Automotive Campus 30
5708 JZ Helmond
P.O. Box 756
5700 AT Helmond
The Netherlands

www.tno.nl

T +31 88 866 57 29
F +31 88 866 88 62

**TNO report**

**TNO 2020 R12165 | Final report**

# Human Factors Guidelines Report 3: Use and Mental Models

| | |
|---|---|
| Date | 19 Februari 2021 |
| Author(s) | Jan Souman, Marijke van Weperen, Jeroen Hogema, Marika Hoedemaeker, Frank Westerhuis, Arjan Stuiver, Dick de Waard |
| Copy no | |
| No. of copies | |
| Number of pages | 43 (incl. appendices) |
| Number of appendices | |
| Sponsor | Rijkswaterstaat |
| Project name | RWS Human Factors Guidelines |
| Project number | 060.45606 |

# 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.

The current report (Report 3) summarizes the literature identified in Report 1 concerning what we know about how ADAS are used and to what extent users are able to build accurate mental models of these systems, enabling them to use ADAS appropriately and safely. This report limits itself to those ADAS described in Report 2 on which sufficient information was available in the literature.

# 2 Method

## 2.1 Information sources

In the first phase of the current project, a large amount of literature from various sources concerning different ADAS, how they work, how they are used and how they impact driving safety was identified, collected in a structured repository [ID5351] and classified according to the different ADAS and additional keywords [ID5357]. This repository and its classification served as the basis for the current report. Where necessary, the repository was updated and expanded with additional sources.

In addition to the literature, interviews were conducted with a number of person car drivers and truck drivers. These interviews were aimed at finding out how users of cars and trucks with driver support systems experience the systems; which ones do they use and why and what is their understanding of the systems.

## 2.2 Information selection

Two largely overlapping literature reviews were performed, based on the repository. In the first, literature concerning the actual usage of the different ADAS was identified, using the keywords that were attributed to the different sources in the repository. This involved information on how often people use ADAS, in which situations (for instance, on which roads or at which driving speeds), how they use the systems and which factors determine the way people use them. The second review was based on literature that investigated users' mental models concerning ADAS, their quality and their implications for traffic safety. The reviews were largely overlapping, as they often concerned the same sources, only read with a different filter. The reviews are meant to be representative of the literature, but not exhaustive or complete, since the latter was not feasible within the scope of this project. To ensure quality, both reviews were performed by at least two different team members.

# 3 ADAS use

This report only describes ADAS about which relevant information was found. Therefore, the following ADAS are described in this section: Intelligent Speed Assistance (ISA), Adaptive Cruise Control (ACC), Connected Adaptive Cruise Control (CACC), Platooning Trucks, Lane Departure Warning (LDW), Lane Keep Assist (LKA), Lane Centering (LC), Forward Collision Warning (FCW), Autonomous Emergency Braking (AEB), Blind Spot Warning (BSW), Driver State Monitoring (DSM) and Active Driving Assistance (ADA).

## 3.1 Intelligent Speed Assistance (ISA)

Intelligent Speed Assistance (ISA) is a speed limitation ADAS that informs drivers about the current speed limit. In addition, it can actively restrict driving speed based on that limit [ID5354]. Carsten distinguishes two ISA systems: (1) ISA which only provides information without intervening in the driving task (e.g. 'advisory' or 'warning' ISA), or (2) ISA which actively intervenes in the driving task, which the driver may be able to override or not ([ID220]; cited in [ID604]). [ID5304] divides ISA into open, half-open, and closed systems.

In terms of safety, ISA is potentially one of the most promising systems to decrease the number of road crashes due to high-speed driving (see e.g., [ID28] [ID604]). Field trials in the UK revealed that with overridable ISA enabled, drivers stayed close to the speed limit more frequently and less speed variation between drivers was found. The frequency of excessive speeding was also found to be reduced [ID604]. [ID199] found in a field test in Sweden that drivers that received ISA speed-warnings were spending less of their driving time exceeding the speed limit. Mean driving speed was also reduced. However, this effect decreased with time [ID199]. In a study using both instrumented vehicles and a driving simulator, effects of ISA on mean driving speed were not found [ID686]. The author argued that mean driving speed might not be an appropriate measure for ISA effectiveness, because this variable seemed affected by speed variability on congested roads [ID686]. The results did reveal a reduced tendency for ISA-drivers to drive above the speed limit. A considerable part of the safety effects of ISA are based on restricting driving speed, it is therefore crucial to know how, when, and why drivers use ISA, because it is potential safety benefits cannot not be realised if the system is not being used [ID637].

With regard to the use and acceptance of different ISA systems, multiple driving simulator studies have been performed to directly compare different variants. [ID211] tested the hypothesis that informative ISA systems are more accepted than mandatory ISA systems. Two experiments were performed in which drivers' acceptance of ISA with (1) low vs. high-force resistant gas pedals and (2) tactile vs. 'dead throttle' gas pedals were compared. In both experiments, these conditions resembled informative vs. mandatory forms of ISA, respectively. Low-force ISA was accepted more than high-force ISA, and even though the differences between tactile and dead-throttle ISA systems were less profound, these findings were in line with the hypothesis that informative systems are more accepted than mandatory.

Taking into account that [ID211] found that the more mandatory forms of ISA were more effective in reducing driving speed compared to the informative versions, they conclude that for optimal acceptance of ISA, it is not only important to focus on HMI design, but also on the implications of voluntary vs. mandatory designs of ISA [ID211]. Similar results were found by [ID596], also investigating the effects of mandatory vs. voluntary ISA in a driving simulator (n = 26). Their results indicate that mandatory ISA was found to be more useful, but also more frustrating than voluntary ISA [ID596]. Furthermore, drivers performed 35% fewer overtaking manoeuvres with mandatory ISA, while with voluntary ISA, no reduction was found [ID596]. The overtaking manoeuvres were also less successful and less safe with mandatory ISA (e.g. more frequent crossing of hatched areas, shorter following distance; frequency of crossing hatched areas did not differ). As a potential solution for improving the safety of overtaking with mandatory ISA, the authors conclude with a recommendation to combine mandatory ISA with a system that supports in estimating the safety of a gap in oncoming traffic [ID596].

In a driving simulator study (n = 23), three forms of ISA ranging from informative to intervening were compared, namely (1) informative, (2) warning, and (3) intervening ISA [ID561]. The informative ISA only showed the current speed limit with a short explanation (e.g. “Residential Area”), while the warning ISA was basically an informative ISA expanded with an audible warning tone, which was presented when the driver exceeded the speed limit with 2mph. The intervening ISA did not allow for driving faster than the speed limit despite the driver being able to push the gas pedal further than that point. The results showed that, of the three systems, the informative ISA had the least effects on driving behaviour as it did not affect driving speed. The authors conclude that this system might be used as a reminder tool for drivers who unintentionally drive above the speed limit. The warning ISA improved driving behaviour in terms of reducing average and maximum driving speeds, as well as the frequency of speeding. However, drivers in the warning ISA condition who consciously drove faster than the speed limit, also drove faster than in the other conditions. This could mean that they increase their speed more strongly in order keep the amount of time in which the warnings are heard as short as possible. Intervening ISA resulted in decreased average and maximum speeds, and smoother driving. In this condition, however, some drivers fully pressed the gas pedal continuously and delegated speed control to the ISA. It seems as if these drivers used the system for comfort reasons, this behaviour is likely to have negative effects on driving attention [ID561].

One of the central questions in this chapter is in which locations and in which circumstances drivers tend to use ADAS. However, most of the identified studies about the use of ISA predominantly provide results about factors for deactivating ISA. Indeed, in the UK field trial mentioned earlier for example, it was found that ISA was overruled most frequently on roads where the system would have been most effective for safety (i.e. on highways and in urban areas) [ID604]. Drivers were overriding ISA most frequently on 70 mph highways. On roads with lower speed limits, override frequency increased as speed limits decreased [ID604]. For the urban areas, one potential explanation is provided by [ID181]: they suggested that the frequent overruling of ISA in urban areas may be due to the speed differences between drivers and the necessity to stop regularly for other road users (e.g. pedestrians, cyclists, and other cars on intersections) [ID181]. In urban areas the feeling of “being under pressure” by other road users may also incline drivers to disable ISA to (temporarily) exceed the speed limit [ID686]. [ID604] concluded that not only is ISA switched off more in locations where it would be very beneficial for safety, but also drivers who's behaviour is most deviant from desirable and would benefit the most from ISA are the ones who tend to override it more often (e.g. young, male, high mileage drivers). This finding is supported by [ID181], as they revealed that drivers who 'want to break the speed limit' or 'like to drive fast' also tended to disable ISA more often. In line with this conclusion, [ID5344] found that, based on their FOT with 51 drivers in Denmark, the behavioural effects of ISA were more profound in drivers who feel negative about speeding, as opposed to drivers who feel positive about speeding.

At least some of the behavioural effects of ISA diminish over time [ID199] and drivers may use the system less often after gaining experience with it [ID181]. Frustration may be a factor as, for example, not being able to temporarily exceed the speed limit while overtaking a lead car or merging into traffic could lead to drivers feeling restricted to 'drive normally' and stop using the system completely [ID181]. System acceptance over time therefore remains crucial. Apart from the ISA design factors mentioned above, other possibilities to increase acceptance or keep acceptance higher over time were also explored. For example, [ID598] showed in a driving simulator (n = 40) that adaptive ISA systems which, compared to conventional ISA, provide earlier and more relevant warnings based on information about the driver and the driving environment, increased acceptance while the effects of both systems on driving speed were the same. The authors concluded that combining early (adaptive) warnings with conventional ISA warnings was most effective for influencing driving behaviour [ID598]. [ID586] also report the development of an adaptive ISA (intelligent speeding prediction system, ISPS) and found that their system resulted in increased minimum time-to-collision values, reduced driving speed, less frequent and shorter periods of exceeding the speed limit, and reduced magnitude of speeding.

Stimulating ISA use by means of financial rewards has also been explored, for example, by introducing 'fixed' rewards which are reduced for every speeding offence [ID582] or by providing discounts on car insurance fees for not speeding [ID601]. The effects of such incentives have been mixed, however, as the car insurance discount incentive was found to be less effective in reducing the amount of time driving above the speed limit than informative ISA alone [ID601], while [ID582] found that, although (advisory) ISA alone also showed similar effects, particularly the cash incentive condition reduced speeding. A negative aspect of incentives might be the associated increase in mental demand [ID582]. In situations where speed limitation is important, traffic is already more complex, so further increasing mental demands is a concern, as it may lead to driver overload. Of the latter study, both ISA systems (i.e. with and without incentive) were generally accepted and trusted, even though their auditory warnings were experienced as negative [ID582].

**Conclusions ISA:**

Although there are large potential safety benefits from an ISA system, there are a few considerations:

1. The user groups who need ISA most have a low acceptance rate of mandatory systems and at locations where ISA is most needed, it is switched off most often

2. Advisory or warning systems have less impact than mandatory systems, but they have a much higher acceptance rate.
3. Negative impacts of ISA such as more dangerous overtaking manoeuvres and behavioural adaptation (using ISA to set the speed of car by pressing the accelerator to the max) should be addressed.

### 3.2 Adaptive Cruise Control (ACC)

Next to being a positively rated function for comfort, ACC also seems beneficial for traffic safety by affecting driving behaviour and increasing the gaps in-between cars and trucks (e.g., see [ID170], [ID1107]). According to the literature, users of ACC generally rate ACC systems positively, indicating that it is a highly appreciated, used, and trusted form of ADAS [ID87] [ID164] [ID170]. Trust in ACC is also higher than trust in LKA systems, for example [ID72] [ID465]. There are differences between specific ACC-systems and car manufacturers [ID72], but [ID465] found that ACC properties that are rated positively include (1) smoothly adjust driving speed, (2) keep a desired set distance to a vehicle ahead, (3) keep the driver informed about detection of a vehicle ahead, and (4) detect these vehicles properly.

ACC systems are most commonly used for comfort and safety reasons [ID87] [ID170] [ID178]. In a survey among 98 drivers, 64% mentioned using ACC to manage driving speed and “avoid having to use the throttle” [ID170]. Furthermore, 39% mentioned having used ACC to stretch their legs [ID170]. Although a large majority of drivers report not engaging in secondary tasks while driving with ACC [ID44], there are nevertheless indications that ACC drivers may be more likely to do so, compared to manual drivers [ID134] [ID164]. [ID170] found that in their sample, 13% of the drivers mentioned that they used ACC to be able to read a map, look at passengers, or look at objects within the car. However, they also found that during driving, the chance that users of ACC+FCW initiated a secondary visual task was three times higher than the baseline. In line with this research, [ID44] also found that 5% of their sample of ACC-drivers was comfortable with looking away from the road, making a phone call, or sending text messages while driving with ACC. Even though driving with ACC is not as likely to induce similar levels of non-driving related activities as Active Driving Assist [ID134], it is important to acknowledge that ACC (and similar) does enable circumstances in which it is less effortful to do so [ID103] and that some people may use it to direct attention to the roadway in case a crash relevant event occurs [ID170]. Depending on the motivation of the driver, however, this may lead to either positive or negative effects. For example, if the driver uses the freed-up capacity to pay more attention to the driving environment, situation awareness may increase. If in contrast the driver uses the freed-up capacity to perform non-driving related activities, situation awareness may decrease compared with manual driving [ID134].

With regard to specific situations, multiple studies revealed that ACC is mainly used on (high-speed) highways, particularly during ‘normal’ or low-density traffic circumstances [ID87] [ID164] [ID170]. Indeed, this seems to indicate that drivers use such systems mostly in ‘safe’ environments that allow driving at a relatively high speed [ID164]. This finding is in line with [ID198], who found that drivers tend to deactivate a combined ACC and FCW system in complex, dense traffic situations. This might explain why ACC is rated as more useful and trustworthy while driving on the highway, compared to inner-city driving with Stop & Go ACC [ID44]. Even though it should be noted that Stop & Go ACC is a more recent ADAS than 'conventional' ACC and, therefore, less data are available, first comparisons can be made. Based on a FOT with 15 drivers who were inexperienced with (Stop & Go) ACC prior to the study, [ID122] found that the frequency of using ACC on the highway remained stable in the first two months of getting to know the system, while its use in inner-city traffic gradually increased in the same time period. This could indicate that using ACC on the motorway is relatively quickly learned, while using (Stop & Go) ACC in inner-city traffic may require more time for drivers to learn [ID122].

Drivers seem to prefer ACC headway settings that resemble their own driving behaviour "settings" [ID198], even though settings with smaller headways may be accepted as well [ID136]. Particularly experienced ACC-users and aggressive drivers may choose smaller headway settings compared to novice and less aggressive drivers [ID163] [ID198], suggesting that ACC does not withhold people from risky driving [ID87]. Not only selected ACC-settings, but also use patterns seem to depend on age, experience, and personality. For example, with prolonged ACC use and experience, drivers tend to use ACC for longer periods of time [ID170], set faster speed settings, and intervene less frequently [ID163]. Furthermore, [ID506] found that increased age and experience were related to increased willingness in using multiple ADAS, including ACC. Apart from driver-related characteristics, the selection of speed and headway settings may also depend on the driving environment [ID122]. For example, [ID122] found that on the urban road, the use of the shortest headway settings for Stop & Go ACC showed an increase over time. Furthermore, for both motorway and inner-city locations, they concluded that speed settings were set generally high or close to the system's operation limits. The authors therefore emphasize the importance of default settings: these are often the starting point from which a new user gets to know a system and these may therefore be interpreted as being safe and appropriate for most occasions [ID122].

As useful as ACC may be in the situations described above, there are also situations in which manual driving is preferred or required. In such situations, drivers will need to deactivate or overrule the ACC system and reclaim longitudinal control of the car. Specifically, ACC may be overruled by means of a switch or button, the accelerator pedal, or the brake pedal [ID122] [ID198]. This is performed, for example, (1) while driving behind a slow lead vehicle, (2) while expecting other vehicle(s) to cut in, (3) while wanting to drive faster than the set ACC speed, or (4) while intending to leave a highway [ID53]. [ID53] argued that drivers' decisions with regard to the transition of control from ACC to manual driving may be interpreted based on the Risk Allostasis Theory by Fuller [ID53]. In essence, they concluded that drivers, after reclaiming control from ACC, may change their speed based on a compensation strategy to match their perception of risk and task complexity to their preferred levels [ID53]. In line with this finding, [ID122] argue that overriding by means of the accelerator pedal (i.e. to increase the speed temporarily) could be performed when the driver experiences the situation as being low in complexity and, therefore, actively increases task demands by overtaking a slow car ahead. Furthermore, using the ACC switch or button may be preferred when a driver consciously predicts that the upcoming situation is not suitable for the ACC system to handle. For example, a driver may intend to exit a highway and therefore uses the switch to reclaim manual control of the car before performing this manoeuvre [ID122]. Overall, they found that overruling the ACC was performed more often in inner-city locations, compared to the highway. Also, the strategies differed: the brake pedal was used most often in built-up areas, while either one of the pedals was used most often on the highway [ID122]. With regard to the braking strategy, [ID198] found in their FOT that the most commonly used mode of deactivating ACC is by braking smoothly (65-70% of all deactivations). Even though 33% of all smooth braking actions was followed by hard braking within 1 second, they found that only 5-10% of all ACC deactivations are performed with hard braking. The authors conclude that the latter percentage concerns emergency situations, while smooth braking indicates a deliberate and controlled transfer from ACC to manual driving [ID198].

[ID198] found that drivers deactivate ACC mostly temporarily and for short amounts of time: in their sample, 15% of all ACC deactivations exceeded 5 minutes time, while half of all deactivations were followed by reactivation within 50s. After deactivation, however, [ID560] found that ACC drivers may still keep driving at shorter headway distances due to carryover effects of automation. Furthermore, apart from (temporary) ACC (de)activation, 11% of the drivers surveyed by [ID44] report not using ACC at all. The most commonly mentioned argument is that drivers ‘do not need the system’ or that the expectations they had about the system were not met ([ID44] [ID16]; cited in [ID198]).

Even though ACC is generally rated positively, ACC users acknowledge that the system has operational limitations [ID87]. For example, ACC systems may have difficulties with lead vehicles cutting in at short distances [ID87], reacting to stationary objects, detecting small vehicles (e.g. motorcycles), or detecting relevant vehicles in sharp curves (see e.g. [ID111]). [ID136] performed a driving simulator study in which a selection of similar situations was presented to 31 drivers. They found that while driving with ACC, the majority of drivers kept the system enabled when a lead vehicle exited the motorway. In a curve, however, the majority of drivers did not disable ACC to decrease speed when the system failed to detect the correct lead car, while the majority of drivers at least took their foot from the accelerator to reduce speed in the same situation while driving manually [ID136]. [ID5342] also found that drivers may still trust ACC systems to some degree even if it is highly faulty. It is therefore concluded that reactions to critical situations with ACC enabled may differ from manual driving. Furthermore, ACC-use may also lead to carry-over effects after a system has been deactivated due to an unexpected failure [ID53]. This emphasizes the importance of drivers being aware of the limitations of ACC-systems and adjusting their behaviour accordingly [ID87].

## 3.3 Connected Adaptive Cruise Control (CACC)

Connected Adaptive Cruise Control (CACC) is a system that is currently under development and not (yet) used in practice [ID5354]. Data about CACC use are therefore limited and the identified studies mainly concern expected use, acceptance, and behavioural effects.

[ID5341] state that an important factor for CACC acceptance will be small gap times. Based on earlier studies, they concluded that a gap time between 1-2s towards a lead vehicle is preferred by most drivers. As CACC gap times may be significantly shorter than conventional ACC, it is crucial to know how close drivers still feel comfortable following another vehicle. Even though there are indications that drivers accept shorter headways, they often do not seem to use these in practice [ID5341]. Furthermore, not only one's own following gap preferences will affect acceptance, but also being followed closely by other road users will be of influence. Indeed, as drivers tend to overestimate their own driving capabilities and underestimate these of others, being followed with short gap times may decrease comfort and therefore acceptance of CACC [ID5341]. The authors also argue that, in accordance with other ADAS, user groups that would typically benefit most from using such systems are the ones who tend to use it the least [ID5341]. This may also affect the use of CACC systems and could disrupt its potential effects on traffic throughput [ID5341]. With regard to behavioural effects of CACC, [ID5341] also suggest that with experience, drivers might get used to the short gap times of CACC and potential carry-over effects to manual driving should be investigated.

According to [ID5346], another implication of short CACC gap times could be that merging into a CACC platoon may be found more difficult than merging traditionally. For this reason, they performed a driving simulator study (n=48) in which they compared merging behaviour into a CACC platoon (either with or without providing longitudinal merge assistance) with merging conventionally into non-CACC traffic. The results indicate that CACC merging, both with and without longitudinal assistance, was perceived as less stressful than merging without CACC [ID5346]. The merge assistant also led to shorter travelled distances before merging [ID5346]. Furthermore, [ID5347] investigated whether braking reactions in an emergency situation differed between CACC and manual driving. In the first of two driving simulator studies, they found that CACC drivers (n = 13) had fewer collisions and increased TTC values compared to manual drivers (n = 12) [ID5347]. In their second driving simulator experiment (n = 112), they concluded that both the CACC system's automatic braking response and the auditory warning contributed to the better braking performance in the CACC condition [ID5347]. It should be noted, however, that because these studies have been done in simulators, they do not necessarily generalize to CACC when it will be used on the road.

There are still additional problems to be solved before CACC can be implemented widely. By means of a field trial on open roads in the Netherlands, [ID1190] observed interactions between a CACC platoon with 7 cars and other traffic participants. For the CACC platoon to remain intact for as long as possible, exemptions from local road regulations were required: (1) the platoon needed to drive 10 km/h over the speed limit to prevent hindering other traffic and (2) the platoon was allowed to keep driving on the left-hand lane of the highway to limit problems with merging traffic [ID1190]. Despite these measures and using the shortest headway settings available, the CACC platoon was still regularly cut in by other road users wanting to overtake, even if they had to do this illegally via the right-hand lane [ID1190].

### 3.4 Platooning Trucks

[ID1672] reported three main differences between platooning systems for passenger cars and trucks. Firstly, the main goal of platooning technologies for passenger cars is to make room for non-driving related activities, whereas such systems in trucks mainly serve the purpose of reducing costs and increasing productivity. Secondly, as truck drivers often belong to a fleet, they may receive specific training about the use of (automated) driving systems, whereas passenger car drivers will often not receive such training. Thirdly, truck drivers are not only trained extensively, but also repeatedly after many years of driving experience [ID1672].

As platooning is also still a largely conceptual system, data about use are also limited. What is known, however, is that driver comfort and acceptance of short following distances is also very relevant for platooning, as with CACC [ID1672]. Furthermore, it is known that drivers perceive groups of vehicles with small in-between gaps as driving slower than vehicles with larger in-between gaps [ID5341]. This could influence willingness to take part in platoon driving [ID5341]. Furthermore, a recent study with a 2-truck platoon (33 trips) found that drivers (n = 10) felt comfortable with both 15 and 21m following distances. They preferred the shorter distance because other cars were then less likely to cut into the platoon. Comparison of following distances during manual driving before and after platooning did not show significant differences. However, participants commented that they had to get used to consciously keeping a larger distance again after returning to manual driving. Support by distance keeping feedback may be useful and/or necessary. Furthermore, variability in lateral lane positioning increased significantly for the following driver (not the leader) between post- and pre-platooning (3.6 cm difference). Possibly, this was caused by the passive steering (i.e., hands on the wheel, but no active steering movements) by the driver of this truck during platooning [ID926]. The authors also comment on potential explanations for the differences between the preferred gap times found in their study and those found in other studies, by stating that the usual traffic density and common gap times or distances may have an effect. It could also be a possibility that American drivers are used to larger distances than European drivers. Lastly, perceived system reliability or trust may also have had an influence [ID926].

### 3.5 Lane Departure Warning (LDW)

Lane departure warning systems warn the driver when an unintended lane departure is very likely to happen using visual, haptic and/or auditory feedback [ID5354].

Literature shows that the choice of feedback channel is very important for the acceptance and usage of the system by the driver. Drivers often find warnings beeps disturbing [ID178] and more irritating than haptic warnings [ID164] [ID170]. Other studies support this finding, stating that LDW systems which use vibration in the driver seat or steering wheel were more likely to be turned on than those which only use an auditory warning [ID48]. [ID5314] showed that the use of haptic feedback increased the acceptance of LDW by the driver.

Vehicle owners and test drivers report that they have deactivated their LDW system because it was annoying [ID44] [ID465]. However, remarkably, another study among Volvo drivers (n= 86) showed that annoyance did not lead to system deactivation [ID400]. So although drivers may find the system annoying, they do not turn it off. Usefulness in this case might be more important to drivers than comfort. Other reasons to deactivate the system were the lack of reliability [ID178] and the timing of the warning [ID164]. [ID400] reported that more than 20% of the drivers in their study (n = 378) said the system was too sensitive. Also in a large-scale truck FOT conducted in The Netherlands showed acceptance for LDW results being slightly positive for “usefulness” but negative for “pleasant” [ID5371]. These acceptance results were obtained with a LDW system that was perceived to have a high false alarm rate (especially on narrower lanes). Interestingly, [ID400] also observed that only 8% of the Volvo drivers knew that the sensitivity settings of the LDW system were adjustable. The timing of the warning could be adapted to drivers’ preference and might possibly lead to less annoyance. However, no studies have been found to address the acceptance of different sensitivity settings of LDW.

Experience of the driver with LDW is another important factor for system usage. In [ID5314], the time the LDW system was deactivated increased the first year of driving. At that point, drivers generally settled on whether to activate or deactivate the system. This is supported by [ID170], who found that drivers did not use the system differently after 12 months.
Other factors influencing the usage of LDW are age: increase in age significantly predicts lower odds of LDW deactivation [ID5314] [ID506], speed and distance of the trip: a larger proportion of the trip at high speeds and larger distances increased the odds of system deactivation [ID5314], and number of warnings: higher number of LDW alerts also increases the odds of system deactivation [ID5314].

Although [ID497] found that LDW is not highly appreciated by users and often turned off, most studies suggest drivers are positive about the system, stating it is easy to use [ID164] [ID170], useful [ID44] [ID164], agreed that they could trust the system [ID44] and that acceptance is stable over time [ID164]. However, trust in LDW systems decrease significantly over time, because drivers expect more from the system than it can fulfill [ID164]. Many studies report that drivers find LDW systems helpful in particular situations, such as when they are tired or drowsy [ID400] [ID164]. Drivers who keep the system activated, often agreed they want the system in their next car [ID48].

Misuse of LDW systems seem to be quite rare [ID164]. Only a low percentage of drivers report to engage in secondary tasks such as making a phone call or sending a text message [ID44]. However, another study shows that the likelihood of using other devices tripled with a combination of LDW and FCW during normal driving [ID170]. Interestingly, during crash related events, no difference in device usage was found. So it seems that drivers mainly divert attention to other devices in situations which they deem safe to do so [ID170]. To test the system, drivers do make unnecessary lane changes [ID164], which could lead to hazardous situations. The likelihood of truck drivers to engage in secondary activities was not found to increase by the usage of LDW [ID170].

Research shows that LDW systems have a positive impact on the lateral driving behavior, as the frequency and magnitude of lateral excursions decreases. [ID497] found that this positive impact is carried over to situations where LDW is not active. They observed that drivers show less oscillations around the lane center after LDW was active [ID497]. Moreover, several studies show that LDW systems also have a positive effect on the usage of turn indicators [ID178] [ID164]. With LDW activated, drivers tend to use their indicators more often [ID178], [ID164]. This is probably due to the fact that drivers receive a warning from LDW when they change lanes without using the indicator, while this warning is not issued when the indicator is activated. This positive effect may also carry over to situations where LDW is not active.

### 3.6 Lane Keep Assist (LKA)

The difference between LDW and LKA is that LKAS does not only warn the driver when drifting out of the lane but it also assists the driver to stay within the lane markings by corrective steering action.

Literature indicates that LKA systems are more likely to be turned on than LDW systems [ID48]. Although [ID44] showed that 42% of the drivers (n = 784) indicated that they deactivated LKA, 79% of the drivers agreed the system was useful and 73% of the drivers reported trusting the system. The most important reason for deactivation was that the system was annoying [ID44]. The on-off rate substantially differed per brand and model [ID48]. In general, system with more smooth changes to the lateral position of the vehicle increased agreement of the driver that the system improved driving experience [ID465]. Interestingly, drivers who drive for longer distances and therefore could benefit significantly from this system, are less likely to have LKA activated [ID48].

Drivers using LKA seem to be more frequently engaged in secondary tasks than drivers using only LDW. More than 11% of the drivers (n = 502) in the study of [ID44] at least sometimes engaged in secondary tasks when LKA was active.

The effects of system use on aftereffects and behavioral adaptation have been investigated by [ID45]. After the system was deactivated, drivers (n = 48) showed a significant increase in lateral deviation from the lane center and showed a decreased mean Time To Collision (TTC) [ID45].

[ID8] looked into the effect of LKA in trucks and reported that LKA caused drivers to drive more closely to the lane center and that it reduced the frequency of lane departures for distracted drivers.

### 3.7 Lane Centering (LC)

Lane centering can be seen as a more advanced lane keeping system. The system tries to keep the vehicle in the lane center by corrective braking or steering movements [ID5354]. Not many studies have investigated the usage of LC as a separate system. Most studies have looked into a combination of longitudinal and lateral control and can be found in section 3.12 “Active Driving Assistance (ADA)”.

[ID15] investigated both the combination of ACC and LC and both systems separately. They found that drivers did not engage more in secondary tasks when driving with LC than when driving manually [ID15]. Another study comparing LC to LKA in trucks found higher subjective ratings for LC than for LKA [ID8]. Interestingly, some truck drivers commented that LC does not assist in driving the vehicle with slight offset from the lane centre, as they would generally adopt [ID8].

## 3.8 Forward Collision Warning (FCW)

Forward Collision Warning (FCW) systems warn the driver to perform an action when another road user or object in front of the vehicle is detected and a collision seems imminent [ID5354]. As the system only provides a warning and does not intervene in the driving task, the driver has to perform a manual action to make sure that a collision is prevented or that the impact is mitigated [ID5354]. According to a [ID170], the system is being perceived by approximately 60% of its users as "very important for increasing safety". [ID178] indicate that FCW use leads to an adjustment of driving behaviour in terms of keeping more distance from vehicles ahead and driving more calmly.

Because most FCW systems are automatically enabled beyond a certain driving speed (e.g., see [ID5314]), data about system use are found to be limited to users' perceived usefulness and factors that may lead to system deactivation. In that regard, [ID44] found in their sample of FCW users (n = 519) that a large majority (89%) always has the system enabled. Furthermore, FCW users not only reported finding the system primarily useful on highways and during 'normal' traffic conditions [ID164] [ID170], but also during adverse weather conditions, while driving in the dark, or while being drowsy [ID170]. A small proportion of drivers (11%), however, reported that they disable FCW mainly because they perceive the system as being "annoying" [ID44]. Furthermore, there are indications that high mileage drivers are more likely to deactivate FCW [ID5314], although drivers also report that they do not change their use of FCW over time [ID170]. Older drivers seem to disable the system less often than younger drivers [ID5314]. In terms of trust and usefulness, a large majority of users believe that FCW is useful (85%) and, even though the absolute percentage is lower, the majority of users (69%) also trust the system [ID44]. Using an FCW system does not seem to lead to increased engagement in non-driving related activities, as only 2% of the FCW users reported feeling comfortable in doing so [ID44].

[ID5314] studied the use of and responses to FCW (and LDW) by means of a large-scale FOT. With regard to the use of specific settings, they found that drivers most commonly use the 'far' (default setting), 'medium', and 'near' settings, in that order of preference [ID5314]. Furthermore, they revealed a distinct use pattern over time: drivers tend to first begin with using the 'far' setting, after which they try out the other two settings, to eventually come back to the 'far' setting again [ID5314]. Regarding the responses of drivers towards FCW alerts, the 'far' setting was found to decrease RT with 0.11s, compared to not using FCW [ID5314]. Not only system use, but also the conditions influenced reaction times. For example, faster driving and greater headway distances increased RT with 0.13 s and 0.05 s, respectively. Furthermore, bad visibility conditions due to adverse weather was found to increase brake RT with 0.07 s on average, and even more (0.11 s) in critical conditions (e.g., when drivers were approaching a vehicle that was slowing down or had stopped entirely) [ID5314]. The analyses also revealed that bad visibility, higher speed, and greater distance during the FCW warning can lead to higher average deceleration values, particularly during critical situations [ID5314].

Apart from the relatively ‘conventional’ FCW (and LDW) warnings (i.e. visual and/or auditory signals), drivers could also choose to enable a tactile warning signal coming from the seat [ID5314]. Using this feature greatly increased the acceptance of these systems as compared to the auditory signals (beeps) [ID5314].

### 3.9 Autonomous Emergency Braking (AEB)

The Autonomous Emergency Braking (AEB) system shares its objective with FCW, as it also aims to prevent or limit the impact of a collision with a road user or object ahead of the car [ID5354]. Basically, AEB is an expansion of FCW by introducing an active intervening component: where FCW only warns the driver of a possible collision, AEB also actively brakes if the driver does not respond adequately to the FCW [ID5354]. Indeed, AEB seems particularly effective in situations where drivers do not expect having to brake, as a driving simulator study (n = 30) revealed that AEB was capable of preventing crashes in unexpected critical situations by braking earlier than the drivers could, even if they also received FCWs beforehand [ID611]. The authors emphasize the importance of driver expectations: if drivers do not expect an increased likelihood of critical situations or unexpected manoeuvres (e.g., on a straight road section, instead of an intersection), reaction times to FCW may be too slow and AEB interventions seem required to prevent crashes [ID611].

Data about system use is highly comparable with FCW, probably because these systems are often coupled. For example, when asked specifically about AEB use, 90% of the respondents in a large survey (n = 504) reported that they always had AEB enabled while driving, while 11% reported occasionally disabling AEB because of annoyance [ID44]. Trust and usefulness of AEB are also rated similar to FCW (respectively 66% and 85% of AEB users rated these constructs positively). The overall majority (92%) of drivers did not (or rarely) feel comfortable with performing non-driving related tasks with AEB enabled [ID44]. In the driving simulator study, drivers did also not engage in more secondary tasks while driving with FCW+AEB, although they did shift their attention to the HMI when visual feedback was given [ID611]. With regard to concrete experiences with AEB, 63% reported that they had experienced at least one situation in which the AEB system intervened [ID611].

### 3.10 Blind Spot Warning (BSW)

Blind Spot Warning is designed to warn the driver of vehicles in the blind spot. It helps the driver to monitor the environment around the vehicle and is especially useful when a lane change is (about to be) initiated [ID5354]. As most BSW systems only operate above a certain minimum driving speed, they are not intended to warn when turning left or right [ID5354]. Turn Assist is meant to fill this gap [ID5354].

[ID44] shows that a large part of the drivers (n = 954) uses this warning system in their vehicle. 96% of the drivers responded they never deactivated the system. The other drivers reported they had deactivated the blind spot detection, because it was distracting [ID44].

Blind Spot Warning is designed to warn the driver in case the driver initiates a lane change by using the indicator switch and a vehicle is detected in the blind spot. Studies found that the system is often used as designed [ID178] [ID164]: it complements the visual checks by presenting additional information to the driver, but drivers rarely rely on this information without visual checks. Drivers maintain their usual behaviour of checking the mirrors. [ID660] found that BSW even increased the probability of the driver looking in the right and left mirror before performing a lane change respectively to the right or left. In contrast, some studies show negative effects of the BSW. [ID44] observed that respectively 55% (n = 509) and 24% (n =73) of the drivers in their study reported they at least occasionally relied on BSW without visual checks when performing lane changes. Respectively 3% and 11% of the drivers did so frequently. [ID170] observed that drivers who drove with BSW enabled but did not receive many warnings tended to use the indicator less often, possibly because they deem indicator use unnecessary when no vehicles are detected.

According to [ID44], drivers' trust in BSW is very high: 84% of the drivers (n = 509) in their study indicated they trusted the system. Moreover, 94% of the drivers in the same study reported they found the system useful [ID44]. Other studies supported this by reporting a usefulness of more than 90% [ID170] [ID164]. Most drivers found the system useful on urban roads with heavy traffic [ID164].

ID164] indicated that while BSW has a high false alarm rate, drivers are still very pleased with the system. They state that it seems the case that drivers are willing to learn the limitations of the system, as the core functionality is perceived useful [ID164]. This might only be the case when false alarms of the system are not experienced as annoying.

### 3.11 Driver State Monitoring (DSM)

[ID164] report that driver drowsiness detection has a very high usage. According to the authors, this is because it is very easy to use and the warning interface is very intuitive. Drivers perceive the system as most useful on the highway. The system seems to work as expected and drivers find it is calibrated properly, which is needed as the driver has to take action himself. There is little interaction required, which is also reflected in the low workload. However, many drivers commented that other factors, such as the desire to get home or social pressure, forces them to disregard the warning. These subjective ratings are found to be stable over time [ID164]. However, according to another study, users were frequently frustrated with the drowsiness detection system because they did not understand what triggered it and experienced a lack of compatibility between their own state and the system response [ID178].

### 3.12 Active Driving Assistance (ADA)

Active Driving Assistance (ADA) is a combination of different ADAS used in the vehicle at the same time. These ADAS at least include lane centering and ACC, enabling the system to assist in both longitudinal and lateral vehicle control, but other functions such as Emergency Assist, ISA and Lane Change Assist can also be included [ID5354].

When using ADA in a vehicle, the system controls both the longitudinal and lateral velocity of the vehicle. During activation, the driver is not in direct control of the vehicle but plays a supervisory role. Research shows that user behaviour, acceptance and trust changes over the different phases of system experience. [ID15] found that in the first phase, trust in ADA may be low as the driver has no experience with this kind of automation. Once drivers get more familiar with the system - moving from the novelty phase to the post-novelty operational phase - behavioral adaptation may begin to occur. In this phase trust and overreliance may develop. This includes getting familiar with the limitations of the system. When drivers get even more experienced, overreliance and work underload may occur [ID15]. The effect of long-term behavior has been investigated by the AAA, where test drivers indicated that a combination of ACC and LC did not significantly improve their driving experience because of the need to constantly monitor system performance. This was mainly due to the frequency of unexpected events (on average once every 8 miles) and short take-over times in those situations [ID1].

With prolonged experience, drivers often increase engagement in secondary tasks. [ID15] observed this behavior from the second month of driving with an ADA equipped vehicle. Studies show that when drivers drive with both ACC and LC active, the driver engages more frequently and for longer periods of time in secondary tasks [ID15] [ID1]. In [ID15], the proportion of long glances (larger than 2s) on secondary tasks was higher with ACC and LC active, than with only LC active, ACC active or manual driving. This suggests that drivers feel more comfortable looking away from the road with combined lateral and longitudinal control automation. When automation of vehicles evolves, drivers of highly automated vehicles are expected to be even more inclined to engage in secondary tasks, such as watching a movie or sleeping [ID134]. Next to engagement in secondary tasks, [ID15] also observed that drivers drive faster with ACC and LC active in comparison to only using one of these systems.

Drivers use ADA mainly on the highway for long (>50 km) trips [ID809]. The road and traffic conditions seem to have a higher impact on the usage of ADA than the weather and time of day [ID809].

[ID809] found that behavioral adaptation depends on the frequency and duration of use. Their study showed that mainly drivers who use ADA very often have confidence in ADA and try the system in less ideal circumstances, such as congested traffic. Drivers who use ADA less often are in general more hesitant to use the system in new situations. They use the system mainly in safe situations and experience newly introduced features and their benefits less often [ID809].

When ADA is not able to handle a certain situation or environment, drivers have to take over directly. The results of a simulator study show that drivers employ different strategies on how they deal with the automation failure dependent on the situation [ID136]. If drivers expected the system not being able to handle the situation, they usually took over control before the system reached its limit. This happened in the case when a vehicle in front takes an highway exit and the ego vehicle follows when ADA is active. Drivers took over by manually switching the system off by pressing a button. In the case of a mandatory merge (because of a broken car in front), drivers took over control by using the brake pedal. In a sharp curve, most drivers waited until the automation failed to keep the vehicle in the lane and issued a warning before responding [ID136].

[ID831] investigated the perception of SAE level 3 automation functions (see [ID5359]) in a simulator study (n = 30). They found that drivers with system experience trust the function more, feel safer and less stressed compared to drivers without experience. With repeated usage, drivers feel more comfortable taking their eyes off the road and engaging longer in secondary tasks [ID831]. This is in line with the studies mentioned earlier about experience with ADA. After 4 drives (total of 4.5 hours of driving) in the driving simulator, participants kept using the system in a similar way [ID831].

# 4 Interviews with ADAS users

In addition to the literature review, interviews were conducted with a number of car and truck drivers. These interviews were aimed at finding out how users of vehicles with advanced driver assistance systems experience using these; which ones do they use, why these and what is their understanding of the systems? In total 8 car drivers were interviewed and subjective information from 10 truck drivers was gathered from the Integrator project [ID5369].

The truck drivers (between 34 and 58 years old) already had experience with driving with ACC and were driving most of the time with ACC turned on. Because they were used to it, they were of the general opinion that driving with ACC was not very special. The truck drivers had a high level of trust in the ACC. They commented that they usually used ACC setting 3 (headway 2.4s). In the vehicles used, this is the default setting of the ACC when it is activated, offering a good comfortable distance to the vehicle in front. Only one truck driver indicated that he usually did not use ACC setting 3 on urban and rural roads, because in some cases the system actively brakes to reduce speed instead of just releasing the gas pedal. Truck drivers used their ACC during 70% of their driving time on roads where the maximum allowed speed is 70 km/h or higher, especially under quiet driving conditions. When traffic gets busier they tended to turn the ACC off because they experienced it as annoying when the system started braking all the time. The truck drivers indicated that driving without ACC was very exhausting, especially when the amount of traffic was limited.

The car drivers (between 25 and 62 years old) had experience with a number of different systems in their cars (especially ISA, LDW, LKA, AEB, ACC, BSW, FCW, ADA). One participant indicated not to use the Automated Parking system, because he/she didn’t quite trust it yet. When he/she tried it once in a busy street, it would find parking places that were not allowed (exits). Another participant indicated not to use the speech function that was available.

Most participants indicated that they knew how to switch all of these systems on and off. Some said that LDW could not be switched off and one participant indicated always to switch off the LKA every time he/she started the engine of the car. He/she had to look into the manual to know how that needed to be done. One participant indicated not to use the ACC because he/she did not know how to switch it on and also was not sure how it worked. This same person always switched off the LKA because the jerks on the steering wheel were experienced as annoying.

Most participants indicated that they did not experience problems when using several ADAS together. However, some indicated that it can be confusing that the displayed speed limit may deviate on basis of navigation map and camera. One participant mentioned that the difference between LKA and LC was confusing at first, but after some googling he/she found out how it worked. Another participant complained that the Autopilot system sometimes starts decreasing speed without an apparent reason (no car in front visible). When encountering road works or a sharp curve this participant turns the Autopilot off because he/she doesn’t trust it.

On the question how enjoyable using these systems is for the participants we received the following answers:

“The combination of ACC and LC (ADA) I find quite comfortable to use on highways; in general I find that I’m less tired after driving long stretches (multiple hours) with these ADAS than without; FCW is a bit annoying because it warns mostly in situations where I’ve already seen that I have to be careful and sometimes gives false alarms (less so since I’ve set it to a lower sensitivity). ACC works quite well, never had any hiccups with that. LC is only as good as the lane markings are; as soon as those become less clear or more complex (e.g., exits, crossroads, etc), LC often turns itself off.”

“Blind spot sometimes gives an error and that keeps on popping up. Very annoying.”

“Parking sensors are too sensitive, good that they are there but they respond too early. LDW is irritating.”

“ACC for long distance is great for shorter distance I do not use it”.

“ACC brakes at moments that you don’t expect it and it does not accelerate enough when you want to take over”.

“By using my ADAS systems I can have more attention for the environment”.

“I experience more safety by using the systems; they warn you in case something might happen”.

“The ISA is really handy because it prevents you from driving too fast; you just press the gas pedal and it does not speed over the limit you have set.”

In conclusion we can say that these short interviews provided us some direct insights in how drivers experience the systems in their cars. It did not provide extra information on what we already found and described from the literature on the topic of mental models.

# 5 Mental models of ADAS

## 5.1 What is a mental model? How can it be identified?

*“The notion that humans have "*mental models*" of the systems with which they interact is ubiquitous in many domains.“* This was stated by Rouse and Morris in 1986 [ID5348], and based on our own literature study [ID5357] is still the case today. However, definitions of mental models are much scarcer than studies that use them. Here, we describe how we understand the concept of a mental model, and how it relates to other relevant models.

In the domain of manual or supervisory control of vehicles by human operators, mental models have been used as part of human operator models (of pilots, car drivers, etc.). Quantitative operator models (including mental models) have been developed that can be used to simulate and predict operational control performance (e.g., see [ID5353]). To achieve this, a certain model structure has to be assumed for the mental model: either a ‘perfect’ model, in which the mental model perfectly matches the operated system, or an ‘imperfect’ model, which reflects an imperfect representation of the system in the mental model [ID5348]. Perfect models make identification of the operator model easy, but are unlikely to reflect the actual mental models used by operators. Imperfect models, however, are difficult if not impossible to identify, as they may be imperfect in infinitely many ways.

For our current project, the mental models we need do not have a continuous control nature. Instead, they are more of a rule-based nature, focused on how humans understand systems. This is the type of mental models that Norman described as “messy, sloppy, incomplete, and indistinct knowledge structures” [ID5334]. The mental model evolves during interaction with the system. They may be shaped or restricted by earlier experience with similar systems and also by the user’s technical background. Further, people may forget details of the system they are using, especially when they are not regularly exposed to use of (these details of) the system. Various techniques have been applied to map mental models in computer models, using neural networks, a fuzzy rule set or combinations thereof [ID5358]). The neural networks approach is predictive at best but will not be descriptive.

Based on how several research domains deal with mental models, Rouse and Morris (1986) [ID5348] gave the following functional definition:

> *“Mental models are the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states.”*

Purpose and form are of less relevance for our current project, so a more compact definition for now is:

> *“Mental models are the mechanisms whereby humans are able to generate explanations of system functioning and observed system states, and predictions of future system states.”*

Taking this one step further, it is our view that the mental model not only enables the user to generate explanations and predictions, but that the model serves as the basis for the actual use of the system: when, where and how is the system used. A first conceptual model is shown in Figure 1.

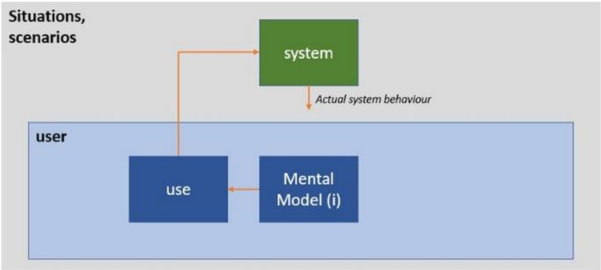
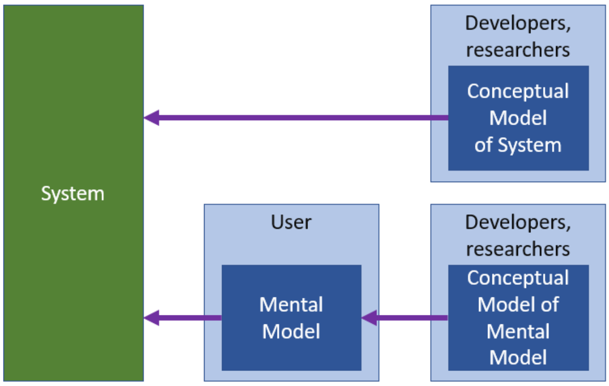



Figure 1 Mental model as the basis for system use.

***Model identification***

Various methods can be applied in an attempt to make the mental models (more) explicit.

- Empirical studies.
- Analytical models (again, mainly of value for continuous control tasks).
- Verbal/written reports.
    - Thinking aloud protocols. Although certainly of value, the verbal/written reports approach does have its drawbacks. They rely on verbalisation of nonverbal knowledge that may result in distortion or biases.
    - Interviews or Questionnaires. Possibly after exposing users to a system and using recorded situations as input for questions (see also the SAGAT method discussed below) . These methods also have their validity challenges. When asked why or how a person has done something, a respondent may feel compelled to come up with an answer, even if (s)he does not really know. It again asks for verbalisation and for making knowledge explicit and verbalised, whereas this knowledge may be implicit or non-verbal in nature.
    - information acquisition strategies and concept mapping [ID5350].




- Figure 2 System and models thereof (purple arrows indicate “is a model of”)

In the context of mental models, Norman distinguishes among several models/systems, as visualised in Figure 2 [ID5334]. The first one is the *actual system*, or target system, as operational in a certain vehicle. For example, a given ADAS, with all its characteristics. Second, there is a *conceptual model* of this system, as utilised by designers, developers or researchers. The third element is the mental model that the user has (or develops). A user's mental model is not static and rarely complete. It is constantly evolving, unstable, does not have clear boundaries (e.g., with mental models of other systems). The fourth and final element is the scientists' conceptual model of the user's mental model. In our current project, we are obviously working on this fourth block: trying to assess the user's mental model, which in turn is some estimate of the actual system's functioning.

If the mental model indeed allows the user to generate explanations of observed states, the model must contain at least the following two elements.

- A set of ***rules*** or production rules. For example, IF (I press this button) THEN (the system is activated).
- A set of ***state variables***. For example representing the mode of an ACC (off, stand-by, active), or its speed setpoint.

Together, as set of rules and state variables can indeed "generate explanations of system functioning and observed system states, and predictions of future system states."

The conceptual model from Figure 1 can be expanded by adding several notions that have already been mentioned around the mental model.
First of all, the mental model (rules and state variables) is not static but develops over time. This model evolution can be incorporated as follows: The model produces *expected* behaviour, and the user can compare this with the observed actual behaviour. If actual behaviour differs from expected behaviour, this can be used to update the mental model. In Figure 3 this is shown as the 'Adjustment mechanism'.
Second, in Figure 3 we added the Human Machine Interface to the system. Part of what the mental model does is keeping track of system states. Typically, these are (partially) communicated to the driver via displays (visual or other modalities) and are directly available for the user. Further, the 'use' of the system can partially be used for model identification purposes. For example, pushing buttons or trying the system in specific situations to observe the system response and thus improve the mental model.

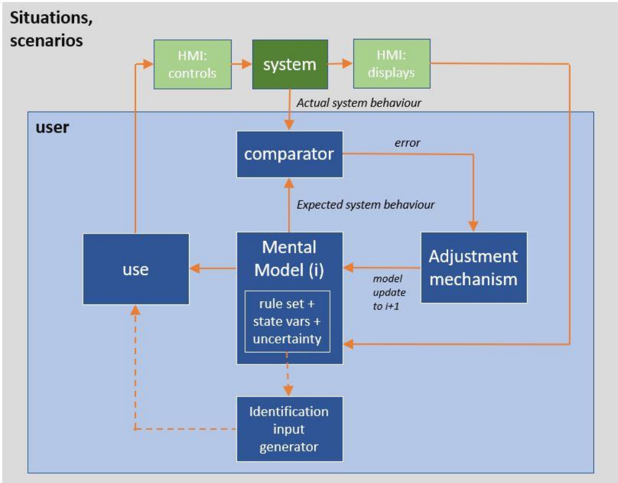



Figure 3 Our conceptual model of the mental model

Endsley mentions the limitations in our ability to determine what a person's mental model really is [ID5350]. She states that the mental models largely represent static knowledge about the system, i.e. stored long-term knowledge. In contrast to this quasi-static mental model, Ensley introduces the concept of Situation Models, closely related to situational awareness (SA). This situation model is dynamic in nature, representing knowledge of the current state of the system. The Situation Awareness Global Assessment Technique (SAGAT) can not only be used to asses someone's SA, but also the situation model. Essentially, a simulation is stopped at various times and then questions are asked to the human operator to determine their SA or situation model at that time.

Note that our conceptual model of the mental model, as described above, is also about dealing with dynamic states rather than with static knowledge. Thus, what Endsley calls a "situation model" is in our terms also part of the "mental model" [ID5350].

## 5.2 The importance of accurate mental models

Accurate mental models reflect a system's functionality, capabilities and limitations to the extent they are relevant for the user. Therefore, they allow the user to use the system appropriately and safely in a dynamic environment. In the specific context of driving with ADAS, a user's mental model allows him/her to explain and predict system performance in varying circumstances [ID111]. It helps the user to be aware of the current status and capabilities of the system (mode awareness) and to use the system appropriately depending on the actual situation and circumstances. It also enables the user to deal with system limitations and failures, in as far as these are part of the mental model.

An accurate mental model is also considered to be the basis for calibrating trust and acceptance in ADAS [ID595] [ID5349] [ID173]. Both over-trust and under-trust may be signs of inaccurate mental models. The former may result from the user not being sufficiently aware of the system's limitations, while the latter may indicate insufficient awareness of the system's capabilities. Overtrust may lead to misuse, using a system in situations for which it was not designed or which it is not able to deal with, which potentially compromises driving safety. Undertrust may reduce the system's use, even to the extent it is not used at all, reducing the additional safety and comfort which ADAS may provide under correct use.

### 5.3 How do users develop and maintain mental models?

The first requirement for the development of an adequate mental model of an ADAS obviously is the awareness that one's car is equipped with the system. Perhaps surprisingly, a large portion of drivers do not seem to know their car comes equipped with specific ADAS. A recent survey among 1355 car owners in the Netherlands showed that for four out of seven ADAS included in the survey (Adaptive Cruise Control, Lane Departure Warning, Automatic Emergency Braking and Forward Collision Warning), 65-83% of the owners were unaware that their car came with these systems [ID5]. Similarly, a small case study in Sweden reported that two out of three buyers of a new Volvo did not know that their new car was equipped with Pilot Assist, Volvo's implementation of Active Driving Assistance [ID52]. A large American survey (n = 1380) found that up to 50% of new buyers were not aware that the vehicle they test drove was equipped with ADAS such as Adaptive Cruise Control, Blind Spot Monitoring, Automatic Emergency Braking or Lane Keeping [ID44]. When users are aware of the availability of ADAS, their previous experience with similar systems will affect their mental model of the new system(s). Here, differences between different generations of the same system or between systems from different brands come into play. For example, early versions of Adaptive Cruise Control were limited to regulating vehicle speed only within a certain range, with the driver being responsible for stopping the car if necessary. Modern ACC systems come with Stop & Go capability and will bring the vehicle to standstill to avoid stationary obstacles, even starting to drive again once the path has cleared (at least within a short timeframe). Users transitioning from one ACC generation to the next will need to update their mental model in order to be able to use the system safely and appropriately. This is even more pressing when changing to a different brand, in which a similar ADAS may have different capabilities, limitations and a different HMI.

Table 1. Information sources for mental model development.

| Category | Source | Description | Remarks |
|---|---|---|---|
| **Before ADAS use** | Expectations | Based on advertisements, newspaper/magazine articles, social media, previous experience | Initial mental models will be largely based on the user's expectations |
| | Explanation/training | At car dealer's or dedicated training facilities | Initial training sets the stage for awareness of ADAS capabilities and limitations |
| | Car manual | The car manual describes ADAS capabilities, limitations and options | Manual quality, readability and completeness varies widely across brands |
| **During ADAS use** | Trial and error | Experiencing system failures (incl. false alarms, misses), trying out features | First negative experiences may limit use; unsafe situations may occur with system failures or usage outside ODD |
| | Car manual | The car manual describes ADAS capabilities, limitations and options | Manual quality, readability and completeness varies widely across brands |
| | System feedback / HMI | The HMI displays ADAS status and control options | Availability and quality of the HMI strongly influences to what extent the user's mental model can be updated |

Since many ADAS such as Adaptive Cruise Control, Automatic Emergency Braking or Lane Centring still have a relatively low market penetration (see [ID28]), many buyers encounter these systems currently for the first time when buying a new car

[ID44]. Their initial mental model, if at all existing, will therefore be largely based on information encountered before actually driving the car, such as advertisements, manufacturer websites, magazine or newspaper articles or social media. The way different car manufacturers name their implementations of various ADAS may play a role in shaping user expectations. For instance, Tesla's name for Active Driving Assistance, 'Autopilot', suggests self-driving capabilities, even though the user is still responsible for driving safely and is required to keep the hands on the steering wheel [ID5310]. Even when aware of the existence of a given ADAS, many first time users indicate that they do not know how the system works (up to over 50% for various ADAS, according to [ID44] (see Table 2).

Table 2. Percentage of new car buyers that agreed with various statements regarding several ADAS (from [ID44]).

| ADAS: | ACC | LDW | LKA | FCW | AEB | BSD |
|---|---|---|---|---|---|---|
| Did **not** understand how system worked before purchase | 52 | 50 | 56 | 51 | 48 | 28 |
| Recalled being offered training at dealer's | 45 | 52 | 56 | 43 | 42 | 50 |
| Learned about system from manual | 48 | 46 | 49 | 46 | 46 | 39 |
| Learned about system by trial and error | 34 | 24 | 31 | 21 | 23 | 26 |
| Did **not** seek information about system | 25 | 31 | 25 | 30 | 28 | 34 |
| Better understanding of system after use | 83 | 90 | 92 | 86 | 83 | 90 |
| Experienced confusion about system | 14 | 13 | 13 | 18 | 16 | 10 |

The first experiences with an ADAS not only strongly influence the actual usage of the system, but the first experiences also have a large impact on the development of an adequate mental model and of trust in the system. Negative first experiences lower the chances of using the system, thereby preventing users from building a correct mental model [ID52]. This implies that the first explanations of how an ADAS works given to a customer by a car dealer's representative play an important role in shaping future use and mental model development. In the survey by [ID44], about half the respondents indicated that they remembered being offered a training by the car dealer, with a large proportion (over 80%) accepting and completing this training [ID44]. Training in the use and limitations of specific systems has been found to improve recognition and understanding of temporary deactivation of for instance the Lane Centring system [ID424]. Although these initial experiences may have a long-lasting effect on usage and mental models, negative experiences may slowly lose their effect if drivers still continue to use the ADAS and further develop and refine their mental model by continued experience [ID153] [ID32].

Regular use of ADAS helps users calibrate their mental models to match the actual capabilities and performance of the systems [ID227] [ID32]. In a sense, the system's fallibility provides users with opportunities to update their mental models and stay 'in the loop' [ID605]. Many drivers indicate that they have learned about the ADAS available in their car largely through trial and error. A recent American survey (n = 51) reported that the large majority of users (82%) were confident that they knew when their car had correctly detected lane markings [ID465]. Just over half of them also reported that lane marking detection was consistent, suggesting that users do become aware of system limitations through usage. However, the most frequent source of information reported by drivers is still the car's manual, used by almost half the drivers [ID153] [ID44] (see Table 2). Our own ADAS overview indicates that manuals from different car manufacturers vary widely in quality, readability and completeness [ID5384]. A substantial part of drivers (up to 25%, depending on the specific ADAS) indicate that they have never sought out any information about their ADAS, which of course does not mean that they did not learn by doing [ID44]. Although learning by trial and error may be effective, it also poses a safety risk, as incorrect use of ADAS may cause dangerous driving situations. Moreover, repeated experience of unexpected failures may result in a steady decrease in trust and acceptance of the system over time [ID153]. Even though informing users of all possible limitations and problems with ADAS before they start using these systems will also lower trust and acceptance in the short run, it may still be more desirable to have users start with a realistic mental model, ensuring that it matches their future experience with the systems. This promotes correct use and allows for further refinement of their mental model with experience [ID153]. One factor that may hinder this process of mental model calibration and refinement is the fact that serious system failures are relatively rare and often occur only in (combinations of) extreme situations. Some authors therefore recommend periodical reminders of system limitations (for example by intelligent tutoring systems), to ensure that these limitations remain active in the user's mental model [ID111]. [ID5361] suggested that drivers could glean the requisite skills and knowledge of the available ADAS in their cars or hired or shared vehicles via an interactive in-vehicle coaching tool, over and above what is provided by a typical owner's manual. Such an in-car tutoring system can be applied when a driver purchases a from a dealership. The following training regime could be instigated:

(1) Forecourt introduction: High-level face-to-face introduction of the main vehicle-specific automation functions at the dealership. Given that this relies on memory and there is no driving context, this introduction should be brief, non-technical and provide an overview of the coaching facility.
(2) Coaching period: When the driver takes possession of the vehicle, it runs in "coaching" mode, where drivers are required to engage/disengage automation, such that handover can be practiced. This is recorded and feedback provided at the end of each trip. The length (time or distance) of the coaching mode depends on driver performance.
(3) Probation period: Following the coaching period, the driver enters a probation period. Feedback can be provided to the driver based on his or her interactions with the automation and the errors/misuses recorded. When a minimum threshold is reached, the driver can proceed to the next stage.

Another factor that determines how much usage of a system contributes to mental model development is the information displayed by the system to the user concerning its status. Studies found that continuous feedback on ACC status increased the frequency of proactive responses to automation failures and improved system understanding, compared to discrete feedback, especially when using a combined visual-auditory interface [ID448]. Thus, both the availability and the quality of system feedback is important in shaping a user's mental model. This includes aspects such as feedback timing, perceptibility (be it visual, auditory or tactile) and discriminability between feedback from different systems.

Mental model development is also affected by several user characteristics (see Table 3). The degree to which a user trusts a system will determine both the frequency of use and the way it is used. Users with a high degree of trust tend to use an ADAS more frequently, in a larger set of conditions. Conversely, low trust reduces use. Also, low trust makes users more sceptical, paying more attention to possible system failures. On the other hand, low trust may also make users less inclined to pay attention to a system's warnings [ID497]. Other motivational factors may also play a role. Users who buy ADAS because they are interested in the newest technology will use these systems differently from those who for instance are merely interested in driving comfortably, with the least amount of hassle. The first group will spend more time gathering information about the system, either from the vehicle's manual or other sources, and will more frequently try out the system in different situations. The second group wants to spend as little time as possible in trying to understand the system and just expects the technology to work. Other motivational factors such as sensation seeking and locus of control will also affect how drivers use ADAS and how they develop their mental models. Several factors may be related to age. Younger users typically have more experience with new technology. Older users in part are more resistant to new technology, but on the other hand also can benefit from ADAS that compensate for the cognitive and perceptual-motor decline that comes with old age. The latter matches findings such as increased willingness to use multiple ADAS with older age and lower likelihood of LDW deactivation [ID5314] [ID506]. Professional drivers, finally, receive more training than non-professional drivers, both in driving and in using vehicle systems such as ADAS. This training often continues on the job, while at the same time they also spend more time driving than most non-professional drivers. This gives professional drivers ample opportunity to refine their mental models.

Table 3. User characteristics that influence mental model development

| User characteristic | Description | Remarks |
|---|---|---|
| Trust in automation | The trust in driving automation and actual use made of automated systems | The degree of trust in automation influences actual system use and thereby exposure to the system's capabilities and limitations |
| Motivation | Intent to use technology, motives behind using a vehicle equipped with ADAS | Safety- or technology focused users may use and understand ADAS in a different way than comfort- or speed-focused users |
| Age | Different age groups | Age can be confounded with other factors, such as exposure to new technology in general, openness to new technology |
| Personality traits | Traits such as locus of control and sensation seeking | Persons with internal locus of control may be reluctant to relinquish control to automation; sensation seeking may lead to misuse; these factors also influence driving style |
| User group | Professional vs. non-professional drivers | Professional drivers receive more training and more experience with system use |

## 5.4 Evaluation of mental ADAS models

Accurate mental models are a necessary but not sufficient condition for the safe use of ADAS. They also contribute to the driving comfort that these systems aim to provide. Users with a good mental model of a system are more likely to use it appropriately and to be able to cope adequately with system failures or limitations [ID4771]. Moreover, good mental models will reduce misuse by awareness of the systems' Operational Design Domain (ODD). Consequently, accurate mental models will help calibrate the user's trust in the system to an appropriate level, neither over- or underestimating its capabilities ([ID108] [ID216]). The question then arises how good current mental models of ADAS users really are.

### *5.4.1 System consistency*

A user's mental model not only depends on the amount of information that is available concerning the system's performance and limitations, but also on how consistent that information is. Since a large part of the information on ADAS comes from experiencing its performance during driving, inconsistent system performance hinders the development of appropriate mental models. Currently, it appears that this varies widely between different ADAS. Many users experience ACC performance as quite good, not noticing any obvious limitations, even to the extent that they are unaware of its actual limitations (for instance in identifying motorcycles near the edge of the lane) [ID5349]. The available information concerning the ACC system, including system performance, apparently is sufficiently consistent to form a stable mental model, albeit an incomplete one. For Lane Centering on the other hand, users in one study noticed that the system often struggled with common road features such as hills and intersections, which made them feel uncomfortable in using the system [ID425]. One reason for this may be that they fail to understand why the system works in some situations, but not in others and therefore cannot predict system performance. Users have also expressed their frustration with Driver State Monitoring, because they did not understand why the system warned of drowsiness when it did [ID178]. Generally, the extent to which ADAS performance conforms to users' expectations is highly correlated with how much these systems improved their driving experience [ID465]. Thus, consistent and predictable system behaviour is a prerequisite for the possibility of forming an appropriate mental model of the system.

#### *5.4.2 Rare exposure to system limitations*

If a system's performance is sufficiently consistent, the user can build a mental model through repeated use. However, many of the limitations of the system may not be obvious to the user during normal use. Hence, the user is not reminded of these limitations and may fail to integrate them into the mental model. As already mentioned above, extensive (positive) experience with longitudinal distance control by ACC seems to make users forget or ignore the system's limitations, for instance in detecting small vehicles [ID4916]. On the other hand, regularly encountered limitations or characteristics of a system feature more prominently in users' mental models. For instance, most respondents (81%) in the large survey (n = 1380) by [ID44] understood that LDW provides a warning when the vehicle is unintentionally leaving its lane and nearly 75% of respondents correctly answered that LDW does not work when the turn signal is activated in the direction that the vehicle is departing its lane [ID44]. Still, 15% of the respondents in this study incorrectly believed that LDW can also gently steer the vehicle back into the lane. [ID44] found similar results for LKA, with 78% of the respondents understanding that LKA would not keep the vehicle in the lane when the turn signal was activated. Only a small group of respondents (4%) did not understand that fog and heavy precipitation could negatively impact the system's ability to perform and 13% of respondents were unsure of the correct response. Another group of systems where limitations (fortunately) are rarely experienced are FCW and AEB, which ideally are only triggered by impending (near) collisions. Nearly one third of respondents of [ID44] incorrectly believed that the FCW system would not only warn, but also automatically brake in the case of an impending frontal collision. For AEB, 10% of respondents thought that the system would also alert the driver about any collisions in the rear of the vehicle. In the case of BSW, nearly 30% of respondents incorrectly believed that this system was also designed to accurately detect motorcycles, bicycles and pedestrians [ID44]. In summary, mental models only are updated to reflect a system's limitations if the user is aware of these limitations and regularly reminded of them. Since this is not often the case during normal use in the most common circumstances, these limitations do not feature prominently in users' mental models. Consequently, when these limitations become apparent to the user, they are often unexpected and harder to deal with safely. In addition, drivers are typically not focused on detecting system failures or limitations. In a video study (n = 80), participants rarely noticed when the ACC system failed to detect a vehicle ahead, nor did they understand the reasons for this [ID424]. Drivers buy ADAS to use their capabilities, not to keep track of their limitations.

#### *5.4.3 System feedback*

Even though studies have reported that almost 50% of drivers indicated that they have used the car's manual to inform themselves about the ADAS functionality in their vehicle ([ID44], [ID153]), it is unlikely that they keep doing this regularly during the entire time they own the vehicle. Therefore, it is critical that the ADAS provide the user with accurate and useful information during actual use. An important caveat here is that the system cannot indicate to the user what it does not know. Hence, when a system for instance fails to detect an obstacle, it cannot report this to the user. It might be possible to show a representation of the sensor data that allows the user to evaluate the accuracy of the system, but care has to be taken not to burden the user with too much information, leading to overload and/or distraction. Another possibility is to let the system indicate limitations in system performance by self-diagnosing sensor performance. For instance, camera-based systems may detect unfavourable lighting conditions and indicate to the user that performance may be unreliable. In fact, Lane Centering and ACC systems already disable themselves in such cases and warn the user visually and/or acoustically (e.g., [ID5288]). This is often not mentioned in vehicle manuals, although the user is warned not to use the systems under these conditions (e.g., [ID5284], [ID5285], [ID5289]). Thus, the user is often left in the dark concerning the reason why a system suddenly deactivates itself while driving, making it difficult to predict the next time this will occur. However, in situations where ADAS deactivate themselves, the user should also not be burdened with too much information, since he/she needs to take over the part of the driving task that the ADAS performed or supported up till then. Thus, a balance has to be found between sufficient information to understand system performance, but not too much information, in order not to be distracting. This becomes even more pressing when multiple, partially overlapping ADAS are present in a vehicle. Research shows that drivers regularly confuse notifications for these systems [ID424].

# 6 Conclusions

## 6.1 ADAS use

Regarding the use of ADAS, some common themes come forward:

1. The use of ADAS and the research that focuses on this subject tends to be prone to selective recruitment. In other words: drivers who already drive safely and are safety-conscious tend to be the ones who adopt new safety systems first. Furthermore, they also seem to be more willing to participate in studies that focus on this topic. This has clear implications for the (safety) potential of ADAS, because the possibilities for improving safe driving of drivers who already drive safely are limited, compared to drivers who drive less safely. Indeed, drivers who are less safety-conscious are the ones who would benefit the most from using ADAS, but they tend to use it the least. In line with this finding, ADAS also tend to be used less or are unusable in situations where they would be most useful (e.g. bad visibility, heavy traffic).

2. Concerning specific systems, the availability of use data is mainly limited to systems that are already available for longer periods of time (e.g. ACC, ISA, LDW). Even though this might provide some information about the use of other systems, as these may be partly based on (combining) some of the earlier available systems, it remains unclear whether use patterns will generalize to other ADAS. Furthermore, there is also little knowledge about the effects of variations between system designs of different car brands, for example.

3. Longer use of and experience with ADAS may not only influence the amount trust in a system, but also how often a system is used and how it affects driving behaviour. This differs between systems as, for example, the effects of ISA may wear off over time because the system is used less often; for ACC, use seems to increase over time; while findings about the use of LDW over time are inconsistent. It is therefore difficult to form general conclusions about how system use develops over time. Use over time will be correlated with the feelings of drivers while using the system. Particularly annoyance or frustration should be prevented, as this could lead to reduced ADAS use, even when drivers believe that it is a useful or safe system. However, there are also indications that drivers keep using a system despite it sometimes being annoying, as long as they believe that a system is useful and/or safe. Customisable system settings could provide a solution for finding a balance between perceived usefulness and annoyance, as adjustable settings may enable drivers to find a ‘less annoying’ setting without having to disable a system entirely.

4. The use of ADAS can also lead to behavioural adaptation and carry-over effects. For example, drivers could get used to shorter following distances due to driving with (C)ACC and may therefore follow cars more closely while driving manually as well. Furthermore, turning off LC may lead to

increased swerving while BSD use could lead to a decrease in indicating direction usage. Perhaps most importantly, however, is that increased experience and trust in ADAS may also lead to more engagement in non-driving related tasks, which could undermine traffic safety. Even though most drivers report not feeling comfortable with engaging in activities such as making a phone call or texting while driving, research indicates that providing ADAS does increase the chances of drivers doing so. In particular while using systems that automate multiple parts of the driving task (e.g. ADA), the chances that drivers will initiate secondary tasks increases significantly. It is therefore important that drivers are always aware that they remain fully responsible for driving the car and that they are conscious of how a system functions in the context of the driving environment.

## 6.2 Mental models

As technological developments keep pushing the boundaries of ADAS, these systems become at the same time more capable and more complex. For the user, this means keeping up with changes in the ADAS he/she is using and adapting to new systems that may combine features from existing systems. Thus, the demands on users' mental models also change. As noted above, a user's mental model is never complete or 100% accurate and neither does it need to be. A mental model needs to enable the user to use a system effectively and safely in a dynamic environment. Human Factors guidelines for ADAS should promote the development of such adequate mental models by guiding the design of ADAS and their HMIs. The literature review described in Chapter 5 suggests several findings concerning mental models that should be considered when formulating these guidelines:

1. Once formed, mental models tend to resist major change. Even though mental models are not static and are refined through experience, research suggests that users rarely adjust their basic understanding of a system. Therefore, it is crucial to promote the development of appropriate mental models at or even before first use, since fundamentally incorrect models are hard to change later on. Training and clear but succinct information when starting to use ADAS can support users in starting on the right track.

2. Users tend to overgeneralize their positive experience in daily use of an ADAS and to forget or ignore its limitations. However, it is exactly these limitations that can cause unexpected system behaviour and safety risks. Although it is not realistic to expect users to be aware of all system limitations at all times, system design, system HMI and user training should be aimed at promoting sufficient awareness of these limitations to be able to deal with them when they arise. Part of the challenge is to determine what 'sufficient' awareness is and how it could be measured.

3. The concept of a mental model is closely related to that of trust in a system. Adequate mental models of a correctly functioning ADAS will engender trust in that system through experience. For a bad system, an accurate mental model will lead to low levels of trust, which in turn may lead to less system use. Conversely, a user's level of trust also influences the development of a mental model. Low trust makes users sceptical and may

even prevent them from using a system. High trust may make them complacent, causing them to ignore a system's limitations. Thus, both may limit the development of an accurate mental model of the system. The appropriate level of trust of course depends on the degree to which a system's capabilities and that of the user correspond. Trust and mental models should be considered together in formulating guidelines for ADAS.

4. System feedback during use is important for refinement and calibration of a user's mental model. Therefore, usability of the system's HMI plays an important role and guidelines should specify requirements for HMIs. An important consideration is how the HMIs for different systems work together. As modern vehicles are equipped with an increasing number of ADAS, which also start to overlap in their functionality (for instance, ACC, FCW and AEB, or LDW, LKA and LC), both consistency and discriminability of the HMIs become more important. This not only holds for within one vehicle, but also between vehicles from different brands.

5. Mental models do not only depend on system performance and the information concerning a system that is available to the user, but also vary across different types of users. Drivers have different capabilities in understanding and interacting with ADAS, as well as different motives in using them. The literature pays little attention to these individual differences. The question is whether guidelines for the Human Factors aspects of ADAS should focus on an average user, or should describe different requirements for different groups of users. This is of course related to the question whether system functionality itself should be adapted to the user.

6. Little is known regarding the long term changes in and effects of mental models concerning ADAS. Most studies test the effects of different systems or system variants on users' trust, mental models and/or performance at one point of time. Longitudinal studies that track these aspects over long periods of time are only rarely conducted. As systems increasingly are updated during their lifetime (e.g., by software updates), ensuring that mental models are not only adequate when a driver starts using a new system, but also over time becomes more and more important.

# 7 References

[ID1] AAA (2020). Evaluation of Active Driving Assistance Systems (report). Washington, D.C.: American Automobile Association, Inc.

[ID5] Harms, I. M., Bingen, L. & Steffens, J. (2020). Addressing the awareness gap: A combined survey and vehicle registration analysis to assess car owners' usage of ADAS in fleets. Transportation Research Part A: Policy and Practice 134, 65-77.

[ID8] Roozendaal, J., Johansson, E., de Winter, J., Abbink, D. & Petermeijer, S. (2020). Haptic Lane-Keeping Assistance for Truck Driving: A Test Track Study. Human Factors 0 (0), 0018720820928622.

[ID15] Dunn, N., Dingus, T. & Soccolich, S. (2019). Understanding the Impact of Technology: Do Advanced Driver Assistance and Semi-Automated Vehicle Systems Lead to Improper Driving Behavior? (report). Washington, DC: AAA Foundation for Traffic Safety.

[ID16] Ekman, F., Johansson, M., Bligård, L.-O., Karlsson, M. & Strömberg, H. (2019). Exploring automated vehicle driving styles as a source of trust information. Transportation Research Part F: Traffic Psychology and Behaviour 65, 268-279.

[ID19] Kidd, D. & Reagan, I. (2019). Attributes of Crash Prevention Systems that Encourage Drivers to Leave Them Turned on. Advances in Intelligent Systems and Computing 786, 523-533.

[ID28] SWOV (2019). Intelligent transport and advanced driver assistance systems (ITS and ADAS). The Hague: SWOV.

[ID32] Bazilinskyy, P., Petermeijer, S., Petrovych, V., Dodou, D. & de Winter, J. (2018). Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays. Transportation Research Part F: Traffic Psychology and Behaviour 56, 82-98.

[ID42] Madigan, R., Louw, T. & Merat, N. (2018). The effect of varying levels of vehicle automation on drivers' lane changing behaviour. PLoS ONE 13 (2).

[ID44] McDonald, A., Carney, C. & McGehee, D. V. (2018). Vehicle Owners' Experiences with and Reactions to Advanced Driver Assistance Systems (report). Washington, DC: AAA Foundation for Traffic Safety.

[ID45] Miller, E. E. & Boyle, L. N. (2018). Behavioral Adaptations to Lane Keeping Systems: Effects of Exposure and Withdrawal. Human Factors, Vol. 61, No. 1, February 2019, pp. 152 –164.

[ID46] Molnar, L., Ryan, L., Pradhan, A., Eby, D., St. Louis, R. & Zakrajsek, J. (2018). Understanding trust and acceptance of automated vehicles: An exploratory simulator study of transfer of control between automated and manual driving. Transportation Research Part F: Traffic Psychology and Behaviour 58, 319-328.

[ID48] Reagan, I. J., Cicchino, J. B., Kerfoot, L. B. & Weast, R. A. (2018). Crash avoidance and driver assistance technologies – Are they used?. Transportation Research Part F: Traffic Psychology and Behaviour 52, 176 - 190.

[ID52] Strand, N., Stave, C. & Ihlström, J. (2018). A case-study on drivers' mental model of partial driving automation. In Proceedings 25th ITS World Congress, Copenhagen. Denmark: 17-21 September 2018.

[ID53] Varotto, S. F. (2018). Driver Behaviour during Control Transitions between Adaptive Cruise Control and Manual Driving: Empirics and Models. Unpublished doctoral disseration, TU Delft.

[ID54] Victor, T., Tivesten, E., Gustavsson, P., Johansson, J., Sangberg, F. & Ljung Aust, M. (2018). Automation Expectation Mismatch: Incorrect Prediction Despite Eyes on Threat and Hands on Wheel. Human Factors 60 (8), 1095 -?1116.
[ID72] Kidd, D. G., Cicchino, J. B., Reagan, I. J. & Kerfoot, L. B. (2017). Driver trust in five driver assistance technologies following real-world use in four production vehicles. Traffic Injury Prevention, 1-7.
[ID87] de Winter, J., Gorter, C., Schakel, W. & van Arem, B. (2017). Pleasure in using adaptive cruise control: A questionnaire study in The Netherlands. Traffic Injury Prevention 18 (2), 216-224.
[ID103] Naujoks, F., Purucker, C. & Neukum, A. (2016). Secondary task engagement and vehicle automation - Comparing the effects of different automation levels in an on-road experiment. Transportation Research Part F: Traffic Psychology and Behaviour 38, 67-82.
[ID108] Schaefer, K. E., Chen, J. Y. C., Szalma, J. L. & Hancock, P. A. (2016). A Meta-Analysis of Factors Influencing the Development of Trust in Automation: Implications for Understanding Autonomy in Future Systems. Human Factors: The Journal of the Human Factors and Ergonomics Society 58 (3), 377-400.
[ID111] Beggiato, M., Pereira, M., Petzoldt, T. & Krems, J. (2015). Learning and development of trust, acceptance and the mental model of ACC. A longitudinal on-road study. Transportation Research Part F: Traffic Psychology and Behaviour 35, 75-84.
[ID122] Pereira, M., Beggiato, M. & Petzoldt, T. (2015). Use of adaptive cruise control functions on motorways and urban roads: Changes over time in an on-road study. Applied Ergonomics 50, 105-112.
[ID134] De Winter, J. C. F., Happee, R., Martens, M. H. & Stanton, N. A. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. Transportation Research Part F: Traffic Psychology and Behaviour 27 (PB), 196-217.
[ID136] Kircher, K., Larsson, A. & Hultgren, J. A. (2014). Tactical driving behavior with different levels of automation. IEEE Transactions on Intelligent Transportation Systems 15 (1), 158-167.
[ID153] Beggiato, M. & Krems, J. F. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. Transportation Research Part F: Traffic Psychology and Behaviour 18, 47-57.
[ID163] Xiong, H. & Boyle, L. (2013). Drivers' selected settings for adaptive cruise control (ACC): Implications for long-term use. In (pp. 1928-1932). . (ISBN: 9780945289432.).
[ID164] Benmimoun, M., Pütz, A., Ljung Aust, M., Faber, F., Sánchez, D., Metz, B., Saint Pierre, G., Geißler, T., Guidotti, L. & Malta, L. (2012). EuroFOT Final evaluation results (Deliverable D6.1).
[ID170] Sanchez, D., Garcia, E., Saez, M., Benmimoun, M., Pütz, A., Aust, M. L., Gustafsson, D., Metz, B., Pierre, G. S., Tattegrain, H., Guidotti, L., Schindhelm, R., Heinig, I., Malta, L. & Obojski, M.-A. (2012). Final results: User acceptance and user-related aspects (Deliverable D6.3). EuroFOT.
[ID172] Xiong, H. & Boyle, L. N. (2012). Drivers’ Adaptation to Adaptive Cruise Control: Examination of Automatic and Manual Braking. IEEE Transactions on Intelligent Transportation Systems 3 (13), 1468-1473.
[ID178] Strand, N., Nilsson, J., Karlsson, M. & Nilsson, L. (2011). Interaction with and use of driver assistance systems: a study of end-user experiences. In Proceedings of the 18th World Congress on Intelligent Transport Systems. Orlando, Florida, USA: October.

[ID181] Lai, F., Hjämdahl, M., Chorlton, K. & Wiklund, M. (2010). The long-term effect of intelligent speed adaptation on driver behaviour. Applied Ergonomics 41 (2), 179-186.

[ID185] Pauwelussen, J. & Feenstra, P. (2010). Driver Behavior Analysis During ACC Activation and Deactivation in a Real Traffic Environment. IEEE Transactions on Intelligent Transportation Systems.

[ID198] Viti, F., Hoogendoorn, S., Alkim, T. & Bootsma, G. (2008). Driving behavior interaction with ACC: Results from a Field Operational Test in the Netherlands. In IEEE Intelligent Vehicles Symposium, Proceedings (pp. 745 - 750).

[ID199] Warner, H. & Aberg, L. (2008). The long-term effects of an ISA speed-warning device on drivers' speeding behaviour. Transportation Research Part F: Traffic Psychology and Behaviour 11 (2), 96-107.

[ID211] Rook, A. M. & Hogema, J. H. (2005). Effects of Intelligent Speed Adaptation HMI Design on Driving Behavior and Acceptance. Transportation Research Record (1937), 79-86.

[ID216] Lee, J. & See, K. (2004). Trust in automation: Designing for appropriate reliance. Human Factors 46 (1), 50-80.

[ID220] Carsten, O. (2002). European Research on ISA: Where Are We Now and What Remains To Be Done. In ICTCT Workshop on Intelligent Speed Adaptation.

[ID227] Boer, E. R. & Hoedemaeker, M. (1998). Modelling driver behaviour with different degrees of automation: a hierarchical decision framework of interacting mental models. In Proceedings of the 17th European Annual Conference on Human Decision Making and Manual Control,.

[ID233] Andre, A. & Degani, A. s. (1997). Do you know what mode you're in? An analysis of mode error in everyday things. In M. Mouloua & J.M.Koonce (ed.),Human-automation interaction: Research and practice. .

[ID400] Braitman, K., McCartt, A., Zuby, D. & Singer, J. (2010). Volvo and Infiniti drivers' experiences with select crash avoidance technologies. Traffic Injury Prevention 11 (3), 270-278.

[ID424] Alexandra S. Mueller, Jessica B. Cicchino, Jeremiah Singer, James W. Jenness, Effects of training and display content on Level 2 driving automation interface usability, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 69, 2020.

[ID425] Ian J. Reagan, Jessica B. Cicchino, David G. Kidd (2020), Driver acceptance of partial automation after a brief exposure, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 68.

[ID443] Chaozhong Wu, Haoran Wu, Nengchao Lyu, Mengfan Zheng. (2019) Take-Over Performance and Safety Analysis Under Different Scenarios and Secondary Tasks in Conditionally Automated Driving. IEEE Access 7, pages 136924-136933.

[ID448] Bobbie D. Seppelt, John D. Lee (2019), Keeping the driver in the loop: Dynamic feedback to support appropriate use of imperfect vehicle control automation, International Journal of Human-Computer Studies, Volume 125.

[ID459] Becic, Edwards, Manser, M.P. and Donath, M. (2018). Aging and the use of an in-vehicle intersection crossing assist system: An on-road study. Transportation Research Part F: Traffic Psychology and Behaviour, Volume 56, pp 113-122.

[ID462] Osama Halabi, Mariam A. Bahameish, Latefa T. Al-Naimi & Amna K. Al-Kaabi (2019) Response Times for Auditory and Vibrotactile Directional Cues in

Different Immersive Displays, International Journal of Human–Computer Interaction, 35:17, 1578-1585.
[ID464] Daniël D. Heikoop, Joost C.F. de Winter, Bart van Arem, Neville A. Stanton (2018), Effects of mental demands on situation awareness during platooning: A driving simulator study, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 58.
[ID465] David G. Kidd & Ian J. Reagan (2019) System Attributes that Influence Reported Improvement in Drivers' Experiences with Adaptive Cruise Control and Active Lane Keeping after Daily Use in Five Production Vehicles, International Journal of Human–Computer Interaction, 35:11, 972-979.
[ID497] Jordan Navarro (2017) Human–machine interaction theories and lane departure warnings, Theoretical Issues in Ergonomics Science, 18:6, 519-547.
[ID506] Dustin J. Souders, Ryan Best, Neil Charness, (2017) Valuation of active blind spot detection systems by younger and older adults, Accident Analysis & Prevention, Volume 106, Pages 505-514.
[ID560] Skottke, E.-M., Debus, G., Wang, L., & Huestegge, L. (2014). Carryover Effects of Highly Automated Convoy Driving on Subsequent Manual Driving Performance. Journal of Black Studies, 56(7), 448–480.
[ID561] Ioanna K. Spyropoulou, Matthew G. Karlaftis, Nick Reed (2014), Intelligent Speed Adaptation and driving speed: Effects of different system HMI functionalities, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 24, Pages 39-49.
[ID582] Ian J. Reagan, James P. Bliss (2013), Perceived mental workload, trust, and acceptance resulting from exposure to advisory and incentive based intelligent speed adaptation systems, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 21, Pages 14-29.
[ID586] Guozhen Zhao, Changxu Wu (2013), Effectiveness and acceptance of the intelligent speeding prediction system (ISPS), Accident Analysis & Prevention, Volume 52, Pages 19-28.
[ID596] Jamson, S., Chorlton, K., and Carsten, O. (2012). Could Intelligent Speed Adaptation make overtaking unsafe?. Accident Analysis and Prevention 48, 29-36.
[ID598] Felipe Jiménez, Yingzhen Liang, Francisco Aparicio (2012), Adapting ISA system warnings to enhance user acceptance, Accident Analysis & Prevention, Volume 48, Pages 37-48.
[ID601] Harry Lahrmann, Niels Agerholm, Nerius Tradisauskas, Kasper K. Berthelsen, Lisbeth Harms (2012), Pay as You Speed, ISA with incentives for not speeding: Results and interpretation of speed data, Accident Analysis & Prevention, Volume 48, Pages 17-28.
[ID604] Frank Lai, Oliver Carsten (2012), What benefit does Intelligent Speed Adaptation deliver: A close examination of its effect on vehicle speeds, Accident Analysis & Prevention, Volume 48, Pages 4-9.
[ID605] Larsson, A.F.L. (2012). Driver usage and understanding of adaptive cruise control. Applied Ergonomics 43 (3), 501- 506.
[ID611] Muhrer, E., Reinprecht, K., and Vollrath, M. (2012) Driving with a partially autonomous forward collision warning system: How do drivers react?. Human Factors 54 (5), 698- 708.
[ID637] Sven Vlassenroot, Karel Brookhuis, Vincent Marchau, Frank Witlox (2010), Towards defining a unified concept for the acceptability of Intelligent Transport Systems (ITS): A conceptual analysis based on the case of Intelligent Speed

Adaptation (ISA), Transportation Research Part F: Traffic Psychology and Behaviour, Volume 13, Issue 3, Pages 164-178.

[ID646] Tsang-Wei Lin, Sheue-Ling Hwang, Paul A. Green (2009), Effects of time-gap settings of adaptive cruise control (ACC) on driving performance and subjective acceptance in a bus driving simulator, Safety Science, Volume 47, Issue 5, Pages 620-625.

[ID660] Raymond J. Kiefer, Jonathan M. Hankey (2008), Lane change behavior with a side blind zone alert system, Accident Analysis & Prevention, Volume 40, Issue 2.

[ID686] Jamson, S. (2006) Would those who need ISA, use it? Investigating the relationship between drivers' speed choice and their use of a voluntary ISA system. Transportation Research Part F: Traffic Psychology and Behaviour 9 (3), 195- 206.

[ID706] Jörgen Garvill, Agneta Marell, Kerstin Westin (2003), Factors influencing drivers' decision to install an electronic speed checker in the car, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 6, Issue 1, Pages 37-43.

[ID809] Orlovska, J., Novakazi, F., Lars-Ola, B., Karlsson, M., Wickman, C., Söderberg, R. (2020). Effects of the driving context on the usage of Automated Driver Assistance Systems (ADAS) -Naturalistic Driving Study for ADAS evaluation. Transportation Research Interdisciplinary Perspectives, 4, 671-683.

[ID831] Metz, B., Wörle, J., Hanig, M., Schmitt, M., Lutz, A. (2020). Repeated usage of an L3 motorway chauffeur: Change of evaluation and usage. Information (Switzerland), 11 (2), 76-87.

[ID849] Blömacher, K., Nöcker, G., Huff, M. (2020). The evolution of mental models in relation to initial information while driving automated. Transportation Research Part F: Traffic Psychology and Behaviour, 68, 616.

[ID851] Cho, J., Heo, J. (2020). The More You Know, The More You Can Trust: Drivers' Understanding of the Advanced Driver Assistance System. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 12212 LNCS, 90052293628-3640.

[ID926] Castritius, S.-M., Dietz, C.J., Schubert, P., Moeller, J., Morvilius, S., Hammer, S., Tran, C.A., Haas, C.T. (2020). Truck Platooning Under Real Traffic Conditions: First Insights on Behavioral Adaptations and Gap Preference of Professional Drivers. Human Factors, , 133-144.

[ID1097] Wang, J., Soffker, D. (2019). Bridging Gaps among Human, Assisted, and Automated Driving with DVIs: A Conceptional Experimental Study. IEEE Transactions on Intelligent Transportation Systems, 20 (6), 9036741.

[ID1107] Epple, N., Dari, S., Drees, L., Protschky, V., Riener, A. (2019). Influence of cruise control on driver guidance - A comparison between system generations and countries. IEEE Intelligent Vehicles Symposium, Proceedings, 2019-June, 3365625.

[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.

[ID1672] Nowakowski, C., Shladover, S.E., Tan, H.-S. (2015). Heavy Vehicle Automation: Human Factors Lessons Learned. Procedia Manufacturing, 3, 80-87.

[ID4771] Gaspar, J., Carney, C., Shull, E. & Horrey, W. J. (2020). The Impact of Driver's Mental Models of Advanced Vehicle Technologies on Safety and Performance (report). AAA Foundation for Traffic Safety, SAFER-SIM.
[ID4916] Sullivan, John & Flannagan, Michael. (2019). Understanding Lane-Keeping Assist: Does Control Intervention Enhance Perceived Capability?. 405-411. 10.17077/drivingassessment.1725.
[ID5162] Houtenbos, M., Hegeman, G., & van Driel, C. (2005). Determining opportunities for overtaking assistance: combined efforts of a user needs survey and an interaction model. In ITS (Ed.), Proceedings 12th World Congress on ITS - Enabling choises in transportation. 6-10 November 2005, San Francisco, California. Paper 2477, on CD-Rom (pp. -). San Francisco, California: ITS.
[ID5264] Martens, M.H., Jenssen, G.D. (2012). Behavioral Adaptation and Acceptance. In: Eskandarian, A., Handbook of Intelligent Vehicles, pp. 117-138. London: Springer.
[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.
[ID5310] Tesla (2020). Model 3 Owner's Manual.
[ID5314] Flannagan, C., LeBlanc, D., Bogard, S., Nobukawa, K., Narayanaswamy, P., Leslie, A., Kiefer, R., Marchione, M., Beck, C. & Lobes, K. (2016). Large-Scale Field Test of Forward Collision Alert And Lane Departure Warning Systems (DOT HS 812 247). Ann Arbor, MI, USA: UMTRI.
[ID5334] Norman, D.A. (1983). Some observations on mental models. In: Gentner,D., Stevens, A.L., Mental Models. Psychology Press, New York, p. 7-14.
[ID5335] Strand, N., Stave, C., Ihlström, J. (2018), A case study of drivers' mental model of partial driving automation. 25th ITS World Congress.
[ID5336] Forster, Y., Hergerth, S., Naujoks, F., Beggiato, M., Krems, J.F., Keinath, A. (2019). Learning and Development of Mental Models during Interactions with Driving Automation: A Simulator Study. Proceedings of the 10th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design: driving assessment 2019.
[ID5341] Jones, S. (2013). Cooperative Adaptive Cruise Control: Human Factors Analysis. U.S. DoT Federal Highway Administration FHWA-HRT-13-045.
[ID5342] Kazi, T.A., Stanton, N.A., Walker, G.H., Young, M.S. (2007). Designer driving: drivers' conceptual models and level of trust in adaptive cruise control. International Journal of Vehicle Design, 45(3), 339-360.
[ID5344] Agerholm, N., Tradisauskas, N., Juhl, J., Berthelsen, K. K., & Lahrmann, H. (2012). Intelligent Speed Adaptation for involuntary drivers: Final results. ITS World Congress.
[ID5346] Balk, S.A., Jackson, S., Philips, B. (2016). Cooperative adaptive cruise control and driver merge type. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 1839-1843.
[ID5347] Inman, V.W., Jackson, S., Philips, B.H. (2016). Driver performance in a Cooperative Adaptive Cruise Control string. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 1184-188.
[ID5348] Rouse, W.B. & Morris, N.M. (1986). On Looking Into the Black Box. Prospects and Limits in the Search for Mental Models. Psychological Bulletin, 1986, 100, 349-363.

[ID5349] Jenness, J. W., Lerner, N. D., Maxor, S., Osberg, J. S., Tefft, B. C. (2008). Use of advanced in-vehicle technology by young and older early adopters: Selected results from five technology surveys (DOT HS 811 004). U.S. Department of Transportation - National Highway Traffic Safety Administration.
[ID5350] Endsley, M. R. (2000). Situation Models: An Avenue to the Modeling of Mental Models. In Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium' (pp. 61-64). Human Factors and Ergonomics Society.
[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.
[ID5353] Kleinman, D. L., Baron, S. & Levison, W. H. (1970). An optimal control model of human response. Part 1: Theory and validation. Automatica 6 (3), 357--369.
[ID5354] Souman, J., van Weperen, M., Hogema, J., Hoedemaeker, M., Westerhuis, F., Stuiver, A. & de Waard, D. (2020). Human Factors Guidelines report 2: Driver Support Systems Overview (TNO and RUG). TNO 2020 R12167.
[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
[ID5358] Zhang, T., Kaber, D. & Hsiang, S. (2010). Characterisation of mental models in a virtual reality-based multitasking scenario using measures of situation awareness. Theoretical Issues in Ergonomics Science 11 (1-2), 99-118.
[ID5359] SAE (2018). Taxonomy and Definitions for Terms Related to on-Road Motor Vehicle Automated Driving Systems; Society of Automotive Engineers: Warrendale, PA, USA, Volume 3016, pp. 1–16.
[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.
[ID5371] Connekt (2009). Accident prevention systems for lorries. Delft, The Netherlands: Connekt.