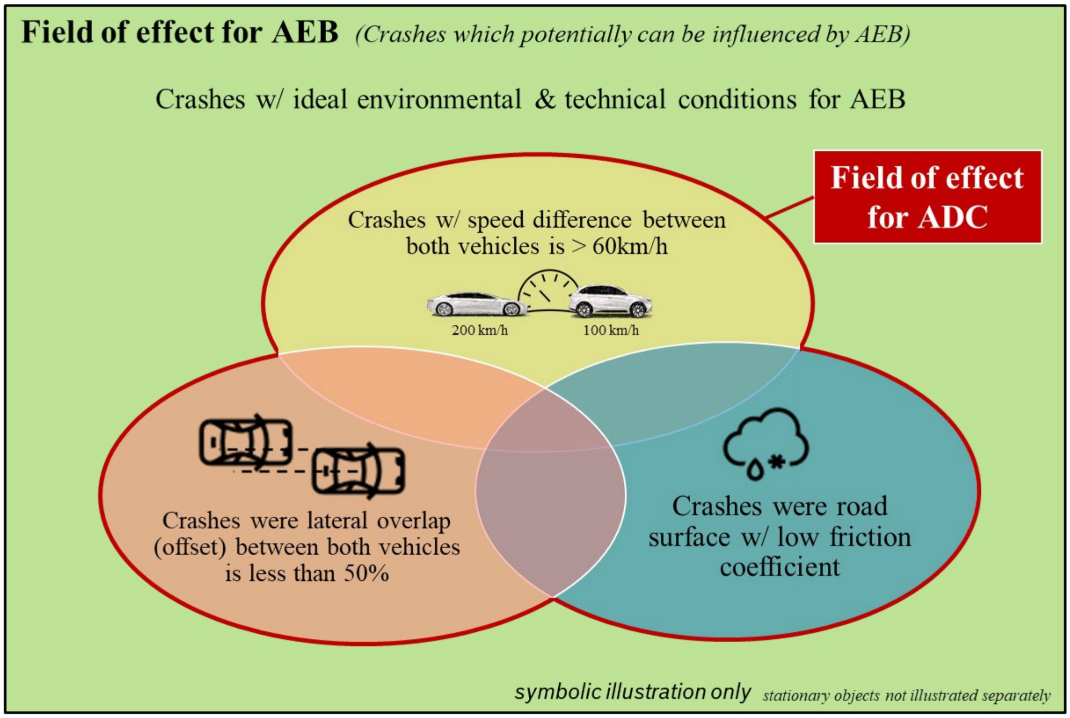


Figure 3: Symbolic illustration – ADC can increase effectiveness of AEB in which real-world constraints given

RESULTS

ADC comfort evaluation: Time headway analysis

Applying the selection criteria on the highD dataset described above, we find the number of vehicles that would be affected by the ADC system. As the ADC system actively prevents the driver to have a THW below the ADC minimum time gap settings t_{min}, every vehicle with a THW below t_{min} would be affected and kept at a distance representing t_{min} or above. For the first step, we assume an ADC system setting with an initial safety distance and minimum distance of $t_i = 1.0s$ and $t_{min} = 0.6s$, respectively, while for the second step, we keep t_{min} as a parameter.

Figure 4 shows the distribution of the minimal THW per passenger car for the highD dataset. The distribution has a maximum at $THW \approx 0.9s$ and is heavily skewed to the left. As a reference, we display $THW = 1.8$s as a vertical line in Figure 4 which is derived from the recommended driving distance on German roads (distance in m equals half travel speed in km/h). As a first result, we count the overall number of vehicles with a THW below the thresholds of 0.6 s and 1.0 s ending up in about 1 out of 12 cars and 1 out of 4 cars, respectively.

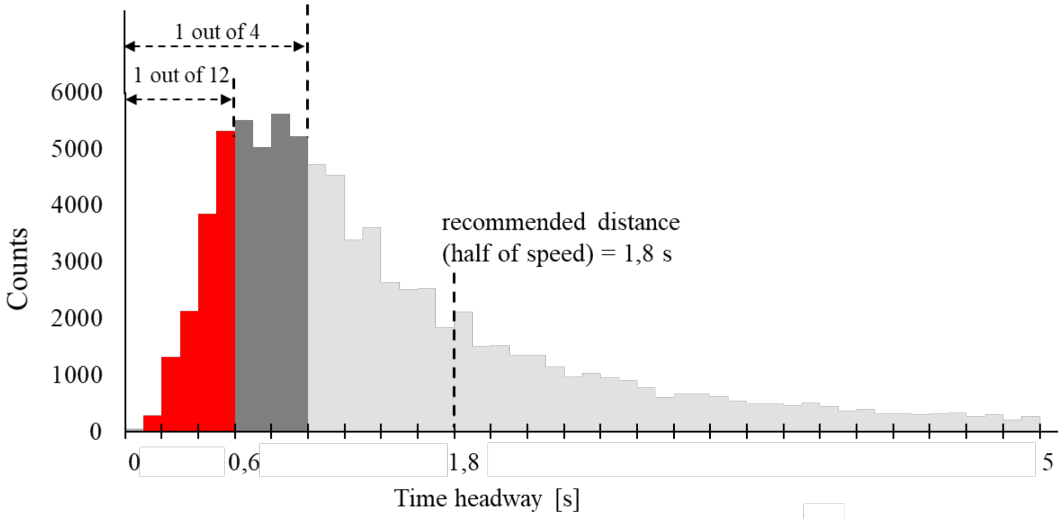


Figure 4: Time headway (THW) distribution of passenger cars on German motorways

In more detail, for an ADC system setting of $t_{min} = 0.6s$, the highD dataset reveals that 7,892 out of 89,139 passenger cars (8.9%) have a $THW \leq t_{min}$ for longer than one second. Table 3 summarizes the relevance for ADC in detail for the highD dataset and $t_{min} = 0.6s$.

Table 3: Relevance of ADC in the highD dataset

Criteria	Number of vehicles	Share
Vehicles in the enriched highD dataset	110,516	
... number of passenger cars	89,139	100%
… w/o lane change	78,722	88.3%
… THW ≤ 0.6s	9,308	10.4%
... THW ≤ 0.6s for more than 1s	7,892	8.9%

In a second step, we analyze the relative share of passenger cars that would be affected by a given ADC t_{min}. Sweeping t_{min} in the range $[0.1s, 1.2s]$ shows a strong sensitivity starting at $t_{min} \cong 0.5s$, i.e., a small increase in t_{min} results in a large number of additionally affected drivers. The full sensitivity curve is shown in Figure 5. We would like to point that driving at distances corresponding to $THW < 0.9s$ is penalized on German motorways. Thus, setting ADC $t_{min} \geq 0.9s$ could not only prevent the driver from potentially dangerous situations leading to front-to-rear-end crashes but also from being penalized due to insufficient safety distance.

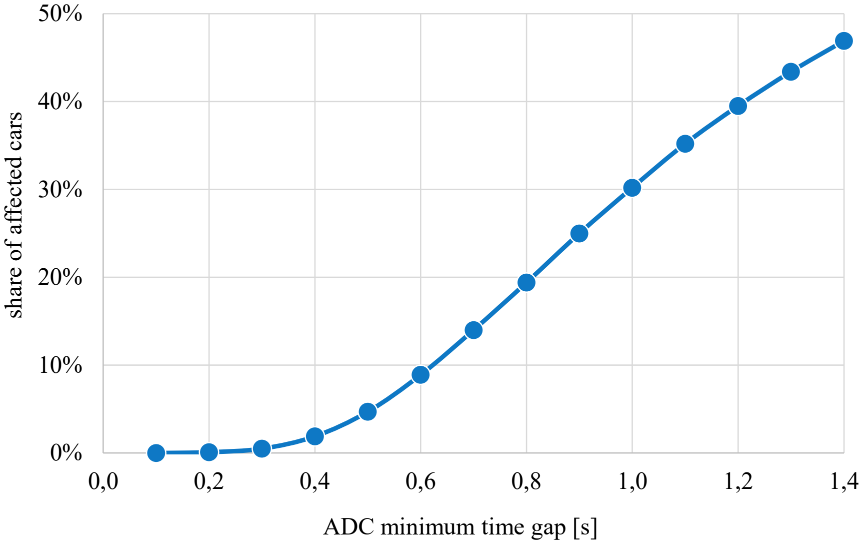


Figure 5: Sensitivity curve for ADC system parameter minimum time gap t_{min} according to highD data

Crash analysis

According to the national statistics (DESTATIS), there were a total of 300,143 crashes with personal injuries or death in Germany in 2019. Most of those crashes occurred on urban (207,625) and rural roads (72,538) whereas the remaining 19,980 crashes occurred on German motorways. Applying the criteria for the AEB field of effect in crashes, as motivated in the method section, to the GIDAS database and extrapolating towards German national statistics unveils a sum of about 40,200 annual crashes with personal injuries or death. Table 4 provides a more comprehensive overview. In the following paragraphs, we will estimate more specific numbers for ADC.

Table 4: AEB field of effect estimated for Germany

Criteria	Estimated number of crashes in Germany (2019)			Source
	Motorway	Rural	Urban	
Crashes with personal injuries or death	19,980	72,538	207,625	DESTATIS
... involving passenger car (M1) as crash triggering vehicle	15,200 (n=1,034)	53,000 (n=3,274)	131,000 (n=14,643)	GIDAS (weighted to Germany)
… w/o skidding before first collision	11,000 (n=695)	38,000 (n=2,001)	124,000 (n=13,832)	
… front-to-rear-end crash	6,100 (n=385)	10,100 (n=460)	24,000 (n=2,154)	
Share of initial still standing preceding vehicles within AEB FoE[1]	8%	27%	44%	

As discussed in the method section, ADC can contribute to increase the effectiveness of the AEB system especially in non-ideal or adverse conditions for the AEB system. Therefore, we additionally evaluate the number of crashes with a potentially reduced AEB system performance due to non-ideal or adverse conditions. Table 5 shows for each combination of the three main AEB limitations (overlap, low friction, and speed difference) per location the share of affected crashes.

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[1] Share of initial still standing target objects (related to a probable classification by AEB/ADC-system) only reliable for motorway and rural streets currently – for accidents at these locations single case analyses were conducted. Share for urban roads was not evaluated in terms of a possible classification by the AEB/ADC-system, therefore system relevant share on urban roads is expected to be smaller.

Table 5: Conditions of ADC for injury crashes

GIDAS (2001-2020)						
	Lateral overlap between both vehicles is less than 50%	Road surfaces with a low friction coefficient, e.g., wet, snowy or icy roads	Speed difference between both vehicles above 60 km/h	Share within AEB field of effect		
				Motorway 6,100 (n*=365)	Rural area 10,100 (n*=430)	Urban area 24,000 (n*=2,085)
Ideal environmental & technical conditions for AEB	No	No	No	30%	32%	56%
Non-ideal or adverse conditions for AEB	No	No	Yes	27%	23%	3%
	No	Yes	No	5%	15%	21%
	No	Yes	Yes	7%	8%	1%
	Yes	No	No	15%	11%	13%
	Yes	No	Yes	13%	5%	1%
	Yes	Yes	No	2%	3%	5%
	Yes	Yes	Yes	1%	3%	<0.5%
	Subtotal			70%	68%	44%
	Subtotal projection to Germany			4,300	6,800	10,600
Total				100%	100%	100%

* number of crashes in GIDAS, cases with unknown overlap or road surface are excluded here

Based on Table 5 we derive[2]:

1) On German motorways, 70% of relevant crashes occur at non-ideal or adverse conditions for AEB. Main constraints are the difference in collision speed (relevant for 48%) and a too small lateral overlap between the colliding vehicles (relevant for 31%).
2) On rural roads, the proportion of relevant crashes is similar at 68%. The low friction coefficient (29%) has a considerably larger share than on motorways. Speed differences > 60 km/h (39%) and overlaps <50% (23%) are less relevant than on motorways.
3) On urban roads, the share of AEB relevant crashes in non-ideal or adverse conditions for AEB is at 44%. Speed differences > 60 km/h are considerably low at 6%. Proportions of low friction coefficient and of too small lateral overlap are comparable to rural roads.

Following the main results of Table 5, we find for non-ideal or adverse conditions for AEB in a total of 21,700 annual crashes with personal injury or death in Germany. A distribution by location (motorways, rural roads, and urban roads), is shown as a subtotal for non-ideal or adverse conditions for AEB in Table 5.

Based on US in-fleet insurance studies [1][2], we assume an average AEB avoidance rate of 60% within the AEB field of effect. Consequently, we expect about 24,100 avoided and 16,100 remaining crashes with personal injury or death annually in Germany (60% and 40% of 40,200 crashes, respectively). Estimating the ADC field of effect, we assume (i) all crashes under ideal AEB conditions are avoided by the AEB system, and (ii) the ratio of crashes not avoided by AEB to AEB-relevant cases under non-ideal conditions is independent of the location. With these assumptions, we apply the location distribution of AEB-relevant cases with non-ideal or adverse conditions to the total of 16,100 remaining cases not avoided by AEB (see Table 6) revealing the ADC field of effect by location for the remaining injury crashes.

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[2] As shown in Table 5, there are overlaps in the boundary conditions, so the proportions listed cannot be summed up together

Table 6: ADC field of effect for injury crashes estimated for Germany 2019

	Motorway	Rural roads	Urban roads	All locations
Non-ideal / adverse conditions for AEB	4,300 (20%)	6,800 (31%)	10,600 (49%)	21,700 (100%)
				Applying the above percentages to the total ADC FoE of 16,100 crashes
ADC field of effect for injury crashes	**3,200**	**5,100**	**7,800**	**16,100** (40% of AEB FoE)

In summary and based on accident numbers of 2019, with full market penetration for passenger cars, ADC could address up to 16,100 injury crashes in Germany annually, thereof up to 3,200 crashes on motorways, up to 5,100 crashes on rural roads and up to 7,800 crashes on urban roads. The possible crash avoidance rates by the ADC system within its field of effect depend on the ADC system design and the location.

DISCUSSION AND LIMITATIONS

After a thorough introduction of the new Adaptive Distance Control (ADC) system and its positive influence on traffic and crashes, we will discuss in the following section the results and potential limitations.

We assume ADC will be a very recognizable system. Unlike many safety systems as, e.g., AEB or ESC, which become active only in emergency situations, ADC will actively interact with the driver's car following control task in regular traffic. According to the drone-based traffic observation highD data, ADC would affect more than a quarter of all car drivers on German motorways for the lowest ADC standard time gap (safety distance) of 1.0s. Every day driving experience already shows a variation of individual time gaps to preceding vehicles in car following situations due to distraction, misjudgment of what a sufficient safety distance is at given speed, or misinterpretation of the situation. Consequently, over a vehicle's time of use, it can be expected that a very large proportion of all drivers will be supported by the system. While we may speculate of the large quantity of drivers keeping a sufficient time gap, we can conclude that the ADC system due to keeping an active state irrespective of regular driver inputs, it will be one of the assistance systems reminding the driver of its presence.

ADC is a comfortable system potentially affecting many drivers and in consequence impacting future traffic. For the active driver additionally pushing the accelerator in a car following situation, ADC may reduce the time gap to a minimal fixed value. Exemplarily setting the ADC minimal time gap to 0.6s would affect one out of twelve drivers on German motorways according to highD data. Yet, distances below the ADC minimal time gap are impossible within the ADC functional boundaries. Only very active drivers would still be able to undercut the ADC minimal time gap in a few cases by temporarily deactivating the ADC system (e.g., kickdown). As the ADC covers a huge range of regular driving situations, the ADC system will have a tremendous effect on the German motorway traffic pushing the time gap between two vehicles to a level above the ADC minimal time gap if every car would be equipped with ADC.

While ADC offers a subjective safety benefit and could transform motorway traffic entirely, the objective safety benefit is complex to assess. In principle, ADC is affecting potentially critical situations which could become relevant for an Automatic Emergency Braking system. Yet, the ADC system is designed to decelerate comfortably and, thus, influence the vehicle speed earlier than an AEB. Consequently, ADC is supporting the AEB system especially in non-ideal or adverse conditions for AEB. In particular, a detailed analysis of the respective shares based on German crash data using the GIDAS database shows that the speed difference is one of the biggest challenges for an AEB system on motorways and rural roads. ADC provides especially in those situations additional support by an early and comfortable deceleration. In all locations, an overlap below about 50% to the preceding vehicle is also a significant limitation of the AEB system. The share of overlap <50% that we see in crash data, among other things, may possibly also an effect of swerving before the collision. The ADC system may intervene in overlap <50% situations more reliably by system design than AEB systems can do.

The safety benefit results of this study are consistent with literature: in about 46% of AEB relevant cases there are ideal environment conditions. This share is smaller than the avoidance rate of about 60% determined by in-fleet studies [1][2]. For the difference (14 percentage points), several explanations are possible: (a) mitigation of injury crashes to property damage only crashes by AEB (b) differences in traffic and accident situations between US and Germany (speed limit, climate conditions, etc.) and (c) potential limitations in the GIDAS database.

We expect an improved avoidance rate of a combined ADC-AEB system if stationary objects are processed reliably. According to Table 4, the shares of still standing preceding vehicles is strongly dependent on the location. In addition, technical challenges in reliably processing those standing vehicles are well known [8] If the object detection subsystem for ADC can reliably process stationary objects due to, e.g., a fusion of radar and camera information, the avoided number of crashes within the ADC field of effect could be increased.

In addition to mitigating or avoid crashes with personal injury or death, ADC could mitigate or avoid property damage only crashes, too. Yet, besides the complexity encountered in the analysis above, the data sources for property damage only crashes are less sufficient regarding its depth of information than existing in-depth accident studies as, e.g., GIDAS. The additional potential for ADC to support in avoiding property damage only crashes is motivated by the fact that there are about eight times more property damage only crashes than injury crashes within police reported crashes in Germany [6][7]. This does not necessarily mean that the ADC field of effect for property damage only crashes is in the same range, yet it shows an idea of the possible extent. For a robust quantification, further analysis based on additional data sources is required.

CONCLUSIONS

The presented study introduces the so-called Adaptive Distance Control (ADC) system as a new driver assistance system enhancing the driving experience while using an existing E/E architecture. As a driver assistance system, it not only supports the driver in challenging situations, but it brings the driving experience to the next level: a regular driver will acknowledge the support in keeping a reasonable distance to the preceding vehicle in traffic, while the active driver may decrease this distance for his active participation in traffic. Yet, the ADC minimal distance is – within the system boundaries – fixed and may not be undercut. Consequently, the driver can rely in all normal driving situations on the ADC system to keep the distance to the preceding vehicle. Subjectively, ADC takes the rather tiresome task of car following, especially in dense traffic, and transforms it into a comfortable experience.

The ADC system is a recognizable system. It is typically active by default and interacts with the driver in car following situations by moderate deceleration interventions to ensure the ADC minimal time gap. Results of an initial user study with 30 participants shows very positive acceptance rates, particularly regarding an increased driving comfort and an increased subjective safety level resulting in a high willingness to use ADC in general.

Although the ADC system is commonly perceived as a driver assistance system to increase the driving experience, it also addresses a considerable share of crashes. We estimate the ADC field of effect, i.e., the number of crashes that may be positively influenced by the ADC system, up to 16,100 annual crashes with personal injury or death in Germany based on accident numbers for 2019 (~5.3%). The potential of ADC on property damage only crashes was not quantified, yet the ADC system may positively influence these crashes, too. In other countries, the ADC field of effect could be in a similar range.

In a future, with most cars being equipped with an ADC system, traffic could be shifted remarkably, especially for motorways. Driving could be more relaxed and safer. In addition, ADC together with other driver assistance systems could even influence the driver's mindset on the path to a vision of traffic without crashes.

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