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TNO report

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Human Factors Guidelines Report 2: Driver Support Systems Overview

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Abbreviations

ABS	Antilock Braking System
ACC	Adaptive Cruise Control
ADA	Active Driving Assistance
ADAS	Advanced Driver Assistance System
AEB	Autonomous Emergency Braking
AES	Autonomous/Assisted Emergency Braking
BSW	Blind Spot Warning
CACC	Cooperative Adaptive Cruise Control
DSM	Driver State Monitoring
ESP	Electronic Stability Program
FCW	Forward Collision Warning
GPS	Global Positioning System
HUD	Head-Up Display
ISA	Intelligent Speed Assistance
LC	Lane Centring
LCA	Lane Change Assist
LDW	Lane Departure Warning
LKA	Lane Keep Assist
ODD	Operational Design Domain
SLIF	Speed Limit Information Function
TJA	Traffic Jam Assist
TSR	Traffic Sign Recognition

Contents

1 Introduction

Driver assistance systems and automated vehicle systems will only be able to realize their full potential in terms of safety effects if they take the end-user into account in their design. In 2019, the Ministry of Infrastructure and Water Management commissioned "Human Factors guidelines for safe in-car traffic information services" [ID5308][1]. These guidelines are intended to provide both policy makers and manufacturers / service providers with guidance in the safety assessment of nomadic devices in vehicles, in particular devices that provide information, such as navigation systems.

In recent years, however, there has also been a strong increase in driver assistance systems, ADAS (Advanced Driver Assistance Systems), which interact with the driver, support tasks, and sometimes even (partly) take over the driving task. The current version of the guidelines contains little or no guidelines specifically related to ADAS. In view of the current developments, it is advisable to expand the guidelines with these types of systems, allowing both system designers and policy makers to take these into account. Here, we follow the definition of ADAS as given by the Dutch Safety Board: *"Advanced Driver Assistance Systems (ADAS) are systems that assist the driver in carrying out the primary driving task. ADAS observe the environment using sensors and are able to take over control of speed or driving direction, subject to the responsibility of the person at the wheel. Systems of this kind are also able to warn the driver in situations that the system considers dangerous."* [ID14] Where possible, Automated Driving Systems (ADS) will also be included in the development of the HF Guidelines.

If there are guidelines that a design must meet, these guidelines can also be used to check if the design complies with them. In other words, where the "HF Guidelines" specify what should be taken into account in the design of in-vehicle systems, they can also be used for the evaluation of these systems when the guidelines are combined with evaluation tools and criteria. After all, a good system must comply with the guidelines. In the end the objective of the development of the "HF Guidelines" is to arrive at a uniform evaluation framework of the interaction processes between vehicle and driver.

RWS has asked Rijksuniversiteit Groningen (RUG) and TNO to provide these Human Factor Guidelines for ADAS and Automated Driving Systems.
To come to these guidelines a number of separate reports have been prepared:

- Report 1: Literature review and overview
- Report 2: Overview and description of the different driver support systems
- Report 3: Literature study on the use of ADAS and the mental models of drivers
- Report 4: Human Factor Guidelines for ADAS and Automated Driving Systems

[1] The ID numbers between square brackets refer to the ID in the repository as explained in Report 1 [ID5357].

- Report 5: Overview of required knowledge to convert HF guidelines into an evaluation tool.

This current report (Report 2) provides an overview of the current and future driver support systems (ADAS) and automated driving systems (ADS). It describes the goal of the system, how it should be handled, how it provides feedback to the driver and how it overrules or interferes with the driving behaviour of the driver. Systems are considered for both passenger cars, busses and heavy vehicles. The main focus will be on the functioning of the systems: which “choices” does it make based on the interaction with the driver (system inputs and driver behaviour), how does the system communicate and what is expected from the driver in terms of knowledge, insights and skills in order to use the systems in a safe way.

1.1 ADAS Selection

For the selection of systems that are included in this report, we first created a longlist of possible intelligent systems in a vehicle and divided these into specific clusters in no particular order (Figure 1). Second, we selected the ADAS that fit in the abovementioned Dutch Safety Board definition [ID14]. In addition, all ADAS that fit the definition but do not require any interaction with the driver or have a relatively low safety impact (for example due to their design being intended specifically for parking and/or low speed situations) were discarded from the selection (Figure 1, yellow and orange cells, respectively). This procedure resulted in the inclusion of the following clusters and systems:

- Longitudinal control, speed limitation systems
- Longitudinal control, cruise control resembling systems
- Longitudinal control, crash avoidance systems
- Lateral control, lane keeping
- Lateral control, crash avoidance
- Driver state systems

Some of the selected systems do not fit these clusters, either because they constitute a combination of longitudinal and lateral control (Active Driving Assistance, Platooning, Traffic Jam Assist). Also, it is important to note that some of these systems will become mandatory in new cars in the EU from 2022 [ID5366][ID5367]. This concerns Driver State Monitoring (drowsiness and attention/distraction detection) and Intelligent Speed Assistance for cars, vans, trucks and buses, Lane Keep Assistance for cars and vans, and Autonomous Emergency Braking and Vulnerable Road User detection and warning for vans and trucks.

Cluster	System(s)				
LO-Ctrl: Speed Limitation	Speed Control Function	Intelligent Speed Assistance, incl. Curve Speed Adaptation	Speed Limit Information Function		
LO-Ctrl: Cruise Control	Cruise Control	Adaptive Cruise Control	Cooperative Adaptive CC	Platooning (Trucks)	Traffic Jam Pilot
LA-Ctrl: Lane Keeping	Lane Departure Warning	Lane Keep Assist	Lane Centering		
LO-Ctrl: Crash Avoidance	Emergency Stop Signal	Forward Collision Warning	Brake Assist	Autonomous Emergency Braking	Autonomous/Assisted Emergency Steering
LA-Ctrl: Crash Avoidance	Blind Spot Warning	Lane Change Assist	Turn Assist		
Driver State	Driver State Monitoring	Emergency Assist			
(Truck) Stability		Trailer Stability Assist (Trucks)	Active Rollover Protection		
Parking	Curb Warning	Park Distance Warning	Remote Garage / Parking Pilot	(Automatic) Parking Assist	Smart Summon
Low Speed	Rear View Camera	Omni view / 360° (AR) View	Exit Warning	Cross Traffic Alert	Automatic Reverse Braking
Visibility Aids	Adaptive Lighting	Traffic Sign Recognition	MirrorCam	Intelligent Headlight	Night Vision Assistant
Impact Limitation	Pedestrian Protection System	Pre-Sense / Pre-Safe			
Information Support	Active Info Display / HUD	(AR) Navigation System	Tire Pressure Monitoring	Temperature Warning	Wrong Way Alert
Control Optimisation	Anti-Lock Braking System	Electronic Stability Program	Traction Control	Hill-Hold Control	Hill-Descent Control
Economy Driving	Gear Shift Indicator	Predictive Efficiency Assist			
Other	Acoustic Vehicle Alert System	Trailer Manoeuvre Assist			

Active Driving Assistance

Colour Code	Meaning
Green	Included according to ADAS definition OVV
Light Green	Indirectly included by means of similar system(s) in same cluster
Orange	ADAS, but with low safety impact
Yellow	ADAS, but with no interaction with the driver
Grey	No ADAS according to definition

Figure 1 Overview of ADAS and the inclusion in the study. Rows in the main table indicate different clusters of ADAS. LO-Ctrl = Longitudinal Control, LA-Ctrl = Lateral Control, AR = Augmented Reality, HUD = Head Up Display.

Below, the resulting list of systems that will be described in this report is given in alphabetical order. For several systems, multiple names exist. We have followed the ADAS Alliance systems name list for those systems that are in this list [ID5365]. For the other systems, we have chosen the most commonly used generic (non-brand specific) name. Most of these systems are already on the market, except for CACC and Platooning.

ACC Adaptive Cruise Control
System that keeps a constant speed or a set following distance to car in front. Also sometimes referred to as Intelligent Cruise Control (ICC), Active Distance Assist or Smart Cruise Control (SCC).

Active Driving Assistance
A combination of ACC and Lane Centring, when available Driver State Monitoring, Emergency Assist, Blind Spot Warning, Lane Change Assist and Intelligent Speed Adaptation are included as well. This system supports the driver in both the longitudinal and lateral control of the vehicle. Each car brand has its own name for this type of system, such as Autopilot, Pro Pilot, Pilot Assist, Highway Assist, Active Drive Assist, Driver Assistant Pro, Super Cruise.

AEB Autonomous Emergency Braking
A system which can automatically detect an impending forward collision and activate the vehicle braking system. Also sometimes referred to as Emergency Brake Assist.

AES Autonomous/Assisted Emergency Steering
A system which executes an evasive steering manoeuvre when a detected impending forward collision cannot be prevented by braking alone. Some systems only support a driver-initiated steering response. Also sometimes referred to as Automatic Emergency Steering Collision Avoidance Assist.

BSW Blind Spot Warning
A system that informs the driver about other vehicles driving in the blind spots of the car. Most BSW systems provides an additional warning if the driver uses the turn signal when there is a car in the adjacent lane. Also sometimes referred to as Blind Spot Monitoring (BSM), Lane Change Warning, or Active Blind Spot Assist.

CACC Cooperative Adaptive Cruise Control
A system which communicates with other nearby CACC vehicles, thus allowing to react to speed changes earlier compared to normal ACC.

DSM Driver State Monitoring
A system that monitors the driver’s availability and/or attention. The goal of the system may either be to warn the driver in the case of drowsiness or low attention, or to monitor the availability of the driver to take over control from another assistance system that is active, such as Adaptive Cruise Control or Active Driving Assistance. In the first case, the system only warns of low attention. This type of system is sometimes also referred to as Fatigue Monitoring, Drowsiness Detection, Drowsiness Alert or Driver Alert System. In the second case, detection of prolonged unavailability may lead to deactivation of the assistance system and/or bringing the vehicle to a halt. This type of system is also called Driver Distraction Recognition.

EA Emergency Assist
A system that automatically stops the vehicle when it detects that the driver is not capable of driving anymore.

FCW Forward Collision Warning
A system that warns the driver when there is a risk of a forward collision with other road users. Also referred to as Frontal Collision Warning.

ISA Intelligent Speed Assistance
A system which supports compliance with the speed limit. The system either warns the driver with visual and/or acoustical signals when exceeding the current speed limit or prevents the vehicle from driving faster than the speed limit. The information on the actual speed limits is based on GPS / Traffic Sign Recognition.
Also sometimes referred to as High Speed Alert or Intelligent Speed Adaptation.

LC Lane Centring
A system that detects the edges of the current lane and keeps the vehicle close to the lane centre by active steering (no steering needed from the driver). Also sometimes referred to as Auto Steer, Active Drive Assist (ADA), Active Steering Assist, Lane Tracing Assist.

LCA Lane Change Assist
A system which changes lanes automatically when the driver turns on the indicator.

Also sometimes referred to as Side Assist.

LDW Lane Departure Warning
A system that warns the driver when the vehicle is coming too close to the left or the right lane. Also sometimes referred to as Lane Departure Warning Assistance or Assistant (LDWA).

LKA Lane Keep Assist
A system that detects the edges of the current lane and steers the vehicle back from the edge when it comes close to the edge or crosses it without using the turn indicator. Also sometimes referred to as Lane Keeping System (LKS).

Platooning (Trucks)
According to ACEA (European Automobile Manufacturers Association), Truck Platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems like ACC.

TJA Traffic Jam Assist
A system which controls vehicle speed and lane position at low speeds. This system is a combination of Adaptive Cruise Control in slow traffic (< 60km/h) and Lane Centring. Also sometimes referred to as Stop & Go Assist.

TA Turn Assist
System that warns and brakes for other road users at low speeds when turning left (oncoming traffic) or right (cyclists, pedestrians). Also sometimes referred to as Right Turn Assist and Left Turn Assist.

2 Method

2.1 Information sources

The information described in this report was gathered from several sources. Most importantly, the literature repository constructed in Work Package 1 of the project was used to identify sources that provided information concerning specific ADAS. In addition, car manufacturers' websites and vehicle manuals were used to find information on these systems. We also consulted technical experts in our organization and used websites from international organizations such as Euro NCAP and the European Commission to collect relevant information.

2.2 Vehicle selection

Although the literature collected in the repository [ID5351] and described in Report 1 [ID5357] contains some information concerning separate ADAS, this information often was quite general. Therefore, we also included several car manuals as additional information sources. The selected cars represent a variety of brands, both in terms of nationality and market segment:

- BMW 5 Series (2020)
- Ford Focus (2018)
- Mercedes-Benz S Class (2020)
- Renault Scenic (2020)
- Tesla model 3 (2020)
- Toyota Corolla (2018)

For some systems, also information on the Audi A5 (2019), BWM 3 Series (2019) and Mercedes-Benz C Class (2019) was included. For all vehicles, the manual for the most recent model version on the European market was used. In the system descriptions below, these different cars are referred to by reference to the index of their manual in the repository [ID5351]. It should be noted that car manuals vary widely in their completeness and readability. Therefore, the information given below for the different ADAS is only as good as it has been described in these manuals. Moreover, since manuals are mostly far from complete from a technical point of view, it was often unclear whether certain features did not apply to the vehicle in question or if the information was missing. In tables, missing information is marked as "NA": not available.

2.3 Topics to be described per system

In the following results section (Chapter 3) we describe for each of the selected systems the following aspects:

1. Purpose of the system
2. Operational Design Domain (ODD)
3. Sensor input to the system
4. User input to the system
5. User output from the system
6. Vehicle actuation by the system

A system's ODD is defined in SAE J3016 as the "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.” [ID5309]

3 Results

Modern cars may come equipped with a large number of ADAS, which often share input from a limited number of sensors and may overlap in their functionality. They can be organized according to the impact they have on vehicle control (longitudinal versus lateral) and their main functionality. As such, six clusters can be identified:

1. **Speed limitation systems** (longitudinal control):
   - Intelligent Speed Assistance system (ISA)
2. **Cruise control systems** (longitudinal control):
   - Adaptive Cruise Control (ACC)
   - Cooperative Adaptive Cruise Control (CACC)
   - Platooning
3. **Crash avoidance systems** (longitudinal control):
   - Forward Collision Warning (FCW)
   - Autonomous Emergency Braking (AEB)
4. **Lane keeping** (lateral control):
   - Lane Departure Warning (LDW)
   - Lane Keeping System (LDS)
   - Lane Centring (LC)
   - Lane Change Assist (LCA)
5. **Crash avoidance systems** (lateral control):
   - Autonomous Emergency Steering (EAS)
   - Blind Spot Warning (BSW)
   - Turn Assist (TA)
6. **Driver state systems**:
   - Driver State Monitoring (DSM)
   - Emergency Assist (EA)

However, with increasing vehicle automation, new systems such as Traffic Jam Assist and Advanced Driving Assistance incorporate both longitudinal and lateral vehicle control. Moreover, they combine functionality from several existing ADAS, such as ACC and Lane Centring, thus blurring the lines between these different systems.

Below, the separate systems as listed in Chapter 1.1 will be described.

3.1 Intelligent Speed Assistance (ISA)

Intelligent Speed Assistance is an advanced version of the classic Speed Limiter (also called Speed Control Function). As it needs information concerning the current speed limit, it also encompasses the Speed Limit Information Function and/or the Traffic Sign Recognition system.

3.1.1 Purpose of the system

The Intelligent Speed Assistance system informs the driver of the current speed limit and allows the driver to automatically limit the maximum vehicle speed to this speed limit (or to a lower speed if the driver chooses to do so).
ISA systems can be classified into open, half-open and closed systems [ID5304]:

- Open ISA warns the driver (visibly and/or audibly) that the speed limit is being exceeded. The driver him/herself decides whether or not to slow down. This is an informative or advisory system.

- Half-open ISA increases the resistance of the accelerator pedal when the speed limit is exceeded (the 'active accelerator'). Maintaining the same speed is possible, but less comfortable because of the counter pressure.
- Closed ISA limits vehicle speed automatically if the speed limit is exceeded. It is possible to make this system mandatory or voluntary. In the latter case, drivers may choose to switch the system on or off. Some systems allow the driver to override this speed limit, for example by requiring a "kick-down" on the accelerator to exceed the limit [ID5259] [ID182]. An example of a mandatory system is the ISA system in trucks.

The activation speed for ISA can be fixed, variable, or dynamic [ID5266]:

- Fixed: always the same activation speed, regardless of actual speed limit; used in early systems and often in trucks;
- Variable: adjusts the system activation speed to match the speed limit on the current road (based on I2V communication, map/GPS and/or traffic sign recognition);
- Dynamic: like variable, but also takes into account factors such as weather conditions, road layout and traffic density.

Different car manufacturers use different names for their version of ISA (see Table 1).

Table 1. ISA brand names for different car brands ([1]BMW Speed Limit Info and Toyota Road Sign Assist are not full ISA systems, but only Traffic Sign Recognition)

	BMW 5 Series	**Ford Focus**	**Mercedes-Benz S Class**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**
Brand name	Speed Limit Info[1] / Speed Warning	Intelli-gent Speed Limiter	Active Speed Limit Assist	Overspee d alert	Speed Assist	Road Sign Assist[1]

3.1.2 ODD of the system

The operational design domain for ISA depends on the type of information sources used. For optical traffic sign recognition, a functional camera must be available, as well as weather conditions that permit traffic sign recognition. For speed limit information from the navigation system, accurate GPS localization of the vehicle must be available as well as accurate speed limit data for the current position. Often, temporary speed limits such as for roadworks are not included in this function. ISA functionality may also be integrated with an ACC system. When both ISA and ACC are active and ISA is set to automatic adoption of the detected speed limits, the ACC system will automatically decrease the target speed to the ISA speed limit if the current target exceeds this speed [ID5285].

3.1.3 Sensor input to the system

For ISA based on traffic sign recognition, camera images are used. For navigation system based ISA, the current GPS location is combined with information from the navigation system, such as local speed limit and road layout. Some modern systems also include weather information in setting the vehicle current speed [ID5310].

3.1.4 User input to the system
ISA can be turned on or off by the driver, typically by a dedicated Limiter button. The user can set the system to classic (non-adaptive) speed limit functionality in the car's menu system [ID5284]. To change the speed limit in its classic mode, the driver can use buttons to increase or decrease the set speed. In some cars, the driver has to possibility to set the speed limiter higher than the detected speed limit by some tolerance level [ID5284], [ID5310], [ID5362]. Most systems also allow the user to turn off automatic speed limit adoption, turning the system from a closed into an open, informative system. In addition, some vehicles allow the user to choose the warning modality (visual, auditory, both or none) [ID5362], [ID5310].

3.1.5 User output from the system
The current speed limit derived from traffic sign recognition or navigation information is displayed in the instrument cluster. After some unspecified time without new traffic sign recognition, the speed limit information fades out or disappears from the display [ID5284], [ID5362]. Some systems give auditory and/or visual warnings when the current speed limit is exceeded [ID5362]. In the Tesla model 3, the icon with the recognized speed limit increases in size when speeding, accompanied by a chime [ID5310]. This warning disappears after 10s.

3.1.6 Vehicle actuation by the system
This depends on the type of ISA:

- Half-open ISA can increase the gas pedal return force when the set speed is exceeded.
- The closed ISA system reduces the throttle input to the engine when the set speed is exceeded.

3.1.7 Specific for buses and Heavy Vehicles
Trucks often have a fixed set speed for the speed limiter determined by legal requirements.

3.2 Adaptive Cruise Control (ACC)

ACC assists the driver in longitudinal vehicle control, keeping driving speed constant while maintaining a certain distance to preceding vehicles (Figure 2).

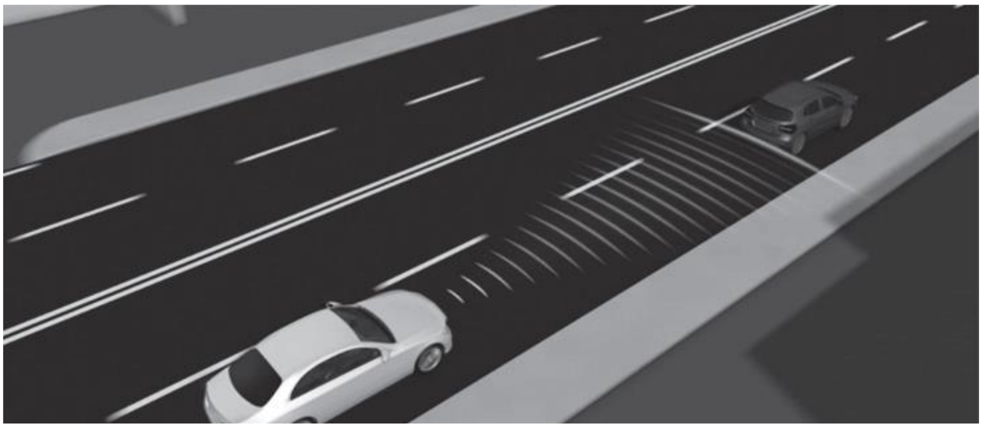


Figure 2. Mercedes-Benz Active Distance Assist DISTRONIC [ID5285].

3.2.1 Purpose of the system

The goal of ACC is a partial automation of the longitudinal vehicle control and the reduction of the workload of the driver with the aim of supporting and relieving the driver in a convenient manner [ID5273]. In contrast to a conventional cruise control system, which is only based on vehicle speed control, the ACC system maintains a minimum gap to the preceding vehicle by taking distance and relative speed into account as well [ID5265]; see Figure 2). The most advanced versions also take speed limit information, road layout and weather conditions into account [ID5285], [ID5310]. Figure 3 shows the basic state transition diagram of an ACC system. The ACC system can often be set to classic cruise control mode (i.e. without distance control) in the car's menu system.

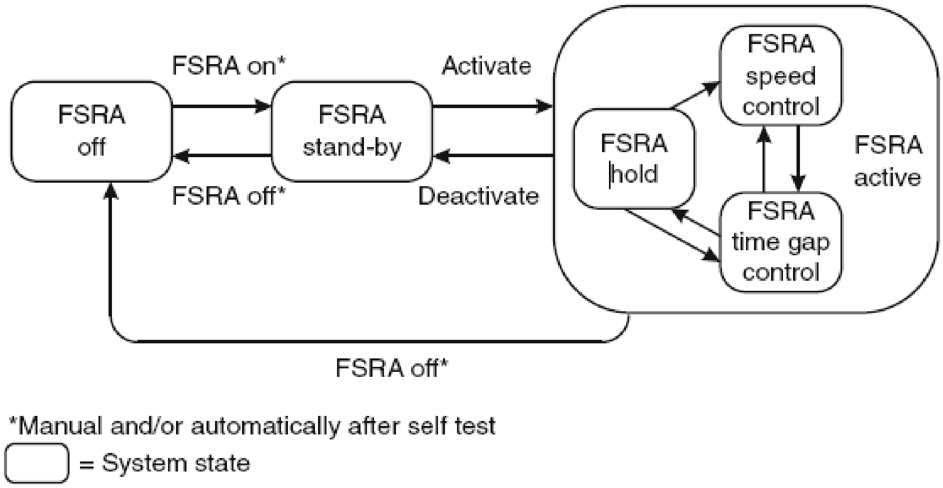


Figure 3. ACC states and state transitions for full speed range ACC (FSRA). (From ISO 22197, cited in [ID5267])

Table 2. ACC ODD for different brands. Speed control range: the range within which the system can control vehicle speed; Speed setting range: the range within which target speed can be set.

	BMW 5 series	**Ford Focus**	**Mercedes-Benz S class**	**Renault Scenic**	**Tesla Model 3**	**Toyota Corolla**
Brand name	Active Cruise Control with Stop & Go Function	Adaptive Cruise Control	Active Distance Assist Distronic	Adaptive Cruise Control	Traffic Aware Cruise Control	Dynamic Radar Cruise Control with full-speed range
Sensors	Radar + camera	Radar + camera	Radar + camera	Radar + camera	Radar + camera	Radar + camera
Precon-dition	Dynamic Stability Control enabled and not active;	NA	ESP turned on and not active	NA	Traction control must be enabled	Vehicle Stability Control and Traction Control

	Dynamic Traction Control off				and inactive	enabled and inactive; AEB inactive
Speed control range	NA	NA	NA	40 – 170 km/h	> 30 km/h (≥ 0 km/h when vehicle ahead is detected)	NA
Speed setting range	> 30 km/h	> 30 km/h	20-210 km/h (max. 200 km/h without Driving Assistance Package)	50 – 160 km/h	30 – 150 km/h	>30 km/h
Distance detection range	NA	NA	NA	Up to 120 m	NA	Up to 100 m
Number of distance settings	4	4	4	3	7	3

3.2.2 ODD of the system

Historically, a distinction is made between limited and full speed range ACC [ID5267]. Limited speed range ACC only functions within a certain vehicle speed range, for example above 30 km/h. Full speed range ACC is able to control vehicle speed across the entire speed range, including coming to a full stop. For this reason, it is also called ACC with Stop & Go. Most modern cars now come with full speed range ACC. Even in this case, however, it is often not possible to set the set speed to a very low speed (for example below 30 km/h [ID5362]). The effective speed range may also depend on the car's configuration. For instance, in the new 2020 Mercedes-Benz S class, ACC speed can be set to a range of 20 to 200 km/h *without*, and 20 to 210 km/h *with* the Driving Assistance Package (which includes several ADAS such as LKA, LC and BSW [ID5285]). ACC systems are deactivated when the ESP system is active longer than a certain period of time, for example to prevent skidding. Because the ACC system controls the gap to the preceding vehicle, it needs reliable distance and lane information about vehicles in front of the ego vehicle. Therefore, its functioning is impaired in conditions with bad visibility. Also, correct identification of preceding vehicles depends on road layout, vehicle type, and relative lateral vehicle position (see Figure 4). According to the Tesla Model 3 manual, Traffic-Aware Cruise Control (Tesla's ACC) is primarily intended for driving on dry, straight roads, such as highways and freeways[2]. It should not be used on city streets [ID5310]. Likewise, the Toyota Corolla manual warns not to use ACC on busy roads, roads with pedestrians and cyclists, or on steep or curvy roads

[2] Freeways are highways with controlled access ('freeway' and 'highway' are roughly equivalent with 'Autosnelweg' and 'Autoweg' in Dutch). Expressway is an alternative term for freeway; motorway is the UK equivalent.

[ID5362]. The Renault Scenic manual instructs drivers to turn off ACC when driving in a tunnel [ID5363]. According to the Ford Focus manual, the system may produce false alarms for sensor blocking when driving in featureless landscapes such as a desert for an extended period of time [ID5284]. The ACC system regulates longitudinal vehicle speed by actuating the brake and throttle systems. The maximum acceleration and deceleration applied by the system depend on current vehicle speed (see Figure 5). However, the exact relationship is not publicly available for most vehicles. Most ACC systems require some form of confirmation of driver availability, for instance by sensing the driver's hand(s) on the steering wheel (see DSM).
If a vehicle is also equipped with traffic sign recognition, it may offer the possibility to adapt the current speed limit as the ACC set speed. This may even happen automatically with ISA. Some systems also adapt vehicle speed based on road layout and weather conditions [ID5285], [ID5310]. In the Tesla 3, the vehicle will only overtake vehicles at 80 km/h or more when the ego vehicle is in a passing lane (left hand lane for right hand traffic, right hand lane for left hand traffic); otherwise, it will stay behind the vehicle in the adjacent lane, preventing overtaking on the wrong side [ID5310].

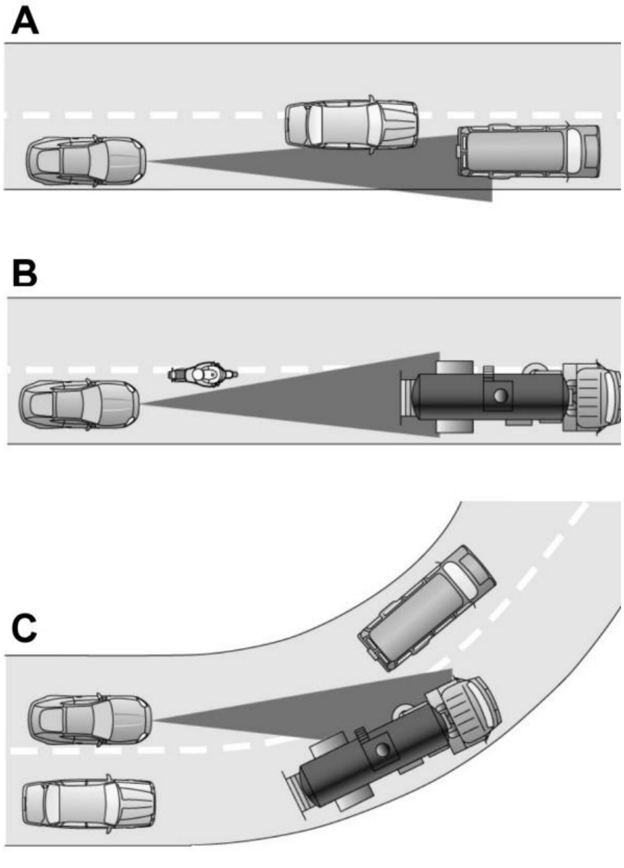


Figure 4. Examples of traffic situations in which the ACC system may respond inadequately [ID5284].

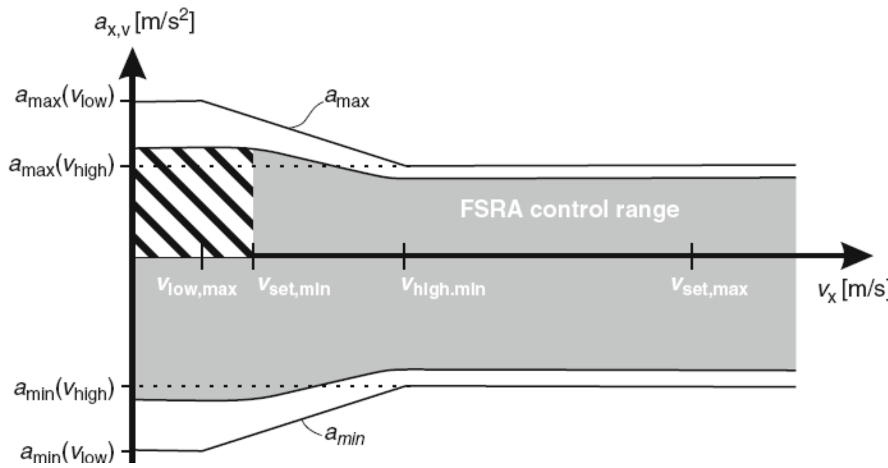


Figure 5. Functional range of full speed range ACC. a = acceleration, v = speed (ISO 22179, cited in [ID5267])

3.2.3 Sensor input to the system

The ACC system requires ego vehicle speed data as well as data from a range sensor (typically radar, but LIDAR or camera-based systems exist as well) in order to control both vehicle speed and gap distance to a preceding vehicle. In order to correctly identify preceding vehicles in the same lane, lane identification from camera-based line detection is required. Driver availability can be detected from steering wheel input (contact pressure, applied torque) or driver camera. More recent systems can also include input from the navigation system (traffic information, road layout) as well as weather information.

3.2.4 User input to the system

Most ACC systems offer the driver several controls:

- Control element to switch ACC system from off to standby
- Control element to activate ACC system
- Control element to deactivate ACC system
- Control element to increase set speed
- Control element to decrease set speed
- Control element to set minimum distance/time gap to preceding vehicle
- Control element to resume ACC activation with previous set speed

Some of these controls can be combined into one (for example one button which toggles between turning ACC on and ACC deactivation). Some cars come with a dedicated ACC lever (Figure 6), while others more commonly include ACC control buttons on the steering wheel (Figure 20). In the Tesla 3, the ACC is activated by moving the gear lever downward (Figure 6B). Moving the lever up again deactivates ACC (and simultaneously activates regenerative braking). Moving the lever down twice activates ACC and Lane Centring [ID5310].

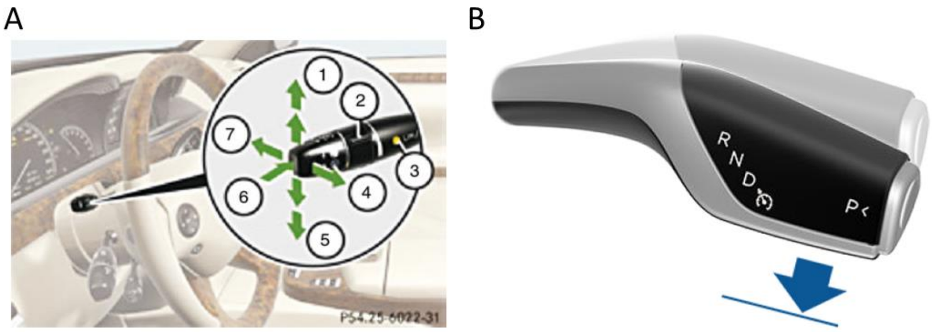


Figure 6. A. Mercedes-Benz W221 DISTRONIC PLUS control lever with 7 functions [ID5267].B. Tesla 3 Traffic Aware Cruise Control lever [ID5310].

Besides these system controls, the driver has the possibility to switch between adaptive and classic cruise control in the car's menu system [ID5284] or by long pressing the cruise control button [ID5362]. Cars differ in the number of distance settings the user can choose from: 3 [ID5362], 4 [ID5284] and 7 [ID5310].

3.2.5 User output from the system:

The ACC system displays to the driver:

- ACC state icon (visual)
- distance setting icon (visual)
- set speed (visual)
- insufficient distance warning tone (auditory)

Winer distinguishes between permanent and situational displays and between essential, important and helpful user output (see Figure 7) [ID5267]. This can serve as a guideline for ACC HMI design.

States	Type	I	T
Activation state	p	e	o
Relevant target object detected	p	i	o
Override by the driver	s	h	o
Go possible (FSRA only)	s	h	o
Transition autom. go → driver triggered go (FSRA only)	s	h	o
System settings			
Desired speed (set speed)	p	e	o
Desired time gap (set time gap)	p,s	i	o
Speed of preceding vehicle	p	h	o
Actual distance to preceding vehicle or deviation between set time gap to actual time gap	p	h	o
State transitions			
ACC off → ACC stand-by, if provided	p	e	o
Handover request when a system limit is reached	s	i	a + o
System shutdown	s	e	a +o
Below a critical distance or time-gap limit	s	i	a (+o)

Figure 7. Display functions for ACC [ID5267]. Type: p = permanent, s = situational. Importance I: e = essential; i = important; h = helpful. Display technology T: a = auditory, o = optical.

In the Renault Scenic, distance warning can operate without ACC. The system informs the driver using a colour coded symbol in the information display, which shows green when no preceding vehicle is detected or the time gap is more than 2 s, orange when it is between 1 and 2 s and red when it is less than 1 s. It the time gap is less than 0.5 s, it will flash in red [ID5363]. The BMW 5 Series shows a distance warning symbol when the distance to the preceding vehicle is too short while traveling at > 70 km/h and ACC switched off [ID5288]. In Tesla, the display also shows a visual representation of other detected vehicles in the display [ID5310].

3.2.6 Vehicle actuation by the system

The ACC system regulates longitudinal vehicle speed by changing:

- Throttle
- Brake

The manuals for some cars indicate that ACC braking force is limited (for example 50% [ID5285] or by 50 km/h [ID5310]).

3.3 Cooperative Adaptive Cruise Control (CACC)

CACC is a system that is still under development and currently not yet on the market. As such, little information concerning its implementation is available, mainly from research studies.

3.3.1 Purpose of the system

CACC is an extension of ACC systems which incorporates vehicle-to-vehicle (V2V) and possibly infrastructure-to-vehicle (I2V) communication to make use of traffic and environment information [ID5265]. Figure 8 shows CACC system components and data flows. According to [ID5286], CACC allows connected automated vehicles (CAVs) to form platoons and be driven at harmonized speeds with shorter time headways between them. By sharing vehicle information such as acceleration, speed, and position in a distributed manner, CAVs within a certain communication range can cooperate with others to obtain the following potential benefits: 1) driving safety is increased since actuation time is shortened compared to manually driven, and downstream traffic can be broadcasted to following vehicles in advance; 2) roadway capacity is increased due to the reduction of time/distance headways between vehicles; 3) energy consumption and pollutant emissions are reduced due to the reduction of unnecessary velocity changes and aerodynamic drag on following vehicles. As such, CACC is an important component in connected automated vehicles [ID5286].

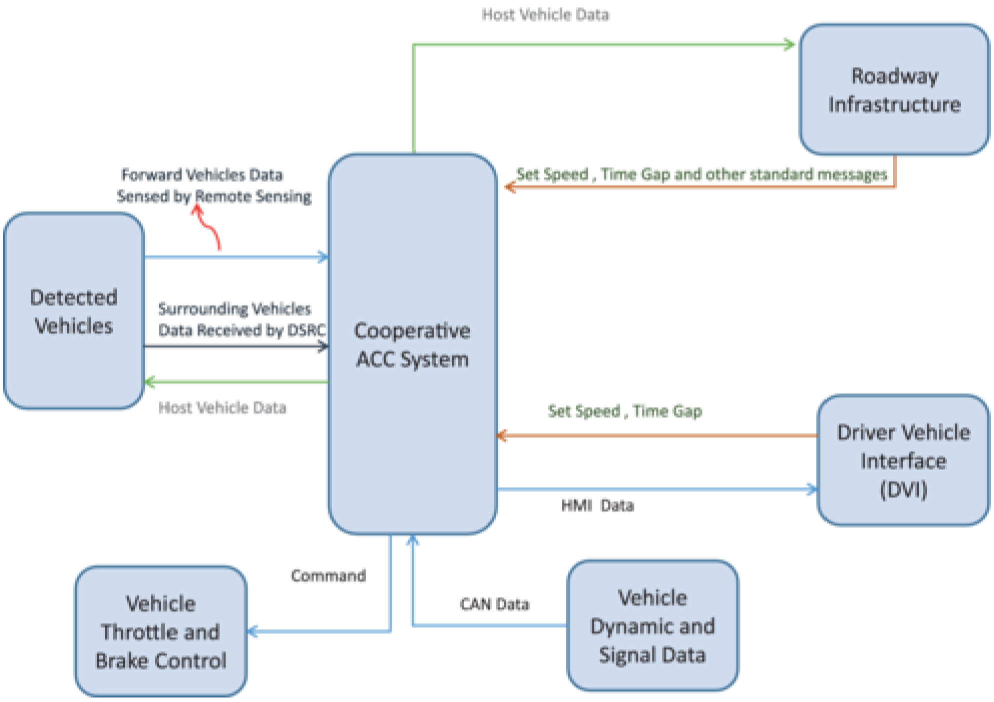


Figure 8. CACC system components and data flow [ID5276].

3.3.2 ODD of the system

Since CACC is an extension of ACC, its ODD is a subset of the ACC ODD. CACC functionality depends on the availability of V2V and/or I2V communication.

3.3.3 Sensor input to the system

To extend the system’s functionality from ACC to CACC, at the minimum it needs input from other CACC vehicles regarding their position, speed and acceleration (V2V). In addition, information from the road infrastructure may be used to further optimize vehicle speed control, for instance information about traffic light status (I2V).

3.3.4 User input to the system

Since CACC systems are currently not yet available in series production vehicles, no HMIs are available for review. Because the functionality of the system to the driver is largely the same as that for ACC, similar user input controls may be used (i.e. for activating and deactivating the system, changing the set speed and changing the minimum following distance).

3.3.5 User output from the system

Similarly to user input, little is known regarding user output from CACC systems. Beyond the information presented to the driver by ACC systems, CACC may display information on nearby vehicles as well as on traffic infrastructure.

3.3.6 Vehicle actuation by the system

The effects on vehicle control by the CACC system are similar to those for ACC systems. It controls longitudinal vehicle speed by actuating throttle or brakes.

3.3.7 Specific for buses and heavy vehicles

Use of CACC systems is most heavily investigated for trucks, in order to make truck platoons possible.

3.4 Platooning (Trucks)

Although platooning is not necessarily restricted to trucks (for example see [ID1190]), this description will focus on its use in trucks.

3.4.1 Purpose of the system

According to the ACEA (European Automobile Manufacturers Association), Truck Platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems like ACC [ID5305].
The benefits envisioned for platooning are: increased traffic safety by connectivity between vehicles and between vehicles and infrastructure, increased efficiency and traffic flow and reduced emissions in combination with lower fuel consumption.
The ENSEMBLE project (www.platooningensemble.eu/library/deliverables) has identified two different levels of platooning:
(1) as a support or assistant function, where the driver is responsible for the driving task and therefore following distances of the platooning trucks are at least 1.4s to enable the driver to react in time to an emergency situation;
(2) as an automated function where the drivers in the following trucks of the platoon are out of the loop or maybe even out of the truck.

3.4.2 ODD of the system

The ODD of platooning trucks is still to be defined since no truck platooning systems are yet on the market. Testing in the ENSEMBLE project is about to start. At this moment most implementations of truck platooning are designed to function on highways with at least two lanes of traffic in the same direction, similar to the preferred ACC domain.

3.4.3 Sensor input to the system

Platooning trucks with the support function use their available ACC system for longitudinal sensing. Additionally, information is communicated between vehicles by means of a standardized communication protocol. This protocol regulates for example trucks joining and leaving a platoon and offers more information on current driving speed, acceleration, deceleration and maximum possible acceleration/speed of the trucks in the platoon. At this moment communication is based on ITS G5, but the communication protocol can also be used in a 5G network once available. Also information from and to roadside units is considered. Furthermore, for ITS G5 implementation, a security framework has been defined.

3.4.4 User input to the system

The driver can (de-)activate the platooning by means of a button on the dashboard.

3.4.5 User output from the system

The driver is informed about the status of the system: platooning active or inactive, position in the platoon, errors in the system, and for instance when being the lead vehicle: if a truck behind has a request to lower the speed to maintain platoon cohesion. Also roadside requests like for example a different minimal following distance are displayed to the driver to react to it in case of the support function.

3.4.6 Vehicle actuation by the system

The actuation by the system is OEM specific and not publicly known. Actuation similar to CACC seems likely.

3.5 Lane Departure Warning (LDW)

From a functional point of view there are three main categories of systems to support the driver in keeping the lane and to avoid unintended drifting out of the lane [ID5269]:

1. Lane departure warning systems
2. Lane keeping assistance systems
3. Lane centring systems (also automated lane keeping, or lane following)

The first one is purely a warning system, activated when the vehicle is about to leave the lane or road. The warning system can use tactile, auditory and/or visual warnings. Corrective steering is only applied by Lane Keeping Systems and Lane Centring systems. Please note that the term ‘lane keeping’ is commonly used for both these types of systems, even though they differ in their functionality (see below). The effectiveness of Lane Departure Warning systems is not only dependent on the warning characteristics (sensory modality, timing), but also on the reaction time of the driver. Since a typical reaction time of a driver is around 1 second and the Time To Collision (TTC) in critical lane changes is approximately the same, a warning system by itself might not be effective enough to prevent lane change crashes [ID5259]. The main function of this warning system is to prevent unintended lane departures.

Both Lane Keeping Systems and Lane Centring systems are supporting the driver in the task to keep the vehicle between the lane lines and are very similar in their way of actuation, but differ in the amount and characteristics of torque applied to the steering wheel [ID5269]. The driver selects the function he/she wants to use. [ID5269]. In modern cars, both can be active at the same time [ID5284]. An overview of the names of different functions is shown in Table 3.

Table 3. Names for lane departure warning, lane keeping assistance system and automated lane keeping system functionalities

	Audi A5	**Mercedes C/S-Class**	**BMW 3/5 series**	**Ford Focus**	**Renault Scenic**	**Tesla Model 3**	**Toyota Corolla**
Collective system name	Active Lane Assist	NA	NA	NA	NA	Autosteer	Lane Tracing Assist

Lane departure warning	Lane Departure Warning	Active lane keeping assist	Lane departure waring	Lane keeping system	Lane Departure Warning	Lane Departure Avoidance	Lane departure alert
Lane keeping assistance system	Active lane assist	Active lane keeping assist	Steering and traffic jam assist	Lane keeping system	Lane Keeping Assist	(Emergency) Lane Departure Avoidance	Steering assist
Lane Centring	Active lane assist	Active steering assist	Steering and traffic jam assist	Lane Centring	NA	Autosteer	Lane centring

In this section, lane departure warning systems will be discussed first. They have been on the market much longer than active lane keeping systems and are available in many vehicles [ID5259]. Currently, lane keeping assistance systems are becoming more and more available in cars from the lower segments and will be discussed in the next section. Automated lane centring can be seen as the more advanced version of the lane keeping assistance system and is currently mainly available in the higher segment although it too becomes more available in midclass vehicles.

3.5.1 Purpose of the system
Lane departure warning systems provide a warning to the driver when an unintended lane departure is very likely to happen and the turn signal is not switched on [ID29] [ID5307]. The purpose of the system is to warn the driver such that he/she can take appropriate action to avoid driving off the lane or road [ID5269]. The way the driver is warned differs between brands and models.

3.5.2 ODD
The main element needed for commercially available lane departure warnings to function properly is reliable detection of the lane markings [ID29]. For Audi A5, Mercedes C-Class, BMW 3/5 series and Ford focus the detection of one lane line is sufficient for the function to be active. The condition of the lane markings and non-homogeneity of the road surface and weather conditions have a big influence on the detection. Light condition, such as direct sunlight on the road surface might cause disturbing reflections [ID5269]. In addition, lanes are only detected if they have a minimum width, although most manufacturers do not specify this in their manuals (see Table 4). Lane Departure Warning is available from a lower speed range and up to a maximum speed. These minimum and maximum speeds are country specific [ID5287], [ID5269]. To avoid frequent activation and deactivation, different speed thresholds for activation and deactivation might be applied.

Table 4 Lower and upper speed limits and minimum lane width for Lane Departure Warning for different brands

	Audi A5	***Mercedes-Benz C Class***	***BMW 3/5 serie***	***Ford Focus***	***Renault Scenic***	***Tesla model 3***	***Toyota Corolla***
Lower speed limit	*65 km/h*	*60 km/h*	*Country Specific*	*65 km/h*	*70 km/h*	*64 km/h*	*50 km/h (less*

							when LC is active)
Upper speed limit	*NA*	*200 km/h*	*210 km/h*	*NA*	*200 km/h*	*145 km/h*	*NA*
Minimum lane width	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*3m*

3.5.3 User input to the system

Lane line detection in commercially available vehicles is done by recognition of the contrast between the road surface and the lane markings using cameras in the windshield, as shown in Figure 9 [ID5290], [ID5269]. From camera images, the position of the car relative to the lane lines is estimated [ID5307]. When one of the front wheels drives over the lane marking or is close to doing so, a warning is provided [ID5269], [ID5289].

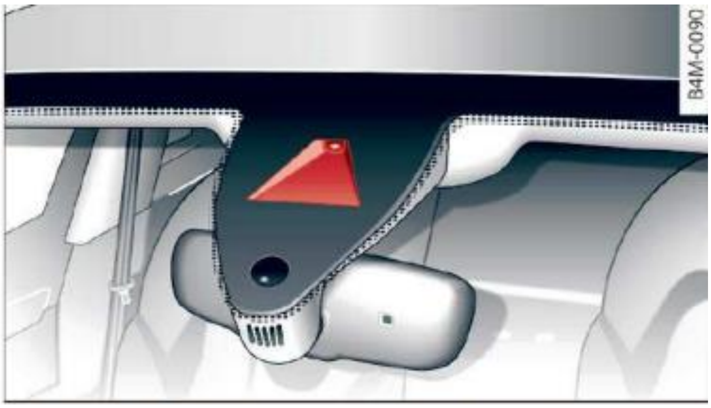


Figure 9 Windshield camera (indicated in red) for lane departure warning systems and lane keeping assistance systems [ID5290].

3.5.4 User input to the system

The driver can choose whether he/she wants to receive warnings. See Table 5 for an overview per brand.

Table 5 User settings for lane departure warning

	Audi A5	**Mercedes C Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**

Switch On/Off	Switch on via infotain-ment system	Switch on in the multimedia system	Switch on via iDrive, after switching on all intelligent safety systems by a button next to the steering wheel	Switch on/off via button on signal control lever	Multifunction screen	Car menu	Steering wheel button
Settings	NA	Sensitivity	Wheel vibration intensity and suppression of warnings	Wheel vibration intensity when 'Alert mode' selected and sensitivity	Volume of auditory warning, intensity of steering wheel vibration, sensitivity for line crossing detection	Off, Warning, or Assist	NA

3.5.5 User output from the system

To warn the driver in case of an unintended lane departure, visual, tactile and/or auditory channels are used. Tactile feedback is often provided via the steering wheel by vibrations [ID5310]. Visual warning are often displayed on the instrument display. Auditory warnings are very common for Japanese brands, where German brands only use visual feedback [ID5269]. Other channels such as vibration under seat cushions (as used by Peugeot and Citroen) are used less often.

To visualize the status of a lane departure warning system, a symbol with a car driving over a lane, as shown in Figure 10, is used in many available systems. In case of an Audi A5, only lane lines are shown (see Table 6).

Figure 10 Typical Lane Departure Warning symbol

When the system is activated and can provide warnings, the symbol or the lane lines in the instrument cluster turn green [ID5287], as shown in Figure 11.

Figure 11 Instrument cluster with Active Lane Assist switched on (left) and Active Lane Assist switched on and active (right) [ID5290].

Table 6 Visual feedback from the system to the driver for lane departure warning

	Audi A5	**Mercedes C Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Toyota Corolla**
Active	both the analog instrument cluster and the virtual cockpit illuminate green lines	lane markings illuminate green in the assistance graphic.	The symbol illuminates green	The symbol illuminates green in the information display when in Alert Mode	Green lines or white LDW icon in instrument cluster	Green icon in information display
Standby	virtual cockpit shows grey lane lines and the lines in the analog instrument panel are yellow	lane markings are light in the assistance graphic	NA	the symbol illuminates grey in the information display	Green lines or white LDW icon in instrument cluster	White icon in information display

Warning	lane lines in the virtual cockpit become red.	NA	NA	the symbol illuminates red	Red indicator light, beep, steering wheel vibration	Orange flashing icon in information display; flashing line in driving support system information screen

3.5.6 Vehicle actuation by the system

When lane lines on at least one side of the vehicle are detected and (about to be) crossed, the vehicle is located in the 'warning zone' as shown in Figure 12. If the turn indicator is not activated, the steering wheel will start vibrating in accordance to the steering wheel vibration setting [ID5290], [ID5269].

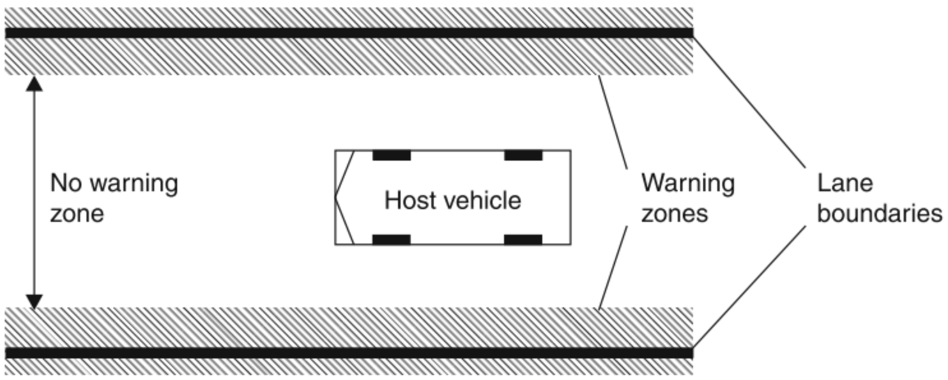


Figure 12 Warning threshold zones and movement of vehicle inside the lane [ID5269]

3.6 Lane Keep Assist (LKA)

3.6.1 Purpose of the system

Lane Keep Assist systems support the driver in keeping the vehicle between the lane lines. They assist the driver by correcting an impending or actual line crossing. This means they use different steering wheel torque characteristics than Lane Centring systems (see below), which keep the vehicle close to the centre of the lane. Both steering torque and selective braking are actuation types used to keep the vehicle in the lane.

3.6.2 ODD

Activation criteria of lane keeping assistance systems differ per brand. An overview is provided in Table 7. Most functions can be activated from 60 km/h and up to a maximum speed of >200 km/h. In order to avoid frequent activation and deactivation, the activation and deactivation speed threshold can be implemented separately. For example, the Volkswagen lane assist activates at 65 km/h but deactivates at 60 km/h [ID5269]. LKA only works if the correct lane position is recognized, either from lane lines or from the road edge. This means that the system is not expected to work when these lane markings are unclear, either because they are in a bad state or because the camera image is degraded by for instance weather conditions (fog, snow, rain) or by bad lighting (for example glare). Also, the system may not function well in small radius curves. In some cars, the ego vehicle follows the path of a preceding vehicle when no lane markings are detected. When this vehicle leaves the lane, the ego vehicle may do so as well [ID5362]. When the turning signal has been activated, LKA is not active on that side of the lane (unless the vehicle is also equipped with Blind Spot Warning and a vehicle is detected on that side; in that case LKA is still active in some cars, for example [ID5362]). LKA may also not work if acceleration exceeds a threshold value (either positive or negative [ID5362]). LKA is temporarily deactivated whenever ABS or ESP are active. It is not available when ESP has been turned off [ID5362].

Another activation criterium is the amount of lane lines that have to be detected for the system to work properly [ID5275]. Lane keeping assistance systems from both Audi A5 and Ford Focus are already active when only one lane line is detected. In case of a Mercedes C-Class, both lane lines have to be detected when driving above 70 km/h. When driving slower than 70 km/h, the system can switch from driving between the lane lines and following the vehicle in front instead. Vehicle manuals do not indicate whether the driver is notified whether lane keeping is based on line detection or vehicle following.

Table 7 Lower and upper speed range and minimum detection criteria for lane keeping assistance systems

	Audi A5	**Mercedes-Benz C Class**	**Mercedes-Benz S Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**
Lower speed range	65 km/h	60 km/h	60 km/h	NA	65 km/h	70 km/h	64 km/h	50 km/h
Upper speed range	NA	210km/h	200 km/h	210km/h	NA	160 km/h	145 km/h	NA
Minimum detection criteria	One lane line	>70km/h: lane lines on both sides. <70km/h lane lines on both sides or leading vehicle	Lane lines on both sides detected	NA	One lane line	Two lines	NA	NA

The camera in the windshield might not be able to detect lane markings properly in every situation. Lane lines might not be detected or detected incorrectly. For example, in case of vehicles driving ahead due to rain, snow or heavy spray of light shining into the camera [ID5290] [ID5289] [ID5287].

The environment can have a significant impact on the lane keeping assistance system. The system is not able to provide assistance when [ID5290], [ID5289] [ID5287]:

- The lane is too narrow or too wide
- The curve is too narrow
- Lane markings are of poor quality
- Driving in construction areas

Lane keeping assistance can be switched on, but will not apply corrective steering in the following situations [ID5290], [ID5289], [ID5287]:

- The driver's hands are not on the steering wheel
- The driver clearly and actively steers, brakes or accelerates.
- The driver has switched on the turn signal indicator.
- A driving safety system intervenes, such as ESP, Active Brake Assist or Active Blind Spot Assist.
- When ESP is deactivated.
- The tire pressure is too low.
- If the windshield in the area of the multifunction camera is dirty, or if the camera is fogged up, damaged or covered.
- If the field of view of the camera or the windshield is dirty or covered in the area of the interior mirror.
- Within 10 seconds after start of the engine
- The anti-lock brake, stability control or traction control system activates.
- At intersections

In Mercedes-Benz vehicles, the LKA system can be active but does not provide corrective steering when the vehicle is not equipped with the Driving Assistance package, which includes various ADAS [ID5285], [ID5289].

3.6.3 Sensor input to the system

All currently available lane keeping assistance systems use a camera with image processing for lane marking detection and recognition [ID5269]. They require visible lane lines or road edges for the system to work properly [ID5290], [ID5284]. More information about the required lane line quality can be found in section “ODD”.

Some cars use the vehicle ahead as a reference for the lane keeping assistance system in addition to the lane markings. For Mercedes-Benz, this is only at lower speeds [ID5289], while Toyota does not give a speed range [ID5362]. Steering and traffic jam assist from BMW uses 5 radar sensors, located in the rear and front bumper, together with the camera in the windshield to determine the position of the vehicle [ID5288]. Sensors in the steering wheel detect whether the driver is holding the steering wheel [ID5288].

3.6.4 User input to the system

Many available lane keeping assistance systems require activation by the driver. In any situation, it must be possible for the driver to override the steering torque of the lane keeping assistance system by turning the steering wheel [ID5275].

The lane keeping assistance systems of an Audi A5 and Ford Focus are activated by pushing a button on the turn signal lever (Figure 13, left). To activate the Mercedes-Benz lane keeping assistance system, the button with the LKA-symbol next to the steering wheel has to be pressed, as shown in Figure 13 (right). When the system is switched on, the indicator light will light up. To switch on the steering and traffic jam assistant from BMW, a button on the steering wheel has to be pressed.

Often, lane keeping assistance systems offer multiple settings, such as sensitivity or timing. These settings can be adjusted in the car menu (for example Mercedes, Ford, Renault and Audi). Since Audi has one system for lane departure warning, lane keeping assistance and lane centering, the preferred option can be selected by the user [ID5290].

Figure 13 Button to activate Lane keeping System for Ford Focus (left [ID5284]) and Mercedes-Benz S-class (right [ID5289]).

3.6.5 *User output from the system*

The status of the lane keeping assistance system is presented to the driver in different ways. Lane keeping is symbolized with a car driving between the lanes, as shown in Figure 15. A steering wheel symbol is often to indicate active steering to the centre of the lane (Lane Centring), as shown in Figure 14

Figure 15 Lane Keeping Assistance system [ID5283]

Figure 14 Active steering symbol (BMW)

If multiple systems are activated by one function, such as in case of the Audi A5, one symbol can represent multiple functions. The activation of at least one system is shown. Table 8 shows how activation feedback is provided to the driver.

Table 8. Lane Keep Assist feedback to the driver

	Audi A5	BMW 3/5 series	Ford Focus	Mercedes-Benz S-Class	Renault scenic	Toyota Corolla	Tesla model 3
Stand-by	Grey lines in the virtual cockpit, yellow lines in the instrument cluster	Grey lane markings symbol	Symbol illuminates white in the instrument cluster	Grey steering wheel icon	Grey lane markings on instrument panel	Symbol illuminates white in the instrument cluster	No lane markings are shown
Lane keeping active, but not steering	Green lines in the virtual cockpit	Green lane markings symbol	Symbol illuminates green in the instrument display	Lane markings are shown in green in the assistance graphic	Lane marking are shown in green on instrument panel	Symbol illuminates green in the instrument cluster	White lane markings are shown
Lane keeping active and steering	Red lines in the virtual cockpit + vibrating steering wheel	Red lane marking symbol + steering wheel vibration	Symbol illuminates red in the instrument cluster + steering wheel vibration	Lane markings are shown in red in the assistance graphic + steering wheel vibration	Lane marking on the affected side turns orange	Symbol flashes orange in the instrument cluster	Lane marking of the affected side turns blue

When the lane keeping assistance system from Mercedes intervenes, this is shown on the multifunction display by a car close to the lane lines, as shown in Figure 16. Figure 17 provides an example of system feedback provided in the Ford Focus.

Figure 16 Multifunction display of Mercedes C-Class showing lane-correcting brake application [ID5289].

When the steering wheel has not been touched for some time (duration not further specified in manuals), the system provides a warning to the driver. In a BMW 5 series, the steering wheel icon will become red and a warning sound is activated.

The active steering system becomes inactive. If ACC is turned on, the car slows down in speed [ID5288]. In case of an Mercedes, first only an optical warning is given. When the driver does not react, a warning sound is added to the visual warning [ID5289]. All warnings stop the moment the driver touches the steering wheel again.

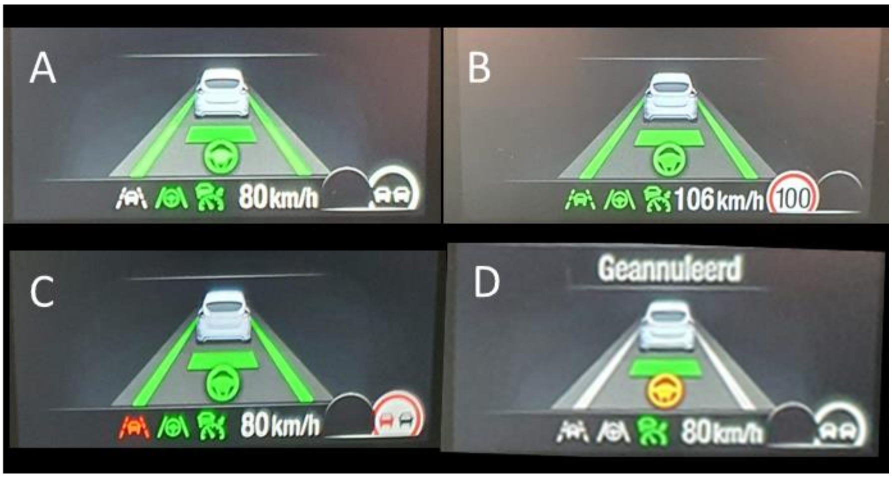


Figure 17. Instrument cluster symbols for Lane Keeping System, Lane Centering and Adaptive Cruise Control in 2018 Ford Focus. A. LKA standby, LC and ACC active; B. LKA, LC and ACC active; C. LKA active and correcting, LC and ACC active; D. LKA standby, LC canceled, ACC active.

3.6.6 Vehicle actuation by the system

When the lane lines are detected, the position of the vehicle relative to the lane lines can be obtained. The system uses lateral offset and orientation within the lane as well as the road curvature as inputs to determine the steering torque required to keep the vehicle between the lane lines [ID5269].

Different torque characteristics in lane keeping assistant systems lead to different functions of the ADAS. In Figure 18 three kinds of assistance torques are presented against the deviation from the lane centre. The most left diagram shows the ‘loose guidance’, which only supports the driver when the vehicle is very close to the lane line. This is the most ‘basic’ variant of lane keeping systems. Depending on the torque applied by the system, the system is able to keep the car between the lines without support of the driver. This characteristic is applied in the lane keeping system from Ford.

A lane keeping assistance system with ‘tight guidance’, will support the driver in the lane keeping task from the middle of the lane. Therefore, the system keeps the car in the lane centre. An example of such a system is the active steering system from BMW and Ford. The right diagram below shows ‘comfort-oriented torque’, which is a combination of the earlier mentioned torque characteristics. Both Honda and Nissan are using this characteristic, which is based on cooperation principle between driver and vehicle [ID5269].

In the Audi A5 the settings for torque characteristics can be adjusted via the infotainment system. Setting the timing to early will result in a tight guidance. Putting the A5 in late steering mode, will lead to loose guidance. However, also low visibility can cause the system to switch from early to late steering assistance [ID5290]. From the user manual, it is unclear whether the driver is notified about this.

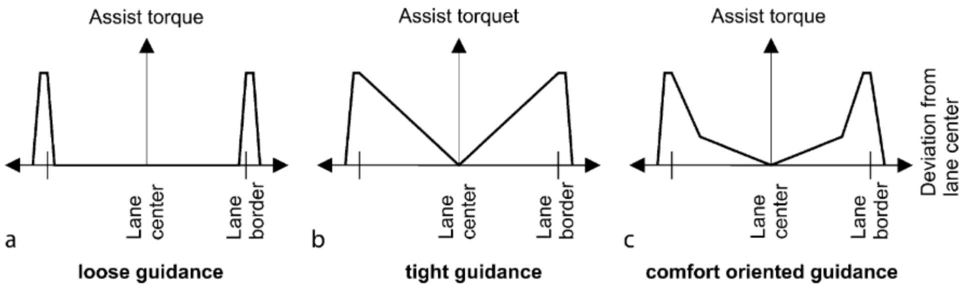


Figure 18 Examples of assist torque of lane keeping assist systems; (a) loose guidance, (b) tight guidance, and (c) comfort-oriented guidance [ID5259].

The lane keeping assistance torque is based on the lateral position and heading of the vehicle and the curvature of the road. A block diagram of a lane keeping assistance system is shown in Figure 19. The assistance torque is added to the driver's torque and together result in the final steering power.

Next to steering torque actuation, some vehicles use slight braking to prevent the vehicle from leaving the lane [ID5307]. This selective braking of the wheels to change the heading of the vehicle is used in lane keeping systems from Mercedes-Benz and Nissan [ID5269].

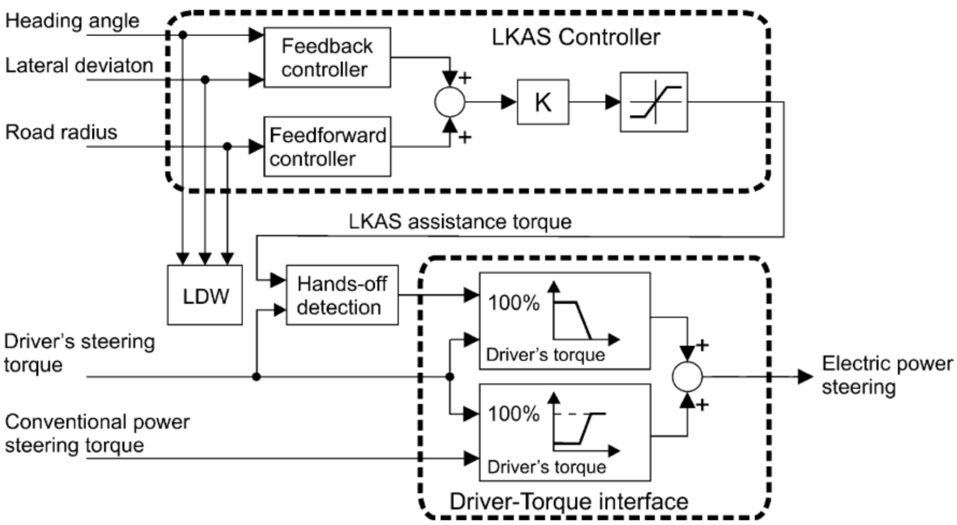


Figure 19 Block diagram of a lane keeping assistance controller [ID5259].

3.7 Lane Centring (LC)

3.7.1 Purpose of the system

A Lane Centring system aims to keep the vehicle in the centre of the detected lane while driving. Thus, it is constantly actively steering the vehicle in order to follow the lane, in contrast to the Lane Keeping System, which only affects steering when close the lane edges. Some versions of Lane Centring will use the lateral position of a preceding vehicle to steer the ego vehicle when no lane markings are detected [ID5310].

3.7.2 ODD

LC is most frequently combined with ACC and can only be active when ACC is active. Since the driver is still responsible for driving even when ACC and LC are active, LC in the majority of cars only works when driver availability is detected, in most cases through hands on the steering wheel. When hands on the wheel are not detected for some period of time while LC is active, the driver is warned both visually and acoustically to put the hands back on the steering wheel. When the driver does not comply, the vehicle may either slow down and come to a stop [ID5284], [ID5310] or increase warning intensity [ID5362]. Furthermore, because LC depends on lane detection, clear lane markings or road edges need to be visible to the system. This means that the system will not work, or work incorrectly, if lane markings are missing or badly visible due to bad weather conditions (fog, rain, snow), bad lighting (glare) or bad maintenance. Some systems resort to using the lateral position of a preceding vehicle in this case [ID5310]. Tesla labels its Autosteer function as being a 'Beta' function [ID5310].

Table 9. Lane Centring system ODD

	Audi A5	**Mercedes-Benz C Class**	**Mercedes-Benz S Class**	**BMW 5 Series**	**Ford Focus**	**Tesla model 3**	**Toyota Corolla**
Lower speed limit	65km/h	60km/h	0 km/h	0 km/h	65km/h	30 km/h free driving; 0 km/h following	50 km/h
Upper speed limit	NA	210km/h	210 km/h	210km/h	NA	150 km/h	NA
Minimum detection criteria	One lane line	>70km/h: 2 lines; <70km/h: 2 lane lines or lead vehicle	NA	NA	One lane line	NA	NA
Abort criteria	NA	NA	NA	• User steering input	NA	• User steering input	NA

				• Vehicle speed > 210 km/h • Steering wheel released • Leaving own lane • Turn indicator use • Narrow lane • No lanes or preceding vehicle detected		• Vehicle speed > 150 km/h • Braking • AEB active • Door opened • Gear change	

3.7.3 Sensor input to the system
LC is based on lane marking detection by camera. The camera is most commonly located behind the top center part of the windscreen (see Figure 9).

3.7.4 User input to the system
In most cars, Lane Centring needs to be activated by the driver. This activation is coupled to the activation of the ACC [ID5284], [ID5362], [ID5269]. An exception is LC in the BMW 540i, which activates as soon as the engine is turned on and lanes are detected, even when ACC is off. To activate Mercedes active steering assist (lane centring assistance system), the LC button with steering wheel and lane lines icon next to the lane keeping assistance button has to be pressed [ID5289]. Similarly, activation of LC in the Ford Focus requires the user to push the LC button on the steering wheel ([ID5284]; see Figure 20). The last user setting for LC is remembered when ACC is activated next time. In the Tesla model 3, Lane Centring is activated by moving the gear lever downward twice (see Figure 6B), which also activates ACC.

Figure 20. Ford Focus steering wheel ISA, ACC and LC controls.

3.7.5 User output from the system

LC system status is displayed in the information display. In the 2018 Ford Focus, it is indicated by means of a steering wheel between two lines icon [ID5283]. When the system is activated, the icon is visible, when it is turned off, it is not visible. In standby mode, the icon is light grey or white, while it lights up green when active. The Toyota Corolla has only one icon for both LKA (Steering Assist) and LC [ID5362].

3.7.6 Vehicle actuation by the system

LC provides torque input to the steering system in order to keep the vehicle close to the center of the lane.

3.8 Traffic Jam Assist (TJA)

3.8.1 Purpose of the system

Traffic Jam Assist essentially is a low speed version of Adaptive Cruise Control with Stop & Go functionality (typically up to 60 km/h), in modern cars combined with Lane Centring [ID5361]. It is meant to increase driver comfort when driving in congested low speed traffic (see Figure 21).

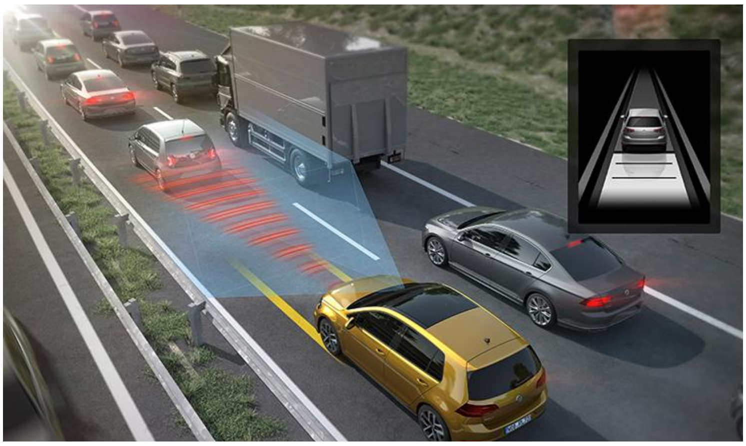


Figure 21 Traffic Jam Assist (Volkswagen)

3.8.2 ODD of the system

The TJA ODD is similar to that for ACC and Lane Centring, within a restricted speed range (typically < 60 km/h; Audi A5: < 65 km/h [ID5290]). Even though some manufacturers market TJA as a separate system, functionally it is the same system as ACC combined with Lane Centring.

3.8.3 Sensor input to the system

The same sensors are used as for ACC and Lane Centring. Radar or Lidar is used to estimate distance and speed differences to other vehicles, while camera-based lane detection is used to identify vehicles in the same lane and in adjoining lanes as well as to guide Lane Centring.

3.8.4 User input to the system

If a vehicle is equipped with TJA, it is activated together with ACC and Lane Centring.

3.8.5 *User output from the system*

User output is similar to that for ACC and Lane Centring. An example for the 2020 BMW 5 Series is given in Figure 22.

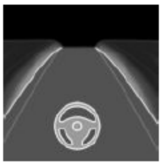
Symbol	Description
	Gray steering wheel symbol: The system is on standby.
	Green steering wheel symbol: The system is activated.
	Yellow steering wheel symbol and a signal sounds, if applica-ble: System interruption is imminent.
	Green steering wheel symbol and lane marking symbol: The system supports the driver in keeping the vehicle within the lane.
	Green steering wheel symbol, gray lane marking symbol: No lane marking detected, the vehicle follows the vehicle ahead. The limits of steering support when cornering may have been reached.

Figure 22. BMW 5 series symbols for TJA/ACC/LC [ID5288].

3.8.6 *Vehicle actuation by the system*

Similar to ACC combined with Lane Centring, TJA controls both longitudinal and lateral movement of the vehicle by actuating throttle, brake and/or steering.

3.9 Forward Collision Warning (FCW)

3.9.1 Purpose of the system

Forward Collision Warning warns the driver to take action in case a likely collision with an obstacle in front of the vehicle, be it another vehicle, cyclist or pedestrian, is detected. The system does not actuate the vehicle in order to avoid or mitigate the collision, but leaves taking action to the driver. It is part of a chain of vehicle systems meant to avoid or at least mitigate the impact of forward collisions (Figure 23).

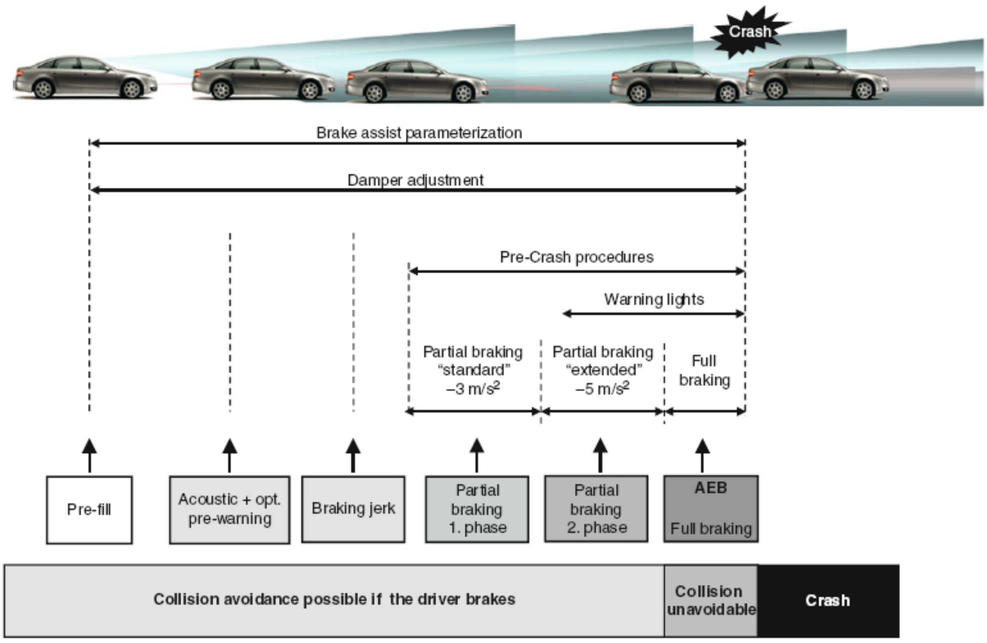


Figure 23. Forward collision warning/avoidance/mitigation chain in Audi A8 [ID5269]

Table 10. Forward Collision Warning systems in different car brands ([1] with Driving Assistance Package)

	BMW 5 series	Ford Focus	Mercedes-Benz S class	Renault Scenic	Tesla Model 3	Toyota Corolla
Brand name	Front collision mitigation	Pre-collision Assist	Active Brake Assist	Active Emergency Braking	Forward Collision Warning	Pre-Collision Warning
Obstacles that can be detected	NA	• Vehicles • Pedestrians NOT: animals	• Vehicles • Pedestrians	• Vehicles • Pedestrians	• Vehicles • Bicyclists • Motorcycles • Pedestrians	• Vehicles • Bicyclists • Pedestrians
Operational speed range	> 5 km/h	5-80 km/h for pedestrians, >5 km/h for vehicles	7-80 km/h for pedestrians, 7 – 200 km/h for stationary vehicles, 7 – 250 km/h for moving vehicles[1]	7-160 km/h for vehicles, 7-36 km/h for pedestrians	10 – 150 km/h	10 – 180 km/h for vehicles, 10 – 80 km/h for bicyclists and pedestrians

User settings	• Enable/disable • Warning timing (3 levels)	• Enable/disable • Warning timing (3 levels)	• Enable/disable • Warning timing (3 levels)	• Enable/disable	• Enable/disable • Warning timing (3 levels)	• Enable/disable • Warning timing (3 levels)
Default setting on engine on	Enabled	NA	Enabled	Enabled	Last user setting	Enabled

3.9.2 ODD of the system
FCW responds to obstacles (vehicles, cyclists, pedestrians) in front of the vehicle that either move more slowly in the same direction or are stationary. It may not respond adequately to obstacles moving towards the vehicle. It only operates when the vehicle is above a certain speed (see Table 10). Pedestrians may only be detected below a certain driving speed (for example 80 km/h [ID5284], [ID5362]). Manufacturers indicate that FCW may not detect obstacles in some conditions, such as bad weather (rain, snow, fog), bright light from the front, approaching an obstacle from another than head-on angle, obstacles with unusual shapes, and so on [ID5362], [ID5363]. Moreover, car manuals also warn that the system may sometimes warn about obstacles that are not directly in the vehicle’s path, but in adjacent lanes or at the roadside, especially on curvy roads [ID5362], [ID5363].

3.9.3 Sensor input to the system
Sensing of obstacles in front of the vehicle is based on radar sensors, lidar, camera, or a combination of these. Radar sensors are typically placed behind the vehicles front grille, while cameras are usually located behind the top centre part of the front windscreen.

3.9.4 User input to the system
The driver can enable/disable FCW in the car’s menu system; some cars also allow the user to set the system’s sensitivity of FCW (warning timing) in the car’s menu system [ID5362].

3.9.5 User output from the system
The system warns the driver visually and acoustically. In the 2018 Ford Focus, the colour of the distance indicator in the instrument cluster is determined by the detected gap time to the preceding vehicle (gray for gap times > 0.9s, yellow for gap times gap time between 0.6 and 0.9s and red for gap times < 0.6s [ID5284]). When an imminent collision is detected, a red rectangle with distance warning is displayed in the instrument cluster, accompanied by warning tones (Figure 24).

Figure 24. Forward Collision Warning in 2018 Ford Focus [ID5284].

In case of a Renault Scenic, the FCW can be given in 2 ways, dependent on the version of the car. In the first option, the warning light shown in Figure 25 is displayed in red on the instrument panel and a warning sound is given. In the other option, a symbol for vehicles and pedestrians is displayed on the instrument cluster (and on the Head Up Display, if present), as shown in Figure 26, accompanied by a warning beep to warn the driver of collision risk. When a risk of collision is detected at a vehicle speed lower than 45 km/h, the FCW is activated at the same time as the AEB [ID5363]. When FCW of a Renault Scenic is not available, a warning symbol lights up with the message: “Active Braking: Sensor Blind” or “Radar-camera: no visibility” [ID5363].

Figure 25 Warning symbol (option 1) for FCW Renault Scenic [ID5363]

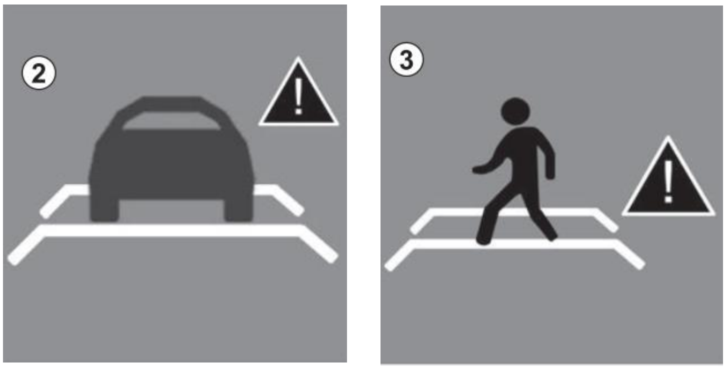


Figure 26 Warning symbol (option 2) for FCW for detected vehicles (left) or detected pedestrians (right) Renault Scenic [ID5363]

3.9.6 *Vehicle actuation by the system*

The FCW system by itself does not actuate the vehicle’s longitudinal or lateral speed control.

3.10 Autonomous Emergency Braking (AEB)

3.10.1 Purpose of the system

Like the Forward Collision Warning, the Autonomous Emergency Braking system aims to avoid or at least reduce the impact of collision with an obstacle in front of the vehicle. In contrast to FCW, AEB systems automatically engage the vehicle's braking system (Figure 27). AEB often includes Brake Assist, which enhances braking power when an obstacle in front of the vehicle is detected and the driver brakes hard [ID5362] [ID5363].

Figure 27. Mercedes-Benz 2020 S class AEB [ID5285].

Table 11. Autonomous Emergency Braking systems in different car brands ([1] with Driving Assistance Package)

	BMW 5 series	**Ford Focus**	**Mercedes-Benz S class**	**Renault Scenic**	**Tesla Model 3**	**Toyota Corolla**
Brand name		Pre-collision Assist	Active Brake Assist	Active Emergency Braking	Automatic Emergency Braking	Pre-Collision System
Obstacles that can be detected	NA	• Vehicles • Pedestrians	• Vehicles • Pedestrians	• Vehicles • Pedestrians	• Vehicles • Bicyclists • Motorcycles • Pedestrians	• Vehicles • Bicyclists • Pedestrians
Operational speed range	> 5 km/h	> 5 km/h (up to 80 km/h for pedestrian detection; up to 130 km/h	7-70 km/h for pedes-trians, 7 – 200 km/h for statio-nary vehicles, 7 – 250 km/h	7-160km/h for vehicles, 7-36km/h for pedestrians	10 – 150 km/h	10 – 180 km/h for vehicles, 10 – 80 km/h for bicyclists and pedestrians

		without ACC)	for moving vehicles[1]			
Precondition	Dynamic Stability Control must be on	NA	NA	Not available while cornering	NA	Vehicle Stability Control must be on
User override	• Acceleration • Steering input	NA	• Accelerator or kickdown • Release brake pedal	• Acceleration • Steering input	• Strong acceleration • Strong steering input • Press and release brakes	• Strong acceleration • Steering input
User settings	Enable/disable Warning timing (3 levels)	• Enable/ disable • Warning timing (3 levels)	• Enable/ disable Warning timing (3 levels)	• Enable/ disable	• Enable/ disable • Warning timing (3 levels)	• Enable/ disable • Warning timing (3 levels)
Default setting on engine on	Enabled	NA	Enabled	Enabled	Enabled	Enabled

3.10.2 ODD of the system

The speed range at which AEB systems function may depend on the availability of other ADAS. For instance, in the 2018 Ford Focus, AEB works up to 130 km/h in vehicles without ACC, but across the entire speed range in vehicles with ACC [ID5284]. In a Renault Scenic, braking is only triggered at vehicle speeds above 45km/h if the preceding vehicle is moving: not for stationary vehicles [ID5363]. The system cannot be activated while the gear lever is in neutral state, the parking brake is active or while cornering [ID5363]. Table 11 gives an overview of several ODD aspects of AEB for different brands.

3.10.3 Sensor input to the system

Like FCW, AEB is based on input from radar, lidar, camera or a combination of these.

3.10.4 User input to the system

The driver may set the sensitivity of AEB in the car's menu system [ID5362].
In a Renault Scenic, activating or deactivating the system can be done on the screen of the navigation system, if present or otherwise on the steering wheel at standstill [ID5363]. The system is reactivated every time the engine is switched on, which seems to be true for most brands (Table 11).

3.10.5 User output from the system

As the FCW usually is part of the AEB system, the same warnings as in FCW are displayed when AEB is activated. When AEB of a Renault Scenic is not available, the warning symbol as shown in Figure 25 lights up with the message: "Active Braking: Sensor Blind" or "Radar-camera: no visibility" [ID5363].

3.10.6 Vehicle actuation by the system

The AEB system engages the vehicle's brakes in order to reduce its longitudinal speed. In a Tesla model 3, the system releases the brakes once vehicle speed has been reduced by 50 km/h (for initial speeds above 56 km/h [ID5310]. In a Renault Scenic and Toyota Corolla, the brake force is increased if the driver depresses the brake itself but there is still a risk of collision detected by the system [ID5363], [ID5362].

3.11 Lane Change Assist (LCA)

3.11.1 Purpose of the system

A lane change assistant system supports the driver when changing lanes on multilane highways [ID5288]. A steering torque is applied to the steering wheel when the driver uses the turn signal indicator [ID5289]. Thus, in contrast to Blind Spot Warning systems, which only warn the user of vehicles in the adjacent lane, LCA actively supports lane changes by steering the vehicle into the adjacent lane. Lane changes are triggered by the user by using the turn signal.

3.11.2 ODD

Lane change systems are available in multiple higher segment cars. The ODD description in this section is based on the owner manuals of a BMW 5 Series [ID5288], Mercedes C-Class [ID5289], Mercedes-Benz S-Class [ID5285] and Tesla model 3 [ID5310].

Table 12. Lane Change Assist characteristics

	BMW 5 Series	**Mercedes-Benz C-Class**	**Mercedes-Benz S-Class**	**Tesla model 3**
Lower speed range	70km/h	80km/h	50 km/h	45 km/h
Upper speed range	180km/h	180km/h	180 km/h	150 km/h
Other system activation required	Blind spot collision warning and steering intervention	Active Steering Assist	Active Steering Assist	Autosteer

Manufacturers suggest to use Lane Change Assistance in the following environments [ID5288]:

- Driving on a road without pedestrians or cyclists and with physical barriers to oncoming traffic, such as crash barriers
- Outside city limits

According to the manual, it is recommended not to use the system:

- In construction areas
- In rescue lanes
- Driving in narrow lanes

The system does not work when the lane markings cannot be detected reliably and when recognition of other vehicles is poor. In wet conditions, snowfall, slush, fog or glare as well as insufficient lighting conditions or light shining into the camera, the system may not function.

3.11.3 Sensor input to the system
Lane change assist uses the same sensors as Blind Spot Warning (rear radar) and Lane Keeping / Lane Centring assistance systems (forward camera).

3.11.4 User input to the system
In order to activate the lane change assistant system, the system must be turned on and the turn indicator activated in the direction the user wishes to change lanes. When no vehicle is detected in the adjacent lane, the lane change is started. The lane change assistant can be activated or deactivated via the multimedia system. [ID5289]. Both Mercedes and BMW do not offer different settings for characteristics of the applied torque. The lane change assistance can be cancelled by steering in the opposite direction or by braking.

3.11.5 User output from the system

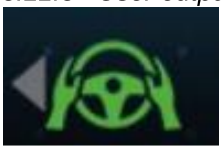


Figure 28 In a Mercedes C-Class, the arrow indicates lane change assistance to the left [ID5289]

When a lane change is initiated by the driver by using the turn signal indicator, a green arrow next to the steering wheel symbol (which is also green) lights up. When a lane change is not immediately possible, the arrow turns grey as shown in Figure 28. When the lane change assistance starts, the turn signal indicator is automatically activated simultaneously. In the instrument cluster, a schematic of the lane change is shown during the actual lane change. If the lane change is not possible, the grey arrow fades away after a few seconds and a cancellation message is shown. A new lane change should be initiated by the driver again [ID5289].

3.11.6 Vehicle actuation by the system
After the turn indicator has been activated by the driver, the lane change assistant system applies a steering torque in the chosen direction [ID5288]. If ACC is active and current speed is below ACC target speed, it may also accelerate the car.

3.12 Blind Spot Warning (BSW)

Blind Spot Warning is designed to detect vehicles in the blind spots during driving. However, the coverage zone of the function might not be limited to the blind spot. Some functions described below have a greater coverage zone, such as coverage of the rear zone in adjacent lanes. In this section the functionality of detecting vehicles in the blind spot and adjacent lanes is covered. Different brands have different names for this functionality. Some of those are listed in Table 13.

Table 13. Blind Spot Warning system names and speed range per brand

	Audi A5	Mercedes-Benz C-Class	BMW 3/5 Serie	Ford Focus	Renault Scenic	Tesla model 3	Toyota Corolla
Brand name	Side assist	Active blind spot assist	Blind spot collision warning	Blind spot information system	Blind Spot Warning	Blind Spot Collision Warning Chime	Blind Spot Monitor
Lower speed range	15 km/h	30 km/h	Country specific	10 km/h	30 km/h	12 km/h	16 km/h
Upper speed range	NA	200 km/h	155km/h	NA	140 km/h	140 km/h	NA

3.12.1 Purpose of the system

Blind Spot Warning warns the driver when a vehicle is driving in the blind spot and when vehicles are approaching in the adjacent lanes. It helps the driver to monitor the environment around the vehicle which is especially important when a lane change is (about to be) initiated.

3.12.2 ODD

The lower speed threshold from Blind Spot Warning assistance systems are quite low. This means Blind Spot Warning can be used on highways, regional roads and urban areas [ID5270]. The specific lower and upper speed values for some vehicles (if available) are shown in Table 13.
In some situations, the blind spot indicator may turn on when there is no vehicle located in the adjacent lane, for example when:

- The lane lines are too narrow or too wide
- When driving on the edge of you lane
- When driving through a curve
- When detecting other objects such as guardrails
- When cargo protrudes

In poor weather conditions, the Blind Spot Warning function is limited. These weather conditions conclude fog, wet conditions or snowfall. The system may not function properly when [ID5289]:

- A vehicle is approaching at speed much faster than the ego vehicle.
- There is a narrow vehicle, such as bicycle or motorbike in the adjacent lane
- Vehicles in the adjacent lane do not drive in the middle
- Driving close to crash barriers
- Vehicles overtake too closely on the side, placing them in the blind spot area of the blind spot warning sensors.
- Steering, braking or accelerating significantly.
- A driving safety system intervenes, for example ESP or Active Brake Assist.
- A loss of tire pressure or a faulty tire is detected.

- ESP is deactivated.

Blindspot is not active when reverse gear is engaged.

3.12.3 Sensor input to the system

Blind Spot Warning in commercially available vehicles is often based on radar. The radar is usually positioned in the sides of the rear bumper, as shown by the red squares in Figure 29.

Figure 29 Position of the BSW radar sensors (in red) [ID5290].

Vehicles to the left and right of the car are detected by an expanded side lobe of the radar sensors. Therefore, also vehicles in the blind spot can be detected [ID5270]. The coverage zone is schematically shown in Figure 30.

The detection distance differs greatly between vehicle brands, as shown in Table 14. Vehicles with a short detection range cannot detect approaching vehicles with a high speed within sufficient time. Therefore systems on these vehicles are less suited to be used on highways [ID5270].

Table 14 Detection range from Blind Spot Warning sensors.

	Audi A5	**Mercedes C Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**
Detection range from rear of the car	70-100m	40m	NA	<48km/h: 4m >48km/h: 18m	NA	NA	3 – 60 m
Detection range next to the vehicle	NA	3m, from 50cm next to the vehicle	NA	3m	NA	NA	0.5 m

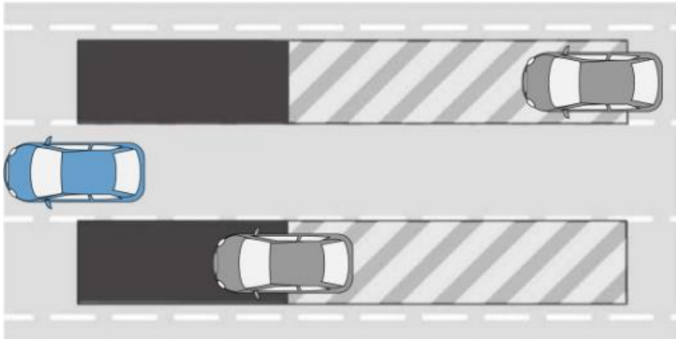


Figure 30. Coverage zone of Blind Spot Warning sensors. Dark grey: blind spot area; dashed light grey: approach zone [ID5284]

3.12.4 User input to the system

For all brands, the Blind Spot Warning system can be turned off (see Table 15). In the BMW multiple settings of warning time and steering wheel vibration intensity are available [ID5287]. Likewise, Toyota's system allows configuration of the sensitivity by changing alert timing (early, late, intermediate, or only when a vehicle is detected in the blind spot zone [ID5362]). In Audi and Toyota the brightness of the BSD warning light can be adjusted [ID5290], [ID5362]. In the Audi, the light also adjusts to the brightness of surroundings [ID5290].

Table 15 User settings for Blind Spot Warning system

	Audi A5	**Mercedes C Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**
Switch on	Via the infotainment system	Via the multimedia system	Via iDrive, after switching on all intelligent safety systems	Via the information display	Via multifunction screen or steering wheel buttons	Via car menu	Via multi-information system
Settings	Brightness of the light	NA	Warning time and steering wheel vibration intensity	NA	NA	NA	Brightness of blind spot indicator in mirror; alert timing

3.12.5 User output from the system

When a vehicle is detected in the blind spot, this information is provided to driver by lighting up a warning light in or next to the mirrors. Ford, Mercedes Benz and BMW use a lamp on the outer edge of the mirror. Audi has located the light in the shell of the mirror on the inside, as shown in Figure 31. When the turn indicator is activated while a vehicle in the blind spot is detected, the attention of the driver is directed to the mirrors. Some systems use flashing lights and others a change in colour. An overview of some systems is shown in Table 16.

Figure 31 Blind spot information system light in mirror (Ford [ID5270]) and next to the mirror (Audi A5 [ID5290]).

Table 16. Symbols per brand for critical situation (turn indicator active and vehicle in blind spot), Active (Vehicle in blind spot, but no indicator active), system switched on and whether the status of the system is shown on the display.

	Audi A5	**Mercedes C Class**	**BMW 3/5 serie**	**Ford Focus**	**Renault Scenic**	**Tesla model 3**	**Toyota Corolla**
Vehicle detected, indicator on	Display light flashing	Light lights up red	Light flashing	Light flashing	Warning light flashes	NA	Warning light flashing
Vehicle detected, indicator off	Display light on but dim	Lights light up yellow	Light lights up dimmed	Light lights up	Warning light illuminated	NA	Warning light illuminated
System active, no vehicle detected	Briefly light flashing	NA	Briefly flashing light	Light flashes twice	Warning light not illuminated	NA	Warning light not illuminated
Status on display	NA	Yes	NA	Yes	NA	NA	Yes

When the warning lights indicate a vehicle in the blind spot, the driver is advised to look in the mirror and the blind spot. In the Toyota Corolla the same mirror warning lights are used for Rear Crossing Traffic Alert [ID5362]. The faster a vehicle approaches, the sooner the display in the outside mirror will turn on. The display will not turn on if you quickly pass a vehicle with a speed difference greater than 15km/h [ID5290] [ID5289]. In some vehicles, additional warning channels are used to warn the driver of a vehicle in the blind spot. When the indicator switch is activated in a BMW, while a vehicle is detected in the blind spot, the steering wheel vibrates briefly in addition to the flashing light in the mirror [ID5287]. If the Blind Spot Warning System of a Mercedes detects a vehicle in the blind spot and the driver activates the turning indicator, a warning tone is activated once [ID5289]. The Tesla 3 has the possibility to produce a warning chime when an obstacle is detected in the blind spot and a collision is possible [ID5310].

3.12.6 Vehicle actuation by the system

Next to a warning function, the Blind Spot Warning system from Mercedes, called Active Blind Spot Assist, applies course-correcting braking in the case a vehicle is detected in the blind spot and the turning indicator is switched on by the driver. So the system actively supports you to prevent a collision [ID5289]. Tesla's Emergency Lane Departure Avoidance applies corrective steering when a vehicle is detected in the adjacent lane and the turn indicator is activated by the driver [ID5310].

3.13 Autonomous/Assisted Emergency Steering (AES)

Autonomous or Assisted Emergency Steering is designed to support the driver in the steering task when full braking is not enough to prevent a collision with an object in front. In this case a steering manoeuvre is needed to avoid the object. AES has multiple names for different brands, as shown in Table 17.

Table 17. Names of different brands for AES functionality.

	Audi A5	**Mercedes C Class**	**BMW 3/5 series**	**Ford Focus**	**Toyota Corolla**
Brand name	Evasive steering support	Evasive steering assist	Evasion Assist	Evasive steering assist	NA

There are three kinds of emergency steering (or evasive emergency assistance, as it is also called):

- Driver-initiated evasive assistance
- Corrective evasion assistance
- Automatic evasion assistance

The difference between the three is that Driver-initiated evasive assistance is only activated when the driver initiates a steering manoeuvre (Assisted Emergency Steering). When no steering torque is applied to the steering wheel by the driver, the evasion assistance system will not perform the evasive manoeuvre on its own. Corrective evasion assistance system can perform the evasive manoeuvre on its own, but can only prevent collisions where a small steering torque is required. Automatic evasion assistance can also perform the evasive manoeuvre on its own and is not limited in the amount of torque it can use to prevent a collision (Autonomous Emergency Steering) [ID5271]. The kind of emergency steering integrated in a vehicle, is only evident from the vehicles' user manuals.

Dang et al. have presented a comparison between the braking distance and steering distance at different velocities of the ego vehicle [ID5271]. Figure 32 shows both distances when a lateral offset of 1 m at the inflection point and 2 m at the end of the manoeuvre is needed. The maximum braking deceleration is assumed to be 10 m/s^2 and the maximum lateral acceleration is limited to 6 m/s^2. When driving at a higher speed than 35 km/h, an evasive manoeuvre could already be more effective than braking at small distances to the object in the front.

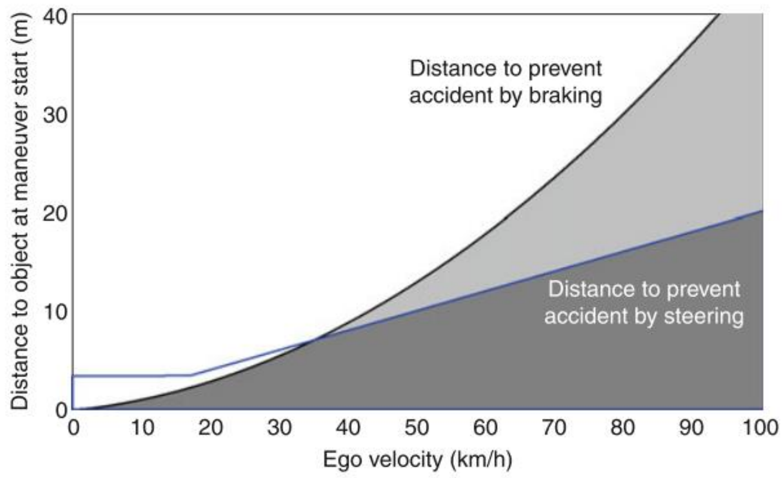


Figure 32 Braking distance and steering distance for different velocities [ID5271].

3.13.1 Purpose of the system

The purpose of the AES system is to support the driver in an evasive manoeuvre to prevent a collision with an object in front. In some vehicles, this manoeuvre needs to be initiated by the driver (Assisted Emergency Steering [ID5290], [ID5288] [ID5284]), while other vehicles are capable of initiating the steering automatically [ID5285], [ID5310].

3.13.2 ODD

AES is only available at a certain speed range. As this differs per brand, an overview of some brands is given in Table 18.

Table 18. Lower and upper speed limits of AES

	Audi A5	**Mercedes C-Class**	**BMW 3/5 serie**	**Ford Focus**
Lower speed limit	30km/h	20km/h	40km/h	5km/h
Upper speed limit	150km/h	70km/h	250km/h	Pedestrian detection until 80 km/h

AES may not function in some conditions [ID5290] [ID5289] [ID5287]:

- In snow, rain, fog, heavy spray, if there is glare, in direct sunlight or in greatly varying ambient light.
- If the radar is impaired due to interference with other radar sensors.
- In complex traffic situations where objects cannot always be clearly identified.
- If pedestrians or vehicles move quickly into the sensor detection range.
- If pedestrians are hidden by other objects.
- If the typical outline of a pedestrian cannot be distinguished from the background

- In tight curves
- If the driving stability control systems are limited or deactivated, for instance DSC OFF.
- If the camera or the windshield is dirty
- During calibration of the camera immediately after vehicle delivery.

The sensors might not detect [ID5290] [ID5289] [ID5287]:

- Slow moving vehicles when you approach them at high speed.
- Vehicles that suddenly swerve in front of you.
- Sharply decelerating vehicles.
- Vehicles with an unusual rear appearance.
- Two-wheeled vehicles in front of the vehicle.

All of these restrictions and limitations are only evident from the vehicles' user manuals.

3.13.3 Sensor input to the system

Since emergency steering requires the change of vehicles trajectory, the vehicle's environment must be detected reliably. This includes objects in the front and relevant sides but also lane markings, curves etc. [ID5271].

Dang et al. have made an overview of different sensors that could be used for evasive manoeuvre assistance [ID5271]:

- Radar: long radar sensors can achieve coverage of large areas for highway and urban driving. However radar is not preferred for detection of static objects or objects with a small cross section, such as pedestrians, motorcycles or bicycles.
- Lidar: Lidar has a wide range of about 70 m around the vehicle and a precision within centimetres. They perform well in object detection, but they are often too expensive to be used in commercially available vehicles.
- Camera: object detection based on stereo cameras and classification are widely used in commercially available vehicles. Infrared cameras are not limited to the visible range and therefore can be used in night time.

To maximize AES availability and reliability, on commercially available vehicles often a combination of camera located in the windshield and radars located in the bumper are used for detection of vehicles around the ego vehicle (Figure 33). Data from these sensors is combined in sensor fusion [ID5290], [ID5288].

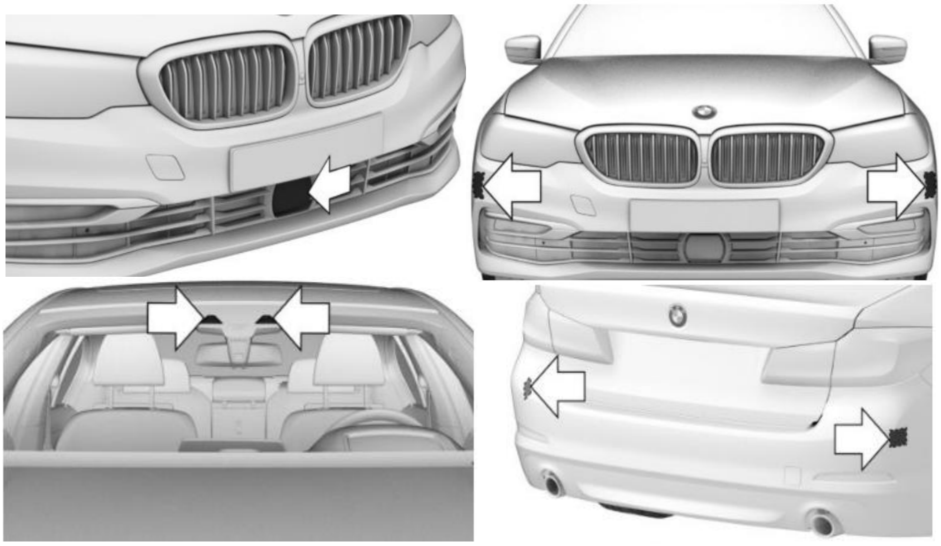


Figure 33 Sensors in the front bumper, rear bumper and windshield used for evasive manoeuvres [ID5288]

3.13.4 User input to the system

For Assisted Emergency Steering, the driver needs to initiate the steering manoeuvre. When the driver initiates a steering manoeuvre, the AES can support this manoeuvre by applying extra steering torque to help the driver steer around the vehicle in front. For Autonomous Emergency Steering, no driver input is needed. An evasive steering manoeuvre can always be prevented or cancelled by actively steering to the other side. The evasive manoeuvre assistance can be switched off via the multimedia system. However, manufacturers recommend not to do this. The system will be switched on automatically every time the engine is switched on. Most systems can only be activated when emergency braking is also active.

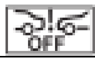
3.13.5 User output from the system

At the moment of intervention, the driver will notice the torque on the steering wheel, so he/she can overrule if needed. During the manoeuvre, it is very important that the driver knows the system supports the steering task. Therefore, the evasive manoeuvre assistance is often combined with visual feedback to the driver [ID5271]. Below, different signs for an evasive manoeuvre assist are shown in Table 19. Both in BMW 5 Serie and Ford Focus models, the driver is informed to initiate an evasive manoeuvre which is then supported by the system. Audi and Mercedes only show an evasive manoeuvre symbol when the system is turned off.

Table 19. Symbols for AES when active and when the system is switched off

<table>
<tr><th>Brand</th><th>AES symbol</th></tr>
<tr><td>Audi A5</td><td>When active:


When system is switched off:
</td></tr>
<tr><td>Mercedes S Class</td><td>When active:

When system is switched off:


</td></tr>
<tr><td>BMW 5 Serie</td><td>When active:
</td></tr>
<tr><td>Ford Focus</td><td>When active:
</td></tr>
</table>

3.13.6 Vehicle actuation by the system

By supporting the driver with additional steering torque to the steering wheel during an evasive manoeuvre (Assisted Emergency Steering) or by automatic steering (Autonomous Emergency Steering), the systems aims to prevent a collision. Evasive trajectories often use clothoid or sigmoid functions to guide steering behaviour. As an invasive manoeuvre primarily serves safety, not comfort, the most important goal is to reach an lateral offset of half the vehicle width plus halve the object width, in order to prevent a collision. If the environment allows, a larger lateral offset might be preferred. This is schematically shown in Figure 34 [ID5271]

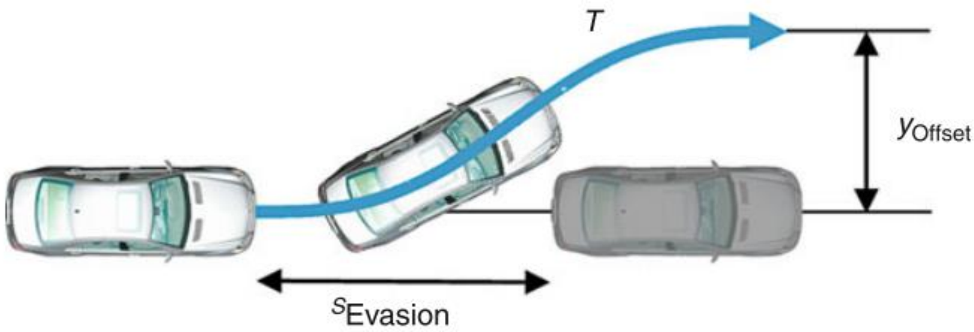


Figure 34 Steering distance and lateral offset during evasive manoeuvre [ID5271].

In theory there are several possibilities to influence the lateral movement of the vehicle [ID5271], such as:

- Steering torque actuator: adds additional torque to the torque the driver applies to the steering wheel.
- Steering angle actuator: adds additional steering angle to the angle the driver applies to the steering wheel.
- Rear wheel steering: the rear wheels can assist the driver by the lateral movement.
- Single-sided braking: adds an additional yaw rate to the vehicle by applying the brakes at one side of the vehicle

Due to the fact that the purpose of the AES is to assist the driver in the steering action, it's most intuitive to use the steer torque actuator. This additional torque is directly fed back to the driver as he is also applying torque to the steering wheel. This way of assisting the driver is used in most commercially available vehicles [ID5271].

3.14 Turn Assist (TA)

Different names are used to define the Turn Assist functionality for different brands, as shown in Table 20. Not many brands have incorporated this functionality in their cars at the moment of writing. However, Turn Assist is becoming increasingly common in trucks, in particular for detecting cyclists and pedestrians in the blind spot on right-hand turns (in left-hand drive vehicles).

Table 20 Names for turn assist functionality for different brands

	Audi A5/A8	**Mercedes C-Class**
Brand name	Turn assist	Cornering function

3.14.1 Purpose of the system

The purpose of a turn assist is to prevent a collision with traffic when turning either left or right. For turning left (in a left-hand drive vehicle), collisions with oncoming traffic are prevented by a braking intervention [ID5289] [ID5290]. For turning right in a right-hand drive vehicle (and left in a left-hand drive vehicle), Turn Assist monitors the blind spot to the right (or left) of the vehicle, especially for cyclists and pedestrians. This latter version is especially relevant for trucks, which have a large blind spot on the non-driving side. Turn Assist is aimed at the scenario where the vehicle is turning from standstill, for example at a traffic light.

3.14.2 ODD

The turn assist can only prevent collisions when the ego vehicle is driving at a slow speed. For instance, for the Audi A5, the system only works for speeds up to 10 km/h [ID5290], while it is limited to 15 km/h in the Mercedes-Benz C-Class [ID5289]. The system is not able to prevent a collision in every situation. The system may not function correctly in the following situations [ID5289] [ID5290]:

- In snow, rain, fog, heavy spray, if there is glare, in direct sunlight or in greatly varying ambient light.
- If the sensors are dirty, fogged up, damaged or covered.
- In complex traffic situations where objects cannot always be clearly identified.
- In unclear traffic situations, such as turning lanes, exit ramps, construction zones, rises or dips that obstruct visibility and intersections.
- If the sensors are impaired due to interference from other radar sources, for example strong radar reflections in parking garages.
- If a loss of tire pressure or a faulty tire has been detected and displayed.
- If pedestrians or vehicles move quickly into the sensor detection range.
- If the typical outline of a pedestrian cannot be distinguished from the background.
- If the ESC is limited or switched off

The Turn Assist from Mercedes-Benz can detect pedestrians, when they are moving slowly and they are distinguished from the surroundings correctly. The Turn Assist from Audi does not recognize pedestrians, animals or other objects that are not detected as vehicles [ID5289], [ID5290].

3.14.3 Sensor input to the system

The turn assist makes use of the same sensors as the Autonomous/Assisted Emergency Steering system [ID5290].

3.14.4 User input to the system

The braking intervention of the system can be interrupted by acceleration noticeable or steering. The system can be deactivated in the multimedia system. The same symbol as shown for switched off AES will be shown [ID5290], [ID5289].

3.14.5 User output from the system

The feedback to the driver from the turn assist functions is the same as for Assisted Emergency Steering (AES).

3.14.6 Vehicle actuation by the system

When turning across an oncoming lane and a vehicle is detected in that oncoming lane, the vehicle brakes automatically before leaving the lane the ego vehicle was driving in [ID5289]. By this braking intervention the ego vehicle stays in its own lane and a possible collision is prevented [ID5290]. For right-hand turns, the vehicle brakes automatically when a pedestrian, cyclist or vehicle is detected in the right-hand blind spot.

3.15 Driver State Monitoring (DSM)

3.15.1 Purpose of the system

DSM systems can have two possible purposes. The first, more ‘traditional’, one is drowsiness detection. This kind of system aims to sense signs of sleepiness in the driver, either through direct monitoring of the driver (for example eye blinks or eye closure) or of the driving behaviour and warn the driver. Driver drowsiness detection systems often consist of three parts:

- A detection system (an algorithm that analyses data from sensors and detects any onset of sleep)
- A warning or alarm that alerts the driver and conveys the information to the driver through appropriate medium
- Other non-technological countermeasures that help prevent the onset of sleep [ID5272].

Some systems only warn in the case driver drowsiness is suspected, while others also show an estimate of the driver’s alertness level (Figure 35).
The second variety of DSM system serves to detect driver availability, especially when ACC, LC or ADA are active. Most commonly, steering input by the driver is detected, either by measuring torque input by the driver or by measuring grip pressure on the steering wheel. Alternatively, eye/face tracking is used.

Figure 35. Mercedes-Benz Attention Assist message [ID5285].

3.15.2 ODD of the system

How and under which conditions the system functions is generally poorly documented. Some manufacturers indicate that driver drowsiness detection only works in a certain speed range (for example 60 – 200 km/h [ID5285]; over 65 km/h [ID5284] and over 70 km/h [ID5288]), see Table 21. Moreover, a minimum trip duration (time since ignition on) is often necessary (for example 30 min [ID5285]). Manufacturers indicate that the system may work poorly under difficult driving conditions (for example bad road conditions, strong side wind; [ID5285]). In addition, since steering behaviour is often analysed in order to evaluate driver drowsiness, the system may not work together with automatic Lane Centring [ID5285] or poorly visible road lines [ID5284]. However, in other cases, drowsiness monitoring is part of the lane centring system (for example sway warning in the Toyota Corolla, which is part of Toyota's Lane Tracing Assist system [ID5362]).

Table 21. Driver drowsiness detection system characteristics

	BMW 5 Series	**Ford Focus**	**Mercedes-Benz S Class**	**Renault Scenic**	**Toyota Corolla**
Brand name	NA	Driver Alert	NA	Fatigue Detection Warning	Sway Warning
Speed range	> 70 km/h	> 65 km/h	60 – 200 km/h	> 60 km/h	> 50 km/h
Minimum trip duration	NA	NA	30 min	NA	NA

3.15.3 Sensor input to the system
The sensors used for drowsiness detection are poorly described. Although the scientific literature mentions several potential measures for drowsiness, such as those based on EEG recordings, eye movement measurements or face tracking [ID146], [ID5272], it is often unclear which sensors drowsiness detection systems on the market use. Largely, estimated driver drowsiness is based on time of day and time since engine on. On top of that, driving behaviour distilled from user input via vehicle controls, such as pedals and steering wheel may be used to infer driver drowsiness. Few cars come equipped with a driver camera; if present this may be used to estimate the driver state as well, using eye closure, blinking rate and head posture.

3.15.4 User input to the system
In some cars, the drowsiness detection system is activated automatically when the ignition is turned on [ID5285], while in others the system can be turned on or off in the car's menu system [ID5284]. Mercedes-Benz's S class allows the user to set the sensitivity of the system by choosing one out of two settings in the menu system [ID5285]. This is also true for the system in the BMW 2020 5 series [ID5288].

3.15.5 User output from the system
In case the system estimates that driver drowsiness is likely, it issues a warning to the driver. In most cases, this is a visual warning, either by displaying a coffee cup symbol or a warning text in the instrument cluster. In some cars this is accompanied by an auditory warning signal. The drowsiness warnings may come in two stages: first a temporary warning when drowsiness is first detected and then a permanent warning if higher levels of drowsiness are detected [ID5284].

3.15.6 Vehicle actuation by the system
The driver drowsiness detection system does not change the vehicle's longitudinal or lateral control. However, when DSM is used to determine driver availability for ACC and LC, these systems may induce a controlled emergency manoeuvre when the driver is found to be unavailable (for example when no hands on the steering wheel are detected). In this case, the car is brought to a controlled stop in its lane (see Emergency Assist).

3.16 Emergency Assist (EA)

3.16.1 Purpose of the system
Emergency Assist is a system that recognizes when the driver is unable to operate the vehicle, warns the driver to take over control and in the case of prolonged driver inactivity automatically slows down the vehicle to stand still. In addition, it may inform emergency services. In modern cars, it is part of the ACC and/or lane centring systems.

3.16.2 ODD of the system
The system only works when ACC and/or lane centring is active.

3.16.3 Sensor input to the system
Most commonly, Emergency Assist is triggered by prolonged steering wheel inactivity, either measured by pressure sensors in the steering wheel or torque sensors in the steering column. The duration of inactivity necessary to trigger the system is often not described and may differ from brand to brand.

3.16.4 User input to the system
The driver cannot change settings of the system. Activation of the Emergency Assist can be overridden by user input to the steering wheel or vehicle pedals.

3.16.5 User output from the system
When the system detects prolonged driver inactivity, it warns the driver both visually, by means of an warning icon in the instrument cluster, and acoustically.

3.16.6 Vehicle actuation by the system
Emergency Assist reduces vehicle speed until it stops moving completely, while maintaining its position in the lane when Lane Centring is active. The 2020 Mercedes-Benz S class activates hazard warning lights at speeds below 60 km/h and secures the vehicle with the electric parking brake. In addition, it places an emergency call to the Mercedes-Benz emergency call centre if possible [ID5285]. The 2018 Ford Focus stops the vehicle when prolonged steering inactivity is detected [ID5284]. It only places an emergency call when airbags have been deployed or the fuel pump is shut off in case of an accident [ID5284].

3.17 Active Driving Assistance (ADA)

Active Driving Assistance is a combination of other systems that assists in both longitudinal and lateral vehicle control. Many brands have their own name for this function, such as Autopilot (Tesla), Pro Pilot (Nissan / Infiniti), Pilot Assist (Volvo), Highway Assist (Maserati), Active Drive Assist (Ford) and Driver Assistant Pro (BMW). General Motors has Super Cruise, which differs from Active Driving Assistance in that it is the only system that allows hands-free driving on selected highways that meet certain infrastructure requirements (USA only). At a minimum, ADA includes ACC, LC and DSM, supporting the driver in both longitudinal and lateral vehicle control while continuously checking the availability of the driver. Depending on the availability of other ADAS in the vehicle, it can also include AEB, BSW, LCA, LKA and ISA. Because ADA does not add to the functionality of these separate systems, if will not be further described separately.

4 Conclusions

Chapter 1 gives an overview of the ADAS selected for this review. In researching and describing these systems, we came to several conclusions.

First of all, for most systems there is surprisingly little information available on how they actually work and under which conditions they may be expected to work. Car manufacturers' websites often give only very global information on the functionality of various ADAS. Car manuals often give more warnings about what not to do with a system than actual information on how it works. There are also large differences between the quality and completeness of system descriptions in manuals from different brands. Scientific literature is often focused on testing new concepts and testing drivers' responses to existing systems, but do not provide good descriptions of existing ADAS. Scientific handbooks are a useful source, but are typically outdated and give little information about specific systems on the market. ISO standards provide useful criteria for how systems should be designed, but do not necessarily describe how systems currently on the market actually work.

Second, even though a typical vehicle manual or manufacturer's website easily lists dozens of ADAS for a modern car, their naming and distinctions often seem more motivated by marketing than by functionality. Several ADAS become harder and harder to distinguish from each other. In most modern cars, Lane Centring can only be used in combination with Adaptive Cruise Control, blurring the distinction between the two. Blind Spot Warning may be sold as a stand-alone feature, but may also be integrated in Lane Change Assist. Moreover, the same functionality may be used in Turn Assist, supporting the driver in safely making left- or right-hand turns. Traffic Jam Assist is nothing more than Adaptive Cruise Control and Lane Centring at low speeds. Autonomous Emergency Braking also incorporates Forward Collision Warning. More generally, where historically some systems were aimed at informing the driver, others at warning and again others at actively assisting the driver, most modern system incorporate all three functions into the same system. But then again, similar functionality is sometimes divided into multiple systems, even with separate buttons, such as Lane Keeping (activated once the vehicle is close to inadvertently crossing into another lane) and Lane Centring (lane following in the middle of the lane). Thus, it may be more useful to focus on the underlying vehicle functions (acceleration, deceleration, steering) and how various ADAS affect the driver's role in controlling these functions, rather than on the systems as defined by the manufacturers.

Third, it proves to be quite challenging to produce a comprehensive overview of even this limited selection of ADAS within a reasonable amount of time. Not only do ADAS rapidly evolve in the course of time, different manufacturers use widely different names for the same system and sometimes even the same name for different systems. Moreover, the sensors used for the various ADAS also evolve and may be different for systems from different manufacturers. Not only does this state of affairs make it challenging for researchers to understand and evaluate the user aspects of these systems, it also suggests that the individual user is left standing in the dark when trying to understand their limits and pitfalls.

5 References

[ID14] Dutch Safety Board (2019). Who is in control? Road safety and automation in road traffic (report). The Hague, The Netherlands: Dutch Safety Board.

[ID29] Vlakveld, W. P. (2019). Veiligheidseffecten van rijtaakondersteunende systemen. Bijlage bij het convenant van de ‘ADAS alliantie’ (R-2019-14). Den Haag: SWOV.

[ID146] Saini, V. & Saini, R. (2014). Driver Drowsiness Detection System and Techniques: A Review. (IJCSIT) International Journal of Computer Science and Information Technologies 5 (3), 4245-4249.

[ID182] Lai, F. & Carsten, O. (2010). What benefit does Intelligent Speed Adaptation deliver?-A close examination of its effect on vehicle speeds. Accident Analysis and Prevention 48 (2012), 4–9.

[ID1190] Knoop, V.L., Wang, M., Wilmink, I., Hoedemaeker, D.M., Maaskant, M., Van der Meer, E.-J. (2019). Platoon of SAE Level-2 Automated Vehicles on Public Roads: Setup, Traffic Interactions, and Stability. Transportation Research Record, 2673 (9), 311--322.

[ID5259] European Road Safety Observatory ERSO (2016). Advanced Driver Assistance Systems (report).

[ID5265] Bu, F., Chan, C-Y. (2012), Adaptive and Cooperative Cruise Control. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 191-208. London: Springer.

[ID5266] Blum, J.J., Eskandarian, A., Arhin, S.A. (2012). Intelligent Speed Adaptation (ISA). In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 581-602. London: Springer.

[ID5267] Winner, H. (2012). Adaptive Cruise Control. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 613-656. London: Springer.

[ID5269] Gayko, J.E. (2012). Lane Departure and Lane Keeping. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 689-708. London: Springer.

[ID5270] Bartels, A., Meinecke, M.-M., Steinmeyer, S. (2012). Lane Change Assistance. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 729-758. London: Springer.

[ID5271] Dang, T., Desens, J., Franke, U., Gavrila, D., Schaefers, L., Ziegler, W. (2012). Steering and Evasion Assist. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 759-784. London: Springer.

[ID5272] Sayed, R.A., Eskandarian, A., Mortazavi, A. (2012). Drowsy and Fatigued Driver Warning, Counter Measures, and Assistance. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 975-996. London: Springer.

[ID5273] ISO (2018). Intelligent transport systems - Adaptive Cruise Control systems - Performance requirements and test procedures (ISO 15622:2018,IDT). Geneva, Switzerland: ISO.

[ID5275] ISO (2014). Intelligent transport systems — Lane keeping assistance systems (LKAS) — Performance requirements and test procedures (ISO 11270:2014). Geneva, Switzerland: ISO.

[ID5283] ISO 7000:2014 Graphical symbols for use on equipment -- Registered symbols.

[ID5284] Ford Focus 2018 User Manual.

[ID5285] Mercedes-Benz 2020 S class operator's manual.

[ID5286] Wang, Z., Wu, G., Bartyh, M.J. (2018). A review on Cooperative Adaptive Cruise Control (CACC) systems: Architectures, controls, and applications. 21st International Conference on Intelligent Transportation Systems (ITSC), 2884-2891.

[ID5287] Owner's manual BMW 3 serie.

[ID5288] Owner's manual BMW 5 serie.

[ID5289] Owner's manual Mercedes C-Class.

[ID5290] Owner's manual Audi A5.

[ID5304] European Commission (2020). Intelligent Speed Adaptation (ISA).

[ID5305] ACEA (2017). Platooning roadmap.

[ID5307] Highway Loss Data Institute (2018). Compendium of HLDI collision avoidance research (report).

[ID5308] Kroon, E.C.M., Martens, M.H., Brookhuis, K.A., De Waard, D., Stuiver, A, Westerhuis, F., de Angelis, M., Hagenzieker, M.P., Alferdinck, J.W.A.M., Harms, I.M., Hof, T. (2019). Human factor guidelines for the design of safe in-car traffic information services (3rd edition). Groningen: University of Groningen.

[ID5309] Czarnecki, K. (2018). Operational Design Domain for Automated Driving Systems - Taxonomy of Basic Terms. Technical Report, University of Waterloo, Canada.

[ID5310] Tesla (2020). Model 3 Owner's Manual.

[ID5351] Hogema, J., Souman, J., Stuiver, A., van Weperen, M., Westerhuis, F., de Waard, D. & Hoedemaeker, M. (2020). Repository Human Factors Guidelines driver assistance systems and automated vehicle systems (Repository in an MS Excel file.). Helmond: TNO 2020 R12163

[ID5357] Westerhuis, F., Stuiver, A., de Waard, D., Hogema, J., Souman, J., van Weperen, M. & Hoedemaeker, M. (2020). Human Factors Guidelines report 1: Literature review (TNO and RUG). TNO 2020 R12166

[ID5361] Montalvo, C. et al (2020). Study on the effects of automation on road user behaviour and performance. Report for the EC. Publications Office of the European Union, 2020. MI-03-20-312-EN-N.

[ID5362] Toyota (2020). Toyota Corolla Owner's Manual.

[ID5363] Renault (2020). Renault Scenic Owner's Manual.

[ID5365] ADAS Alliantie (2020). ADAS Woordenboek. Een geharmoniseerde namenlijst van de meest voorkomende rijhulpsystemen.

[ID5366] European Commission (2019). New safety features in your car.

[ID5367] European Council (2019). Regulation (EU) 2019/2144 of the European Parliament and of the European Council of 27 November 2019.