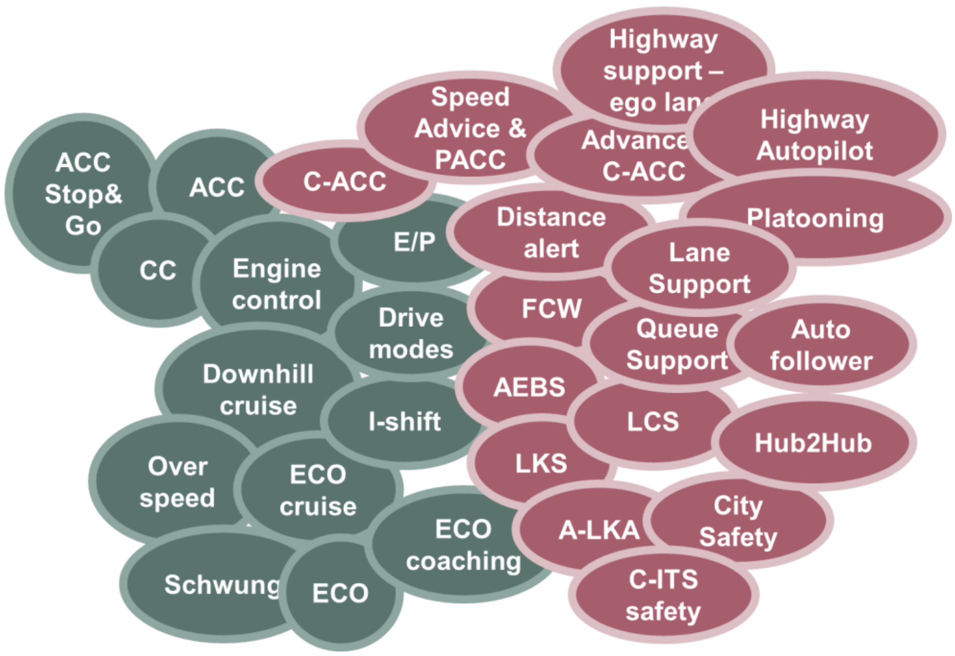
HARMONISE



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Project within Road Safety and Automated Vehicles

FFI Strategic Vehicle Research and Innovation

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1 Executive summary

HARMONISE is an FFI funded project that started in 2017 and ended in 2020. Partners are VOLVO Group Trucks Technology (VOLVO GTT), Volvo Cars and RISE. The main aim was to investigate different means to simplify and manage how drivers interact with different levels of automation throughout a journey.

The HARMONISE studies have aimed toward both theoretical insight and experimental results. On the theoretical side, RISE has held a series of workshops together with Skövde University on the topic of embodied cognition and its design implications for vehicle automation. Also, a State-of-the-Art report describing current market efforts at vehicle automation was generated early in the project.

On the experimental side, HARMONISE has performed several studies. To start with, a deep dive into truck drivers' everyday life was done to understand what types of secondary tasks they normally do while driving as well as why they do them. A main finding here was that long-haul truck drivers often feel bored and hence use secondary tasks as a coping strategy to alleviate boredom and to create social interaction. Coupled to these results, a simulator study was carried out to investigate in what way higher secondary task engagement might degrade driver performance in terms of visual scanning behavior. The results suggest that if drivers would use lower levels of vehicle automation to increase their secondary task engagement, their visual awareness of the lateral surroundings would decrease, while their visual awareness of the road ahead would remain unaffected.

VOLVO GTT, with support from RISE, also studied the influence of vehicle control algorithms on the risk for role switching, i.e. drivers switching from being active agents to passive observers when automation support increases, even if the vehicle is not fully autonomous. One test track study and one on-road study were performed. The results showed similar vehicle safety benefits for all tested control algorithms. It was however not possible to draw any conclusions regarding the risk for role switching based on the data collected.

Lastly, a potential problem when a car is fully autonomous is that while drivers technically are free to become passengers, they may not feel safe enough to do so, or just have a hard time stopping their normal traffic monitoring. To study these types of threats to the fully autonomous business case, Volvo Cars and RISE conducted an on-road study in a Wizard-of-Oz car where drivers' attention shifts at different levels of automation was investigated, along with their ability to complete a demanding non-driving related tasks under full automation. The results showed that participants could perform the NDRT just as well in the car as in an office environment. Furthermore, they had no problems to switch to a passenger role. In fact, several expressed surprise at how easily they disconnected from the driving task.

2 Background

The potential for vehicle automation to revolutionize transport efficiency in general and vehicle safety in particular is widely recognized, given that as much as 94% of crashes have been attributed to driver-related critical reasons such as recognition, decision and performance errors (NHTSA, 2015). It is assumed that automation, through advanced sensing, algorithms and crash avoidance systems, has the potential to both increase the throughput in the traffic system as well as significantly reduce the frequency of crashes and save lives.

However, it is also clear that the current level of human crash avoidance performance which automation must surpass to improve upon human performance is very high, since the frequency of crashes with injury outcomes is very low in relation to the total mileage in the traffic system (Johansson, 2009; Eugensson et al., 2011). Furthermore, extensive experience with human factors in other industry domains where automation has taken place over the last 50 years indicates that human factors issues are a key hurdle to be overcome if automation is to deliver on its promise of increased safety and efficiency (Bainbridge, 1983; Billings, 1988; Sheridan, 1992; Endsley & Kiris, 1995; Sarter & Woods, 1995; Parasuraman & Riley, 1997; Lee et al., 2017; Wiener & Curry, 1995).

Thus, to realize all the potential benefits of automation without creating new problems in the process, it follows that great care must be taken in its implementation, i.e. there is no reason to believe that driving will not be exposed to the same interaction design problems as other domains have experienced when going toward partial or full task automation. Supporting and interacting with the driver in the best possible way as function complexity and the degree of task automation increases is key to automation success.

3 Goals

The HARMONISE project was designed to generate not all, but at least parts, of the knowledge required to facilitate a smooth and safe transition toward higher levels of vehicle automation. By delivering theoretical insights into human cognition in the context of automation, along with experimental results from studies addressing problems like functional transparency and drivers' role switching, the results from HARMONISE were meant to contribute to Volvo Group and Volvo Cars' safety visions as well as internal research and development projects.

4 Results and goal achievements

HARMONISE has performed a number of studies and experiments in order to meet the goals described above. The results of these are reported below in an overview format, with the main findings from each study shortly highlighted. For further reading, references to either an appendix or a published paper is given at the end of each section.

4.1 Theoretical insights

To facilitate reading, the HARMONISE studies have been divided into work aiming toward theoretical insight and worked aimed at experimental studies. Here, the studies aimed at theoretical insights/overview are reported, while the experimental studies follow below.

The relationship between embodied cognition and automated driving

To develop further theoretical insights into the coupling between human cognition and automation, RISE has held a set of workshops together with Skövde University on the topic of embodied cognition and what design implications can be drawn for the driver role under changing levels of automation. The insights from these workshops resulted in a paper by Maria Klingegård, Jessica Lindblom and Emma Johansson entitled *"Changing point of view: implication of an embodied cognition perspective on the introduction of automated driving functionality"*. The paper has been submitted to a special issue on Critical Robotics Research to be published in AI & SOCIETY: Journal of knowledge, culture, and communication.

State-of-the-Art for vehicle automation in production vehicles

In order to create an inventory of existing efforts at vehicle automation and their respective attributes and implementation models, a State-of-the-Art report was also generated early on in the project. This report documents a set of existing driver support systems from some of the leading vehicle manufacturers, with the aim to provide a baseline understanding of technological readiness regarding automation, as well as design concept maturity. This State-of-the-Art report is attached as Appendix A below.

4.2 Experimental studies

A number of experimental studies have been performed. The main findings of these are reported below, with references to papers or Appendix for further reading.

The influence of vehicle control algorithms on role switching

To begin with, one of the critical vehicle automation risks that HARMOISE aimed to research is the fact that drivers might switch from an active agent role to a passive observer role when vehicle automation increases, even if the automation itself does not have full self-driving capabilities (i.e. still requires true driver engagement). While such switches can happen for many reasons, a very important one (from a vehicle developer's point of view) is the extent to which the actual vehicle control algorithm influences the propensity toward role switching. To understand this further, VOLVO GTT performed one experimental study on test track with a follow up study done on-road with support from RISE. The effectiveness and subjective acceptance of three different designs for haptic lane keeping assistance was evaluated in the test track study. In particular, the concepts of bandwidth vs continuous assistance were pitched against each other.

The results from these experiments showed that compared to unsupported driving, all three assistance systems provided similar safety benefits in terms of decreased absolute lateral position offset from the lane center as well as fewer lane departures during driving. The continuous assistance implementation was also rated higher in terms of acceptance, compared to the two bandwidth based concepts. However, it was not possible to draw any solid conclusions regarding the risk for role switching based on the data collected. Further details on the test track study are given in Roozendaal et al (2020).

As for the on-road study, a draft paper was generated, but as the differences between the lateral control concepts were very small in the on-road context, both in terms of the objectively and subjectively collected data, the project decided to not pursue a potential publication further.

Which role do secondary tasks play in professional driving?

The project also performed a deep dive into the everyday life of truck drivers with the aim of understanding what types of secondary tasks they normally do in their vehicles and which therefore must be accommodated for in safe ways when moving toward higher levels of automation (particularly in the sense that they may induce role switching as described above). In this deep dive, 13 long-haul truck drivers were observed and interviewed. Questionnaire data was also collected.

A main finding in this study that couples to the role switching problem was that long-haul truck drivers often feel bored and therefore use secondary tasks as a coping strategy to alleviate boredom as well as to create social interaction. In the context of vehicle automation, this means that increased levels of driving automation on one hand will make it easier for long-haul truck drivers to alleviate boredom by doing secondary tasks. On the other hand, if there already exists a strong motivation to engage in secondary tasks and increased automation facilitates their execution, the risk of drivers switching roles and potentially disengaging from their responsibilities as a driver increases. Perhaps somewhat counterintuitively, it follows that professional drivers might suffer a higher out-of-the-loop risk than private car drivers. Further details on study design, as well as many other findings regarding what drives secondary task engagement in long-haul truck drivers are reported in Iseland et. al. (2018).

Out-of-the-loop consequences to be compensated for by automation

In many domains where automation of previously manual tasks have been studied, it has been found that operators may suffer from out-of-the-loop problems. In short, even though they are supposed to supervise and intervene when necessary (i.e. remain part of the control loop), not all operators succeed in staying attentive and ready to act when the automation level increases and the need for manual interventions becomes sparse. It was long thought that drivers might be immune to such out-of-the-loop problems since taking action in an imminent traffic conflict has a high self-preservation value. However, recent studies indicate that not all drivers will intervene in an imminent conflict if their confidence in the automation technology is high and the automated driving has been flawless for a longer period of time (Victor et al, 2018).

Now, while this can be viewed as an all or nothing problem, as in whether one successfully avoids an in-lane obstacle as in the Victor et al. study, it is likely also helpful to view it as a more gradual problem. Drivers may be able to perform some tasks competently while performance on other tasks degrade when they start disengaging from the driving task, for example due to higher secondary task engagement. Understanding this potential degradation process for key driver competences is therefore of high importance if one wants to both detect and develop countermeasures for what can be called driver “out-of-the-loop-ness”.

Of all driving tasks, having an adequate visual scanning behavior is certainly one of the most important ones. When it comes to understanding how adequate scanning behavior is affected by secondary task engagement, many previous studies have found that when performing non-visual cognitive tasks, drivers typically display an increased number of on-path glances, along with a deteriorated visual scanning pattern towards potential hazards at locations outside their future travel path (off-path locations). This is often referred to as a gaze concentration effect. However, what has not been explored is more precisely how and when gaze concentration arises in relation to the cognitive task, and to what extent the timing of glances towards traffic-situation relevant off-path locations is affected.

To gain further insights into this mechanism, a driving simulator study was carried out. Car drivers’ visual behavior while doing a cognitive task was studied in two different traffic scenarios; one when driving through an intersection and one when passing a hidden exit. Several new findings came out of this study. The main insight was that while gaze shifts from an on-path to an off-path location were inhibited during cognitive load, gaze shifts in the other direction (i.e. off-path to on-path) were unaffected. Also, the inhibited off-path glances were not compensated for later, i.e. the off-path glances were cancelled, not delayed. Interpreted in the context of driving task automation, these findings suggest that if drivers use increased driving support as a means to increase their secondary task engagement, their visual awareness of what is going on in the surroundings (i.e. where off-path glances normally are directed) can be expected to decrease, even if their awareness of lane keeping and vehicles ahead (which depends on their on-path glances) remains unaffected. This in turn indicates that collision avoidance settings may need a different tuning for lateral threats, based on the level of driving support provided.

Further details on the simulator study are given in Nilsson et al. (2020).

Is the business case for autonomous driving in private cars valid?

While the risk of role switching is a problem for automation support technologies where the driver still is responsible for the driving, a potential inverse of this problem exists at higher levels of automation where the car in fact is fully autonomous. In this case, while the driver technically is free to switch to a passenger role for some time, it may be that drivers do not feel safe enough to exploit this opportunity, or that they have a hard time stopping their normal traffic monitoring, even if they know they are allowed to do so. Since a large part of the business case for providing private cars with autonomous driving capabilities is the “free time” that this provides, it follows that if drivers are reluctant to make use that time as passengers would, the business loses its attraction.

In order to understand drivers’ willingness and capabilities to switch over to a passenger role while still in the driver’s seat under high levels of automation, Volvo Cars and RISE conducted an on-road study in a Wizard-of-Oz car. Drivers’ attention shift in different levels of driving task automation was investigated, along with drivers’ ability to complete a visually and cognitively demanding non-driving related tasks (NDRT) under full automation.

Overall, the results of this study indicates that the business case is not in jeopardy. Participants could perform the NDRT just as well in the driver’s seat as they could in an office environment. Moreover, several of them were surprised by their own ability to, with ease, disconnect from driving. Further details of this study and its outcomes are reported in Klingegård et al (2020).

It should be noted that in addition to the concepts implemented in the truck and Wizard-of-Oz car as described above, VOLVO GTT has also built interaction concept prototypes in virtual reality (VR) and in a small simulator rig involving driver state monitoring (eye-tracking, hands-on detection), input device alternatives for automation level 2 vs level 4 application, adaptation of information depending on automation level etc.

4.3 Project achievements in relation to FFI’s program related goals

As set forth in the project application, the HARMONISE project has conducted extensive research in the field of driving support and related interfaces between the driver and the vehicle as well as for vehicles with different levels of automation introduced gradually (Program area D).

The project has also done work related to Program areas E and G (Intelligent and collision avoidance systems and vehicles and automated vehicles in the transport system) since several of the studies have targeted vehicles with various levels of automation, from assisted driving to highly automated systems, in a variety of use contexts covering both private car ownership and professional driving.

5 Dissemination and publication

5.1 Dissemination of results and knowledge

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	The results integrate into the knowledge building required for development of safe assisted driving and safe autonomous driving
Föras vidare till produktutvecklingsprojekt	X	Part of Autonomous Drive development
Introduceras på marknaden	-	-
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut	-	-

All partners in the project had the opportunity to interact with different stakeholders and organizations throughout the project. Below are a number of examples.

Volvo Group Trucks has been part of the CARTRE and ARCADE projects (ARCADE website) as well as lately the CCAM platform (ref CCAM website) with the role to support the European Commission with input to research agenda as well as to arrange workshops during EUCAD. Volvo Group Trucks have co-chaired the Human Factors area. Volvo Cars were invited to talk during the 2017 session on Human Factors issues related to the different levels of automation as well as on Volvo Cars predictive safety impact analysis. Volvo Group Trucks took part in the panel discussion 2019 where one topic was the potential role on driver training, marketing campaigns etc. in addition to safe and intuitive system design. Volvo Cars attended the 2020 session and discussed with representatives from EuroNCAP and Consumer Report on how best ensure the driver is in the loop for lower levels of automation. Proceedings and recordings from the EUCAD events can be found on the ARCADE website (See list of website references in Section 5.2).

During the duration of HARMONISE a large amount of work has been done in the field of regulation. HARMONISE topics such as ensuring the driver remains in control for lower levels of automation and is able to regain control for higher levels are two examples of areas covered. Both VOLVO GTT and Volvo Cars have been active in the different fora by giving Human Factors input to the draft documents on e.g.:

- CSF. Corrective Steering Support (UNECE, 2018)
- ACSF B1. Automatically Commanded Steering Function, hands-on lateral continuous support. (UNECE, 2018)
- ALKS. Automated Lane Keeping Systems allowing hands off operation of passenger cars below 60 kpm on roads with mid barriers. (UNECE, 2020). There are on-going discussions on both expanding the speed thresholds as well as expanding to other vehicle types.
- Driver State monitoring as part of the ALKS regulation (see UNECE, 2020) as well as in the specific draft regulation on Drowsiness and Attention Warning system (DDAW) (EC, 2020).

The regulatory activities are linked to the EuroNCAP assessment programs where Volvo Cars have been active in the Human Factors area. Two safety campaigns related to ‘assisted driving’ have been launched during the project duration (EuroNCAP, 2018; 2020) where especially the latter very much focus on Human Factors such as taxonomy, instruction/manual, interaction design and perhaps most importantly how to balance driver engagement and level of vehicle assistance.

Within the area of standardization all HARMONISE partners have been active on various automation related topics such as driver monitoring and system intervention, external visual communication from automated vehicles to other road users as well as detailed symbol designs for different automation modes as well as for attention/engagement reminders.

The project partners have also at various occasions disseminated project results to SAFER-partners. We have discussed the project within the SAFER reference group Road User Behavior that consist of experts within the area human behavior representing OEMs, technology companies, universities and research institutes. The project has also been presented once at the SAFER lunch seminar to a broader audience from SAFER-partners. In addition, the project was part of the SAFER pre-event the 3rd Global Ministerial Conference on Road Safety on 19–20 February 2020 in Stockholm.

5.2 Dissemination references

- ARCADE website. https://connectedautomateddriving.eu/about/arcade-project/. Accessed on the 13th of January 2021.
- CCAM https://ec.europa.eu/transport/themes/its/c-its_en. Accessed on the 13th of January 2021.
- EuroNCAP assisted driving campaign (2018). https://www.euroncap.com/en/vehicle-safety/safety-campaigns/2018-automated-driving-tests/. Accessed on the 13th of January 2021.
- EuroNCAP assisted driving campaign (2020). https://www.euroncap.com/en/vehicle-safety/safety-campaigns/2020-assisted-driving-tests/. Accessed on the 13th of January 2021.
- ISO / TC22 / SC39 Ergonomics / WG8 HMI / AV New TF Driver monitoring and system intervention protocols. On-going work.
- ISO / TC22 / SC39 Ergonomics / WG8 HMI / AV TF Ext communication / TR 23735 Road Vehicles – Ergonomic design guidance for external visual communication from automated vehicles to other road users. On-going work.
- ISO / TC22 / SC39 Ergonomics / WG5 Symbols. ISO Symbols concerning automation modes and engagement/attention reminders.
- UNECE (2018) UN R79: Revision 4 https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2018/R079r4e.pdf. Accessed on the 13th of January 2021.
- UNECE (2020) UN press release for ALKS https://unece.org/transport/press/un-regulation-automated-lane-keeping-systems-milestone-safe-introduction-automated. Accessed on the 13th of January 2021.
- DDAW https://circabc.europa.eu/sd/a/7f9912b5-e180-43ab-b9da-82ddfb1cde8a/20200701%20MVWG%20DDAW%20draft%20technical%20req.pdf
- 3rd Global Ministerial Conference on Road Safety (2020) https://www.who.int/news-room/events/detail/2020/02/19/default-calendar/3rd-global-ministerial-conference-on-road-safety

5.3 Publications

1. *Iseland, T., Johansson, E., Skoog, S., and Dåderman, Anna (2018) An exploratory study of long-haul truck drivers' secondary tasks and reasons for performing them, Accident Analysis & Prevention, Volume 117, Pages 154-163, ISSN 0001-4575, https://doi.org/10.1016/j.aap.2018.04.010*

2. Klingegård, M, Lindblom, J., Johansson, E. (submitted) Changing point of view: implication of an embodied cognition perspective on the introduction of automated driving functionality. Submitted to the Special Issue on Critical Robotics Research to be published in AI & SOCIETY: Journal of Knowledge, Culture and Communication

3. Klingegård, M., Andersson, J., Habibovic, A., Nilsson E. and Rydström, A (2020) "Drivers' Ability to Engage in a Non-Driving Related Task While in Automated Driving Mode in Real Traffic," in IEEE Access, vol. 8, pp. 221654-221668, doi: 10.1109/ACCESS.2020.3043428.

4. Nilsson, E., Victor, T., Ljung Aust, M., Svanberg, B., Lindén, P. and Gustavsson, P. (2020) On-to-off-path gaze shift cancellations lead to gaze concentration in cognitively loaded car drivers: A simulator study exploring gaze patterns in relation to a cognitive task and the traffic environment*. Transportation Research Part F - Traffic Psychology and Behaviour, 75,* (1-15)*.*

5. Roozendaal J, Johansson E, Winter J de, Abbink D, Petermeijer S. Haptic Lane-Keeping Assistance for Truck Driving: A Test Track Study. Human Factors. June 2020. doi:10.1177/0018720820928622

6 Conclusions and next steps in research

In retrospect, we think that HARMONISE largely has fulfilled its initial objectives. While some of the studies did not end up with the expected conclusions, that is in our opinion a natural hazard in the field of science to be embraced as long as one learns from those unexpected results.

Going forward, we see that there are still large areas that need further exploration before we can provide a complete picture of how to best simplify and manage how drivers interact with systems which offer different levels of automation throughout a journey.

Of perhaps particular importance is the insight that especially professional drivers might be drawn to further secondary task engagement when the demands from the driving task diminishes; formally to stay productive but informally to alleviate feelings of boredom and social isolation. While mentioned also in other contexts, it has perhaps not received the attention needed to properly address it in the field of interaction design.

7 Participating partners and contact persons

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8 Appendix A – State of the Art report

EMERGENT TRENDS IN AUTOMATED VEHICLE INTERACTION DESIGN

1 A market assessment of design solutions

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2 Abstract

The aim of this literature review is to identify current trends in interaction design of ADAS and automated driving for passenger vehicles. While the study covers different levels of automation, the focus is on systems that provide both lateral and longitudinal support to drivers simultaneously. The study explores design principles for systems that are currently available in production vehicles as well as systems that are currently under development.

A general conclusion is that there are currently large differences in design of systems, both when it comes to products available on the market and concepts. The use of different naming for similar functions is one of major issues since it serves as a direct touchpoint towards the user. Another urgent issue, especially when it comes to systems that support drivers in both lateral and longitudinal control of vehicle, is that seemingly similar functions have in fact different functionalities and request different level of engagement from drivers. On top of that, manufacturers tend to use different human-machine interaction principles when it comes to activation and deactivation of the functions as well as for feedback to drivers. These issues become even more evident if considering that several different functions and systems co-exist in one and same vehicle.

Altogether, this review shows a clear lack of standardized approaches for design of advanced driver support systems and highlights a need for creating more harmonized interactions with drivers across different systems and across different manufacturers.

3 Contents

Introduction

8.1 Background

Various advanced driver support systems (ADAS) are available on the market today, and basically all manufacturers are making attempts to improve these or introduce new systems. A current trend is development of systems that provide both lateral and longitudinal support to drivers simultaneously, or that relief drivers from vehicle control (cf. automated driving). Developing such systems has proven to be challenging both when it comes to technology and design of human-machine interaction.

8.2 Aim

The aim of this literature review is to identify current trends in interaction design of ADAS and automated driving for passenger vehicles. While the study covers different levels of automation, the focus is on systems that provide both lateral and longitudinal support to drivers simultaneously. The study explores design principles for systems that are currently available in production vehicles as well as systems that are currently under development.

8.3 Method

The study is mainly based on review of various publications in media such as press releases by different manufacturers and movies demonstrating system functionality.

8.4 Limitations

The study is not necessarily comprehensive; it focuses on showing the current (Spring 2017/2018) trends in design of advanced driver assistance systems for passenger vehicle. While it provides a rather broad overview, the focus is on design of systems that provide both lateral and longitudinal support to drivers.

9 Terminology

An automated vehicle may be defined as a vehicle with the following characteristics:

- Can sense its surroundings and navigate without any human input.
- Technologies such as radar, lidar, cameras, digital maps and GPS to help the vehicle to know its surroundings.
- Advanced Control System (algorithms) interpret the sensor data to identify suitable routes, obstacles, and relevant signage.

System that are the basis for automated driving includes a variety of driver assistance systems (Advanced Drive Assistance Systems, ADAS) such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Lane Keeping Support (LKS), Lane Change Assist (LCA), Blind Spot Detection (BSD), Pedestrian Detection, Traffic Sign Recognition (TSR), Emergency Brake Assist (EBA), Parking Assist (PA), Rear Collision Warning (RCW), Forward Collision Warning (FCW) and Night Vision (NV).

Today, it is common to refer to the automated systems of various automation levels. To better define and categorize automated systems, organizations such as the US National Highway Traffic Safety Administration (NHTSA), German BASt and the Society of Automotive Engineers (SAE) have proposed classification scales. Differences between these scales have created some difficulties. A clear trend that started to emerge during the last six months is that more and more players use the classification scale developed by the SAE. This is mainly because the US safety organization NHTSA chose to use the SAE-scale in its latest policy for automated vehicles.

This report applies also the SAE-scale (SAE J3016)[1].

10 Current trends: Passenger vehicles

Passenger transportation is an area where major changes are expected to occur with the increased automation in vehicles. The interest from vehicle manufacturers and their suppliers is large, and in 2016/17, several of them have presented strategies suggesting that automation will become an important part of their future. For established players on the market such as Toyota, Volvo Cars, Ford, General Motors, BMW and Mercedes, it is primarily automated driving on highways as well as automated parking that is in focus currently. Newcomers in the field such as Tesla, Google, Faraday Future and maybe Apple are working broader than that and envision automation in other traffic environments. Some selected examples of current activities for both established and new players are described in the following sections.

10.1 Toyota

Toyota is one of the vehicle manufacturers making major investments in automated vehicles. A few years ago, the company started a subsidiary called Toyota Research Institute (TRI) to focus on intelligent transport solutions. Most recently, the company started another subsidiary yet named Toyota Research Institute-Advanced Development

[1] https://www.sae.org/misc/pdfs/automated_driving.pdf

(TRI-AD) focusing specifically on automated driving. The company's focus is on the development of advanced driver assistance systems whose main purpose is to support the driver rather than to replace the driver.

Concepts

The development of the *Guardian*, an advanced driver assistance system that can under certain conditions take over the task of driving (SAE level 3-4), is one of Toyota's short-term goals and can be expected on the market within 5 years[2]. In January 2018, the Toyota Transport Research Institute (TRI) introduced the third version of the system (Platform 3.0). It has a sensor-rich package. The Luminar lidar[3] system with 200-meter range covers the vehicle's complete 360-degree perimeter. This is enabled by four high-resolution lidar scanning heads, which precisely detect objects in the environment including difficult-to-see dark objects. Shorter-range lidar sensors are positioned low on all four sides of the vehicle – one in each front quarter panel and one each on the front and rear bumpers. These can detect low-level and smaller objects near the car like children and debris in the roadway. The new platform remains flexible for incorporating future breakthrough technology as it becomes available[4].

The system includes an autonomy indicator designed into the vehicle dashboard with a consistent user interface across screens (Figure 1), colored lights (*Figure 3*) and a tonal language that is tied into Guardian (and Chauffeur). In Figure 2, a real-time display of the LIDAR's point cloud detection on the multi-media screen in the center stack is shown[5]. There is also an alert system in Guardian mode that warns the driver of impending danger (*Figure 1*)[6] and prompts the driver to take back control after the Guardian system takes corrective action (*Figure 2*). The Guardian system also monitors the driver's eyes for distracted or drowsy driving.

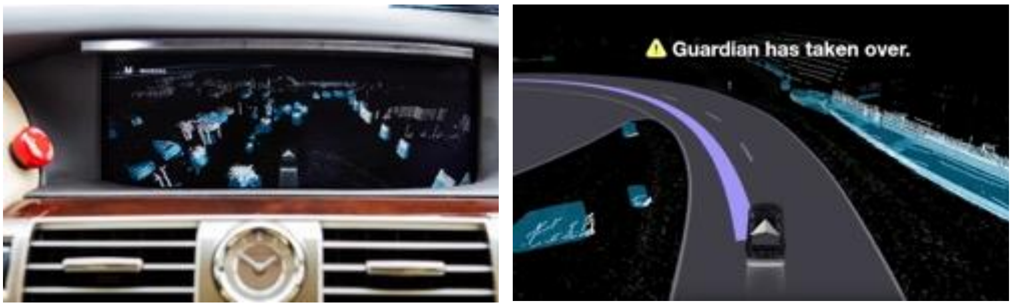

Figure 1 A real time display showing lidar detection in Guardian (left) and information in the display when the system takes over control, e.g., when the driver is drowsy (right).

[2] http://nordic.businessinsider.com/companies-making-driverless-cars-by-2020-2017-1?r=US&IR=T
[3] https://www.luminartech.com
[4] https://newsroom.toyota.co.jp/en/corporate/20564649.html
[5] http://www.carrushome.com/toyota-releases-video-showing-first-demonstration-of-guardian-and-chauffeur-autonomous-vehicle-platform/
[6] https://www.youtube.com/watch?v=ajreRfot6co&feature=youtu.be

Figure 2 Guardian system warns the driver to take control back.

Figure 3 Colored light in the Guardian system (it is blue at first, and then when driver re-engages it becomes purple). The light is accompanied by an audio signal.

The development of *Chauffeur*, a system for fully automated vehicle operation (SAE level 4-5), belongs to the longer-term goals and can be expected on the market in 10 years[7].

During the Consumer Electronics Show 2017, Toyota showed *Concept-i*, the company's vision of how the vehicle operation will look like in 2030 (*Figure 4*)[8]. The concept is built on the idea that driving should be fun. The vehicle AI, called *Yui*, is supposed to learn the driver's characteristics, wherever he/she wants to go, how he/she wants to get there, and on which road sections the driver prefers to drive without automation. According to Toyota's vision, the steering wheel will remain in the vehicle and when the vehicle is operated in automated mode, the driver will be able to take over control basically at any time. The steering wheel, however, will have a different shape (like typical game controllers, *Figure 5*)[9]. Also, colors of the cabin are adjustable to fit outdoor light conditions and match driver's preferences (compare *Figure 5* and *Figure 6*).

[7] https://techcrunch.com/2017/03/03/toyotas-new-autonomous-test-car-2-0-is-a-tricked-out-lexus/?ReillyBrennanFoT
[8] https://www.youtube.com/watch?v=Wv3taIkmmqU
[9] https://www.youtube.com/watch?v=RrtLp7ci_1s

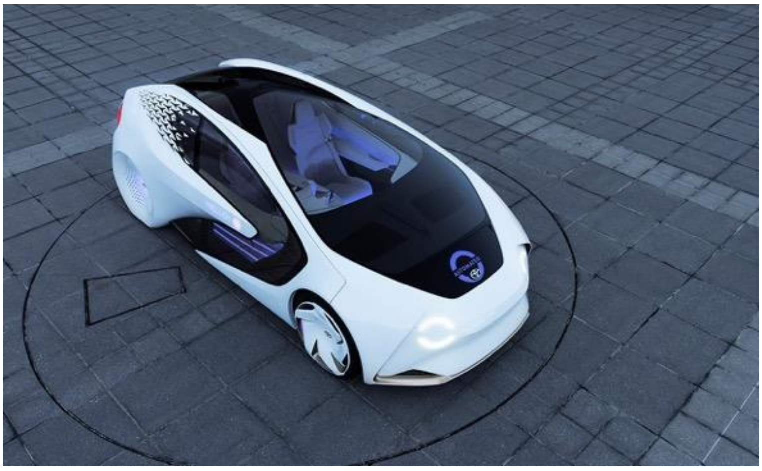

Figure 4 Exterior design of the Concept-i showing Toyota's vision for 2030.

Figure 5 The steering wheel and interior design in Toyota's Concept-i.

Figure 6 The color of the interior lights in Toyota's Concept-i is adjustable.

Deviating from the vision that the steering wheel should always be present, in January 2018 Toyota shown a concept called e-Palette that is a completely self-driving vehicle without any steering wheel (*Figure 7*)[10]. The idea is that the vehicle will be used for new mobility services. To realize these services, the company has formed an alliance for e-commerce with other companies like Amazon, Pizza Hut, Uber, Mazda and Didi Chuxing. In the short term, the Alliance will focus on developing the fully electric e-Palette, which will have an open source interface that enables partner companies to install their own automated drive systems if desired. In addition, Toyota will offer a range of services to help e-Palette customers use their vehicles, including leasing, insurance and fleet management. Users will also have access to communication networks and a so-called Toyota Big Data Center[11].

Figure 7 Toyota's e-Palette concept

Highway Teammate that is showcased as a part of the LS+ Concept will be deployed in 2020 operates on motor-vehicle-only roadways (from on-ramp to off-ramp)[12]. The car will be able to keep itself in its lane, make lane changes and maintain a safe distance from other vehicles.

Production

Toyota will begin to deploy its second-generation Toyota Safety Sense (TSS) driver assistance technology as standard in certain vehicles in mid-2018[13]. The rollout is a step toward its Level 2 semiautonomous driving system, known as Highway Teammate, planned to come in 2020, and falls in line with Toyota's strategy to keep the driver in full control of the vehicle.

[10] https://www.theverge.com/2018/1/8/16863092/toyota-e-palette-self-driving-car-ev-ces-2018
[11] https://www-bloomberg-com.cdn.ampproject.org/c/s/www.bloomberg.com/amp/news/articles/2018-01-08/toyota-taps-amazon-to-join-driverless-delivery-vehicle-alliance
[12] http://www.autonews.com/article/20171025/OEM04/171029816/lexus-concept-tokyo-ls
[13] http://www.automobilemag.com/news/toyota-lexus-inch-closer-to-autonomy-with-new-safety-sense/

This new generation of TSS system adds a pre-collision system with day/night pedestrian protection and day bicycle detection function, lane-departure alert with steering assist, lane-tracing assist (keeps the vehicle in the centre of a lane by assisting the driver in steering control when using the Adaptive Cruise Control (ACC)), road sign assist and full-range dynamic radar cruise control (except on manual transmission cars and trucks) with enhanced forward recognition and acceleration/deceleration[14]. The current TSS system already features pre-collision with pedestrian detection, lane-departure alert with steering assist on certain models, auto-high beams and dynamic radar cruise control.

TSS is offered in the form of two packages: Toyota Safety Sense C (TSS-C) for compact vehicles and Toyota Safety Sense P (TSS-P) for midsize and large vehicles. TSS-C offers Lane Departure Alert, while TSS-P offers Lane Departure Alert with an additional Steering Assist function[15].

Lane departure alert with steering assist is an important part of TSS (*Figure 8*). When driving at speeds above approximately 50 km/h on relatively straight roadways, it will attempt to determine the vehicle's position within its lane using an in-vehicle camera designed to detect visible road lane markings and road edges (it can detect the boundaries between asphalt and such elements as grass, dirt and curbstone). That is, the system functions even on roads that do not have lines. If the system determines that the vehicle is starting to unintentionally deviate from its lane, a warning will be initiated and, depending on the direction of the drifting, one of the lane markings on the dashboard's multi-information display will become orange and begin to flash (*Figure 9*). Together, these warnings tell the driver to check the surroundings and steer back to the centre of the lane. The system may provide small corrective steering inputs for a short period of time to help keep the vehicle in its lane[16].

[14] https://www.youtube.com/watch?v=D1dKnz6C3Rk&frags=wn
[15] https://www.toyota.ca/toyota/en/connect/412/everything-you-need-to-know-about-lane-departure-alert
[16] https://www.youtube.com/watch?v=uPHXqlzWems

Figure 8 Activation of the Lane departure alert (LDA) with steering assist.

Figure 9 LDA with steering assist indicates that the vehicle is drifting to the left.

10.2 BMW

Concepts

In 2021, as a part of the project *iNext*, BMW is planning to launch an all-electric vehicle with features that enable automated driving under certain conditions. In 2025, the vehicle from the project *iNext* is expected to be fully automated. BMW has also shown a part of the technology within the *i3-concept*, such as self-parking feature that enables the user to summon the car from distance.

BMW has recently started a collaboration with Intel and Mobileye to conduct tests with 40 automated vehicles (BMW 7 Series)[17]. The tests began in 2017 in Munich and include a service similar to the services that are today offered by, for example, Uber and Lyft. In each vehicle, there will be a safety driver behind the wheel ready to take over the maneuvering control if needed. The plan is that the service will be extended in the near future to other cities in Germany and in the US[18].

Production

Every BMW and Mini (both brands under the BMW Group) except the Z4 and i8 offers at least some degree of automation through the automaker's self-steering for parallel

[17] https://www.youtube.com/watch?v=_1BGMNMng8M
[18] http://www.reuters.com/article/us-bmw-autonomous-idUSKBN13T0ZH

parking and, in most cases, adaptive cruise control, cruise control that maintains speed as allowed by driving conditions and traffic.

Active Lane Keeping And Traffic Jam Assistant

Active Lane Keeping And Traffic Jam Assistant can be activated to support the driver in monotonous traffic situations. It uses multiple radars and a stereo camera to monitor the environment. At speeds of up to 130 mph on all road surfaces, the system conveniently supports steering and keeps the vehicle in the centre of its lane. At the speeds below 40 mph, the system can also recognize and follow the vehicle in front. The function is activated via a button on the steering wheel (*Figure 11*)[19]. The mode button (to the right of the activation button) is used to switch between "distance control" and "assisted driving mode" which includes steering control[20].

Figure 10 In BMW vehicles offering Active Lane Keeping And Traffic Jam Assistant, it is possible to choose between distance control and assisted driving mode which includes steering control.

When the assisted driving mode is activated, two red lines (symbolizing the road) along with two grey lines (symbolizing undetected road markings) and a grey icon (symbolizing steering wheel) appear in the dashboard. This means that the system is in the standby mode. When road markings are detected, the grey steering wheel icon becomes green and the grey lines become green. The driver must always keep his/her hands on the steering wheel (based on some videos, it seems to be enough with one hand on the steering wheel). If the driver removes his/her hands from the steering wheel, the system warns the driver by showing an orange hands-on-wheel icon (hands on request, animated). If the driver does not return his/her hands to the steering wheel, the icon becomes red (take over request, animated). The visual take over request is accompanied by a sound warning and changing colour on the top of the pads to the left and right of steering wheel. At this point the system goes back to the standby mode.

[19] https://www.youtube.com/watch?v=w24HYJvaCl0
[20] https://www.youtube.com/watch?v=M8ZFdtfCKj8&feature=youtu.be&t=105

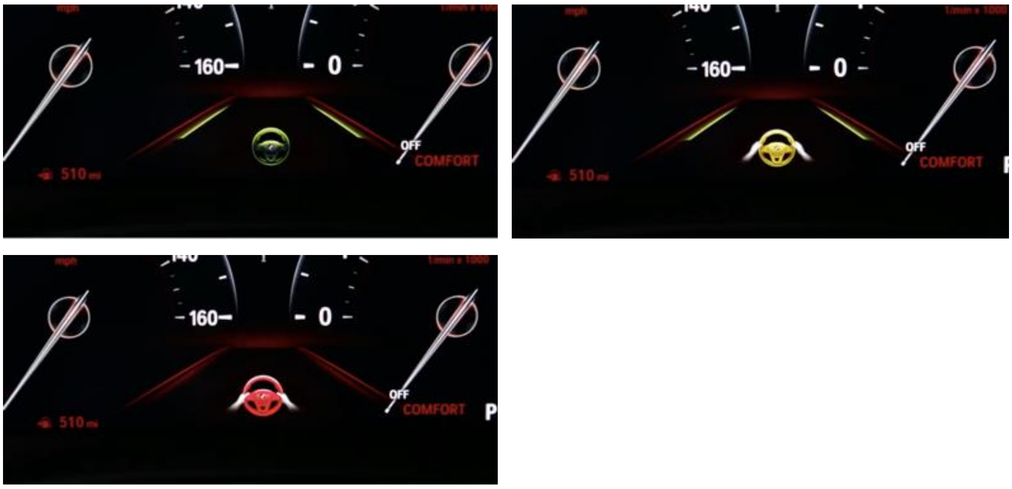

Figure 11 BMWs Active Lane Keeping And Traffic Jam Assistant

Extended Traffic Jam Assistant System

The Extended Traffic Jam Assist (ETJAS) allows hands-off driving and is designed to operate on limited-access highways, in surrounding traffic, at speeds of 60 km/h or less. It will be available as a $1,700 option on e.g., 2019 BMW X5 SUV models starting in December 2019. Drivers activate the system through the steering wheel button (with icon consisting of lines, car and steering wheel) and then selecting "Assisted Driving Plus" via Mode button (*Figure 12*)[21]. Associated LEDs on the steering wheel, plus a message on a dashboard display, indicate when ETJA is available to use (shown also in HUD). In some models, the buttons might be located on the paddles to the right and left of steering wheel. The system uses an optical camera at the top of the instrument binnacle to monitor driver attention while the system is engaged (*Figure 13*). The cameras do not record and store footage. One downside to this that the BMW could have trouble detecting a driver's eyes through polarized sunglasses[22].

Figure 12 Extended Traffic Jam Assistant is activated by selecting the Assisted Driving Plus icon via Mode button on the paddles (or steering wheel depending on the vehicle model).

[21] https://www.youtube.com/watch?v=M8ZFdtfCKj8&feature=youtu.be&t=105
[22] https://www.navigantresearch.com

Figure 13 BMW's Extended Traffic Jam Assistant System uses an optical camera at the top of the instrument binnacle to monitor driver attention while the system is engaged. At the activation of the system, an audio signal and a text message "Always monitor the traffic" are displayed for a short while.

10.3 Audi

Concepts

The company is still working with Nvidia to develop artificial intelligence that enables automated highway driving without any support from the driver (SAE level 4). Tests are scheduled for 2018 (probably with Audi Q7) and the car can be expected in the market by 2020.

Production

Audi AI Traffic Jam Pilot

In 2017, Audi launched a car with a system that meets the requirements for automation level 3 according to the SAE-scale[23]. The system is called Traffic Jam Pilot and, among other things, enables the driver to leave the control of the car at highway driving at speeds up to 55 km/h (Figure 14). In such a context, it can drive itself completely autonomously, meaning the driver can take his or her hands off the steering wheel, eyes off the road and focus their attention on something else, e.g., reading or working. A camera is used to monitor the driver. The system informs the driver when it is available, and the driver can then activate it via a physical button in the center console. The look and color of the display changes (compare *Figure 14* and *Figure 15*). When the system needs to give back control to the driver, an audio signal and a text message are given to the driver. The look and color of the display change as shown in *Figure 16*. To take back control, driver needs to hold the steering wheel with both hands.

[23] https://www.audiusa.com/newsroom/news/press-releases/2017/01/audi-and-nvidia-to-bring-fully-automated-driving-in-2020

Figure 14 Audi AI informs driver when it is available (left) and the driver can activate it via a button in the mid console (right).

Figure 15 When Traffic Jam Pilot is activated by the driver, the display changes in color and look.

Figure 16 When there is a takeover request, the color and look of display changes at the same time as an audio signal and a text message are issued to make driver aware that an action is needed.

10.4 Volkswagen

Concepts

Volkswagen has recently shown an upgraded version of the *Volkswagen ID* that was launched at the Paris Auto Show in 2016 (*Figure 17*). The biggest news is that it is completely self-driving and that the steering wheel is retractable (*Figure 18*). Volkswagen ID is equipped with a head-ups display showing information such as the state of charge and navigation (*Figure 19*). It is built on the company's new platform, *Modular Electric*

Drive (MEB). Currently, it is unclear when this vehicle will be launched; some recent statements in media indicate that it may happen around 2025[24].

Figure 17 Exterior design of Volkswagen's ID Concept.

Figure 18 Interior of Volkswagen's ID Concept with retractable steering wheel.

[24] http://nordic.businessinsider.com/volkswagen-id-electric-concept-car-paris-motor-show-photos-2017-2/

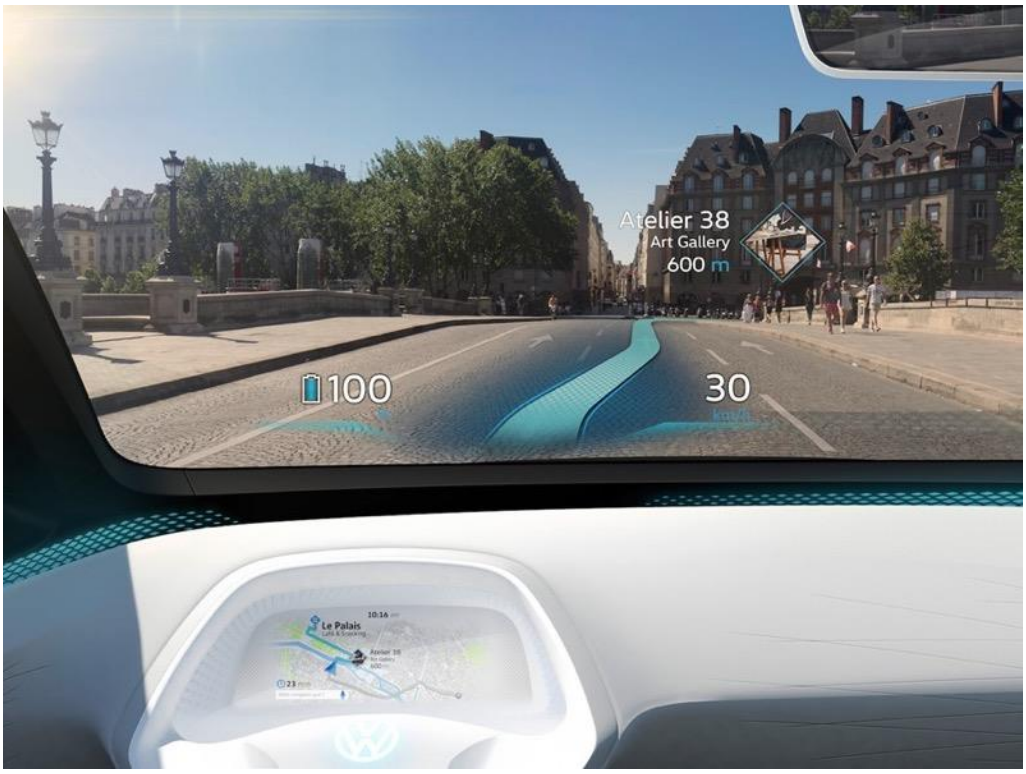

Figure 19 Volkswagen ID has a heads-up display.

Production

10.5 Mercedes

Concepts

In the beginning of 2017, Mercedes launched a partnership with Nvidia with the goal of developing artificial intelligence for cars that will be launched on the market in 2018.

The Vision Van, which was shown in September 2016, uses among other things drones of to collect and deliver packages.

Production

In Mercedes's new E-Class vehicles, Driver-Assistance Package

The 2018 S-Class Sedan Driver-Assistance Package includes 11 driver-assist systems.

- **Active Steering Assist.** Uses cameras and sensors to sense lane lines and keep the vehicle centered while using DISTRONIC adaptive cruise control.
- **Evasive Steering Assist**. Responds to the driver's collision-avoiding evasive maneuvers by calculating steering force to help the vehicle avoid the collision, then straightens the vehicle back out to the center of the lane.

- **Route-Based Speed Adaptation**. Uses the map database to automatically slow the vehicle down in anticipation of curves, traffic circles, toolbars, and highway interchanges—then resume up to the posted speed limit afterward. The system also slows the car when the driver signals for a highway exit.
- **Active Emergency Stop Assist**. Senses when the driver's hands have been removed from the steering wheel for a prolonged period and performs visual and audible alerts. If the driver fails to respond, other systems activate and slowly reduce vehicle speed until it comes to a full stop.
- **PRE-SAFE PLUS**. Uses radar to detect an impending impact and works to protect occupants in a rear-end collision.
- **Active Lane Keeping Assist**
- **Active Blind Spot Assist**
- **Active Lane Change Assist**
- **Active Speed Limit Assist**
- **Active Brake Assist with Cross-Traffic Function**
- **Active Distance Assist DISTRONIC**

In Mercedes E-Class, the Remote Parking Pilot is offered, which allows the driver to park the vehicle in confined parking spaces via a special smartphone app, provided that the driver is within 3 meters of the vehicle (Figure 20) [25]. Before starting the parking, the driver needs to select a relevant parking scenario such as parallel or perpendicular parking, left or right, forward or backward. During the parking process, the driver needs to make a continuous circular motion on the display of his/her smartphone.

Figure 20 Mercedes' Remote Parking Pilot interface in the vehicle.

Steering Pilot and Active Lane Keeping Assist

Steering Pilot that available in 2019 Mercedes S-Class assists the driver in steering the vehicle back into the centre of the lane by means of moderate steering interventions[26].

[25] https://shop.mercedes-benz.com/en-gb/connect/pdp/Remote-Parking-Assist/529?variantCode=QEV111AGWUDD&isInitialTransition=1
[26] https://www.youtube.com/watch?v=iiAA3W6FVL0

It is activated by pressing a button on the steering wheel (on 2018 Mercedes S-Class it is activated via a button to the left of the steering wheel). Though the driver doesn't need to keep a hand on the wheel, it will request a driver response every 10 seconds or so, depending on current road conditions. A pair of capacitive-touch buttons on the steering wheel can be used to acknowledge the request, which starts with a visual notification and escalates to an insistent bonging if ignored. If the warnings are ignored, or in the event of a medical emergency, the car initiates a controlled-but-determined "emergency stop" in the lane, activating the hazard lights to warn other motorists that there's a problem. At the same time, the Mercedes SOS service is activated where a live agent is connected to provide assistance and contact emergency personnel, if needed. On a multi-lane highway, the system is capable of handling lane changes when prompted by the driver. The driver needs to activate the turn signal for a lane change and the car uses blind-spot monitoring and rear-facing radar to do its own checks and make sure there's no car in the way. It's ultimately up to the driver to ensure that the manoeuvre is safe to perform, but once the turn signal is on and the car sees it's OK, it can take care of actually turning the wheel.

Figure 21 The Steering Pilot is basically activated in two steps, by pressing a button to the left of the steering wheel (a grey steering wheel symbol appears in the display) and then by activating the Distronic system via a paddle (the grey steering wheel symbol becomes green).

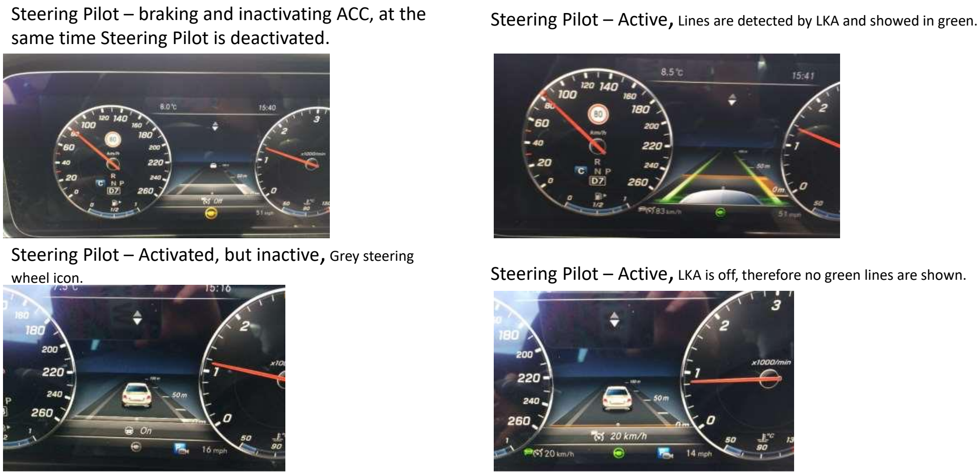

Figure 22 Steering pilot interface during different stages of use.

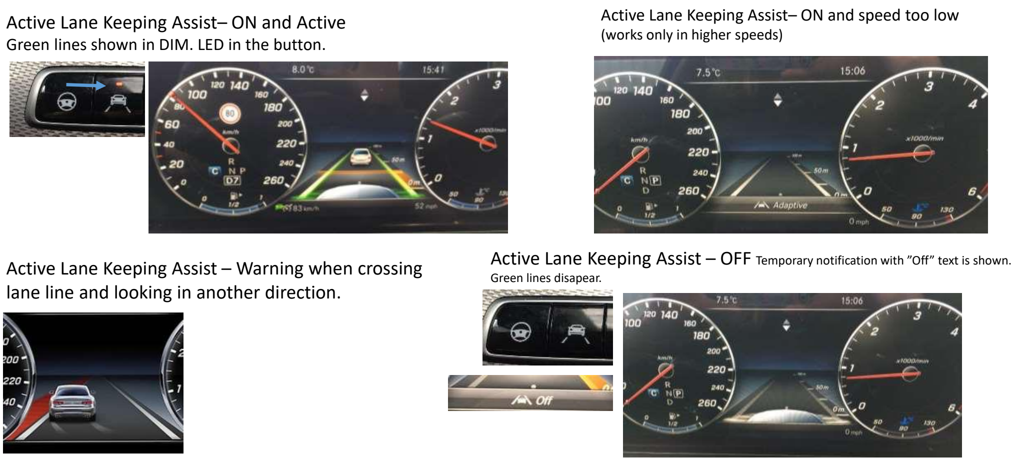

Figure 23 Active Lane Keeping Assist interfaces during different stages of use. [27]

10.6 Nissan

Concepts

During the Consumer Electronics Show 2017, the company showed *Seamless Autonomous Mobility (SAM)*, a NASA-inspired AI system that helps automated vehicles to learn about traffic[28]. What is most unique to Nissan SAM-system is that it will be connected to a control center with a human operator. For example, when an automated vehicle encounters an unknown obstacle on the road and does not know how to handle it, the system will contact the control center and send information about the situation.

[27] https://www.mercedes-benz.com/en/mercedes-benz/innovation/distronic-plus-with-steering-assist-video/

[28] http://nissannews.com/en-US/nissan/usa/releases/press-kit-nissan-intelligent-mobility-at-ces

The operator will then judge what action is appropriate in the given situation and guide the vehicle accordingly. The vehicles will learn from the operators and eventually they will be able handle similar situations on their own. Nissan has not announced a precise time-plan for the launch of the SAM. However, the its plan for intelligent mobility (*Figure 24Figure 24*) suggest that services based on SAM could be expected around 2020[29].

In the beginning of 2018, Nissan and the technology company DeNA announced that they will start testing an app-based autonomous taxi service in Japan[30]. They will perform field tests of the service called Easy Ride in the Minatomirai district of Yokohama, along a certain route of approximately 4.5 kilometers. In the cars, there will be a tablet showing a list of recommended destinations that the test participants can choose to communicate by communicating via text or voice with Easy Rides mobile app. The companies plan to commercialize such solutions in 2020.

Nissan is also one of the few vehicle manufacturers that has shown concepts for city driving, including onboard interfaces for communication with pedestrians and cyclists (*Figure 25*).

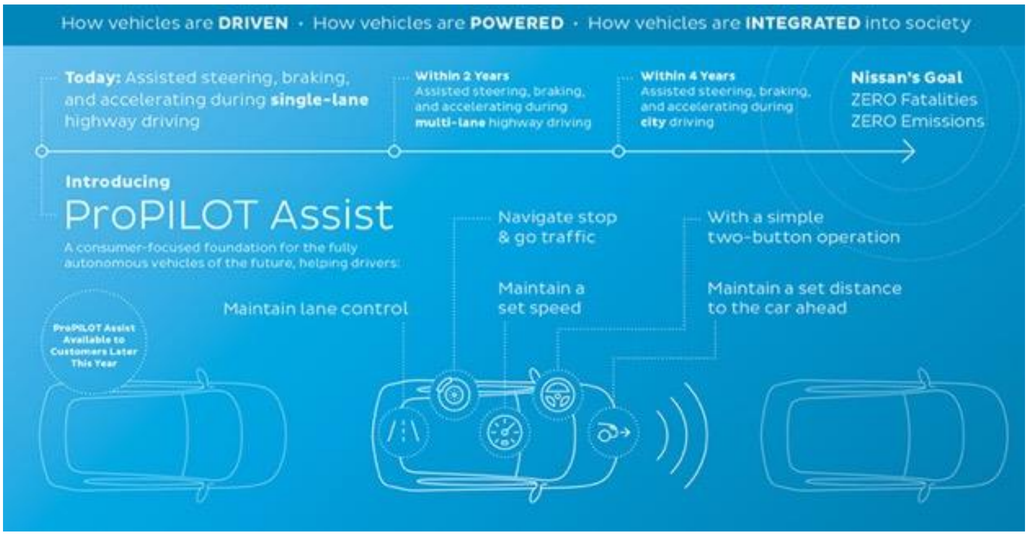

Figure 24 Nissan's time plan for Nissan Intelligent Mobility.

[29] http://nissannews.com/en-US/nissan/usa/releases/nissan-propilot-assist-technology-makes-u-s-debut-on-2018-rogue-reduces-the-hassle-of-stop-and-go-highway-driving
[30] https://www.cnbc.com/2018/02/23/nissan-and-dena-to-test-self-driving-taxi-service-easy-ride.html

Figure 25 Nissan's interface for communication with pedestrians.

Production

ProPilot

In 2017, Nissan launched ProPilot in Nissan Leaf in Japan, a driver assistance feature that allows longitudinal and lateral automated highway driving under certain conditions (i.e. it can be classified as a Level 2 system according to the SAE-scale, however, Nissan has not classified the system itself). By leveraging its Intelligent Cruise Control (ICC) and Steering Assist systems, ProPilot keeps car centered between lane markers at highway speeds (as opposed to "lane keeping" which can bounce the vehicle between lane markers) and during stop and go traffic jams[31]. Nissan, however, stresses it is a hands-on and eyes-on system at any time.

A single radar, located behind the front emblem, senses the speed and distance of the vehicle ahead (ICC functionality), and a single camera at the top of the windshield detects lane markers and determines the vehicle position in the lane (steering assist function). Currently, the function is activated/deactivated via a physical button on the steering wheel (*Figure 26*), and its state is continuously shown in the instrument cluster (*Figure 27*)[32]. It is envisioned that the system will shortly be launched in Europe, China and the US. Until 2020, Nissan plans to extend its capability so that it can handle driving on the motorway without assistance from the driver as well capability to handle city driving to some extent.

[31] https://www.sae.org/news/2018/01/nissans-propilot-assist-is-more-than-lane-keeping
[32] https://www.youtube.com/watch?v=rnke9JkPfUI

Figure 26 Nissan's ProPilot is activated/deactivated via a button on the steering wheel.

Figure 27 Current state of Nissan's ProPilot is continuously shown in the instrument cluster.

ProPilot 2.0

ProPilot 2.0 allows hands-off driving only when the car is traveling in the same lane. When the car switches lanes, Japanese regulations require drivers to have their hands on the wheel. ProPilot 2.0 still changes the lanes by itself; the hand-holding is just a precaution. The system works only on highways that have been mapped in 3D high-definition. The function itself is called Navigated Driving. The system is activated by pressing a physical button (blue) on the steering wheel (*Figure 28*)[33]. If ProPilot 2.0 is activated on a road section that does not allow hands-free driving, the display color and the icons are green (*Figure 29*). The icon shows that the driver needs to keep hands on the steering wheel. When the car reaches a hands-free road section, the display and icons turn blue at the same time as a text message "Navigated Drive Active" is displayed. The text message vanishes after a short while. The icon shows that the driver does not need to hold his/her hands on the steering wheel. The function is lane-centering. If a lane change is needed, a text message is displayed. The driver is then expected to press a

[33] https://www.youtube.com/watch?v=3fcTtOetk88

physical button on the steering wheel with a lane change icon (*Figure 30*). A similar icon is shown on the display, however, the color of the icon in display is blue (turns from grey to blue) while the color of the icon on the button on the steering wheel is grey. Same button is used both for changing lane to the left and for changing lane to the right, as well as for exiting the highway. After the driver has initiated a lane change by pressing the lane change button, the car executes the lane change on its own. However, the driver needs to keep his/her hands on the steering wheel. During the lane change, a text message encourages the driver to watch the traffic in a certain direction (*Figure 31*). A similar approach is used for exiting the highway.

Figure 28 ProPILOT 2.0 is activated by pressing a button (with blue icon) on the steering wheel.

Figure 29 If ProPilot is activated on a road section that doesn't allow hands-free driving, the display color and the icons are green. The icon shows that the driver needs to keep hands on the steering wheel. When the car reaches a hands-free road section, the display and icons turn blue at the same time as a text message "Navigated Drive Active" is displayed. The text message vanishes after a short while. The icon shows that the driver doesn't need to hold his/her hands on the steering wheel.

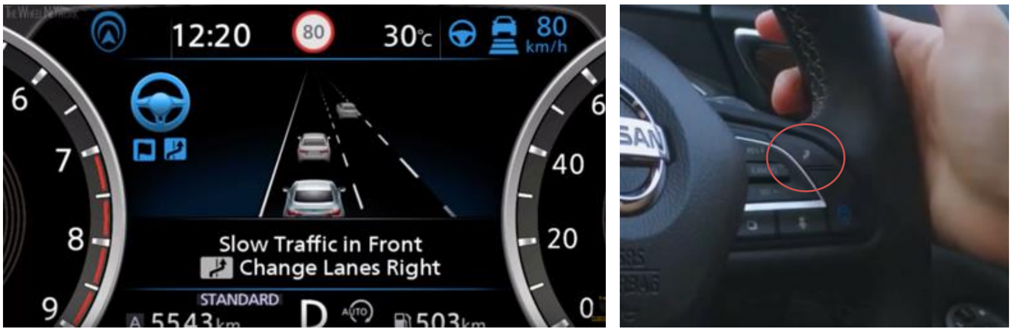

Figure 30 If a lane change is needed, a text message is displayed. The driver is then expected to press a physical button on the steering wheel with a lane change icon. Same button is used both for changing lane to the left and for changing lane to the right.

Figure 31 After the driver initiated a lane change by pressing the lane change button, the car executes the lane change on its own, however, the driver needs to keep his/her hands on the steering wheel. During the lane change, the display and icons are green and a text message encourages the driver to watch the traffic in a certain direction. A similar approach is used for exiting the highway.

10.7 Volvo Cars

Concepts

Volvo Cars was among the first vehicle manufacturers to promise large-scale testing of automated highway driving where the driver does not need to monitor the system (SAE-level 4). These tests will begin this year and are part of the *Drive Me* project. It will include 100 vehicles of type Volvo XC90 in Gothenburg. Volvo Cars was the first to take the responsibility in case of accidents while driving in automated mode.

In 2016, Volvo Cars started a cooperation on automated vehicles with mobility company Uber. In the first stage, Volvo Cars will supply Uber with 100 Volvo XC90 vehicles for testing in Pittsburgh. Uber has added its own technology on these vehicles such as lidar, radar, cameras and other sensors and controllers as well as software, and started testing with them at the end of 2016 in Pittsburgh and Austin in Texas (this after a dispute with authorities in California). At the end of 2017, Uber order 24 000 vehicles from Volvo Cars[34].

[34] https://www.media.volvocars.com/global/en-gb/media/pressreleases/216738/volvo-cars-to-supply-tens-of-thousands-of-autonomous-drive-compatible-cars-to-uber

Production

In 2016, the company launched a function on some models (e.g., Volvo XC90) called Pilot Assist that helps the driver to drive the car between the road lane whilst at the same time maintaining a preselected time interval to the preceding vehicle (Figure 32)[35]. It provides more comfortable driving in slow traffic - up to 50 km/h - on motorways and main roads. The driver sets the desired time interval to the preceding vehicle. Pilot Assist scans the preceding vehicle and the lane markings with the camera and radar unit. The preset time interval is maintained with automatic speed adjustment whilst the steering assistance helps to position the car in the lane. Pilot Assist steering assistance takes into account the speed of the preceding car and the lane markings. The driver can at any time ignore the Pilot Assist steering recommendation and steer in another direction, e.g. to change lane or avoid an obstruction on the road.

Figure 32 Pilot Assist is activated via a button the steering wheel (left) and when it is activated the icon on the dashboard changes colour from grey to green (right).

10.8 Ford

Concepts

In 2016, it became known that Ford plans to launch automated vehicles with SAE-automation level 4 for "mass production" in 2021 (the size of the fleet has not been specified yet). Something else that is unique is that these vehicles will not be equipped with steering wheel and gas and brake pedals. They will be used for mobility services such as car pools and car-sharing. As a step towards achieving these plans, the company showed recently an automated Ford Fusion Hybrid that has updated sensor systems (including new lidars) and better processing power. Ford has also shown a vision called the *City of Tomorrow* showing that Ford sees autonomous road vehicles and drones as a key piece of the future mobility of people and goods. As a concrete example of the vision, the company presented a mobility concept called *Autolivery* where autonomous electric road vehicles and drones help each other to deliver goods to areas where there is a shortage of parking spaces or where traffic congestion is evident.

[35] https://support.volvocars.com/uk/cars/Pages/owners-manual.aspx?mc=v526&my=2016&sw=15w46&article=548956727ac6edfbc0a80151522a4edc

In August 2017, Ford, in conjunction with Domino, launched a new transport service in Ann Arbor, Michigan, dedicated to delivering pizzas with automotive cars. The purpose is to explore interactions with customers and their experience about this kind of services. The test lasted a couple of weeks. Customers are selected randomly, and those who agree to participate will be able to track the delivery vehicle via GPS using an upgraded version of Domino Tracker. They will also receive text messages with instructions on how to unlock the pizza storage cabinet inside the vehicle with a unique code. It is the Ford Fusion Hybrid Autonomous Research Vehicle used in the tests. However, the vehicle will be performed by a human driver, and there will also be some researchers inside the vehicle.

In 2017, Ford also launched a study together with Virginia Tech Transportation Institute to explore interactions between automated vehicles and other road users, and identify if the vehicles need to be equipped with special external interfaces to facilitate interaction[36]. The interface and method are similar to those demonstrated in 2015 in Automated Vehicle Interaction Principles (AVIP); a Swedish research project conducted by RISE, Volvo Cars, AB Volvo, Scania, Autoliv and SAFER[37].

Production

Ford Co-pilot 360

Ford Co-Pilot360 includes standard automatic emergency braking with pedestrian detection, blind spot information system, lane keeping system, rear backup camera and auto high beam lighting. Ford Co-Pilot360 will roll out across Ford's new passenger cars, SUVs and trucks up to F-150 in North America, starting on the new 2019 Ford Edge and Edge ST this fall.

Lane keeping system has three functions:

- The first can notify drivers through steering wheel vibration that they need to correct course when the system detects the vehicle drifting close to lane markings
- The second provides steering torque to steer back toward the center of the lane
- Third, a driver alert system, continuously monitors driving pattern using a forward-looking camera and provides visual and audio warnings when the system estimates the driver's vigilance level to be less than that of an attentive driver.

10.9 General Motors

General Motors (GM) has made major investments in the field by starting, among other things, cooperation with Lyft to develop on-demand mobility services (based on automation). GM has not announced when such services will be ready for launch, but in conversation with some media, representatives of the company have suggested that "they will be ready sooner than people expect".

[36] https://media.ford.com/content/fordmedia/fna/us/en/news/2017/09/13/ford-virginia-tech-autonomous-vehicle-human-testing.html
[37] https://www.viktoria.se/projects/avip-automated-vehicle-interaction-principles

Concepts

GM bought in 2016 the startup company Cruise Automation, which initially specialized in aftermarket solutions for motorway driving. Cruise Automation is currently conducting test operations on motorways in California. In 2017, tests were also initiated by a mobility service in central parts of San Francisco, but so far, only employees of the company have been given the opportunity to use it. The number of test vehicles has doubled in the fall, from 30-40 to 100 vehicles. Consequently, the number of incidents and accidents has increased. In September 2017, GM's test vehicles were involved in 6 minor accidents. In five of these cases, the test vehicle was hit by another vehicle, for example, when it stopped for traffic signs, pedestrians or stationary at traffic lights. In one case, a cyclist crashed with the test vehicle. The test driver could see that a clearly unicycle cyclist came in the wrong direction against the test vehicle. The driver then took control of the vehicle and allowed it to stop before the cyclist collided with the bumper.

Production

In 2017, the company's subsidiary Cadillac launched its Super Cruise that is claimed to be world's first hands-free driving system for the freeway.[38] It works with Adaptive Cruise Control (ACC), which controls acceleration and braking while it is enabled and operating. It takes also care of the steering. Super Cruise support services through OnStar, along with precision lidar mapping, work with in-car cameras, radar sensors, and GPS to detect every curve and hill on the road ahead, helping to make long drives and commutes safe, comfortable, and more convenient. In addition, a small unit is mounted on the steering wheel that monitors whether the driver is paying adequate attention. If the driver has been inattentive for a certain period of time, the system issues a warning. GM has not classified Super Cruise according to SAE-levels, however, according to some online media it is nearly a SAE Level 3 automated driving system, though it is still likely Level 2 technically for the purposes of regulatory compliance, given that it requires a driver to be paying most of the time.[39]

[38] http://www.cadillac.com/ownership/vehicle-technology/super-cruise
[39] https://techcrunch.com/2017/08/03/cadillacs-super-cruise-autopilot-is-ready-for-the-expressway/

Figure 33 Super Cruise Control interface.

10.10 Tesla

Tesla's Auto Pilot is a function for automated driving that has been highlighted by various reasons. Due to its name, the feature is often confused with higher levels of automation, but it is in fact only a driver support system of SAE-automation level 2. It is also worth noting that all new Tesla cars will be equipped with hardware that new features can benefit when they become developed. According to statements from the company's CEO Elon Musk, this hardware will enable fully automated driving when the software is ready. It is currently not known when Tesla plans to launch cars with higher automation level. Based on the statements made 1-2 years ago, it may be about 2018. Tesla also intends to launch its own car-sharing service.

10.11 Uber

In September 2016, Uber began testing its "self-driving" car service in Pittsburgh. During the test period, there will be a driver and an engineer in the front seat who can take over operation control if necessary[40]. It was the first time that such a service was available to the American public. The taxi fleet consists of the Ford Fusion vehicles that Uber modified to enable automated city driving by installing technologies such as 3D cameras, lidars and GPS in them. In December 2016, the fleet was extended with the Volvo XC90 vehicles that are modified in a similar way.

10.12 Waymo

Until 2016, Google's umbrella company Alphabet, Inc. has been responsible for the development of automated driving. In 2016, Google chose to form a new company,

[40] http://www.autonews.com/article/20160914/OEM06/160919947/uber-debuts-self-driving-vehicles-in-landmark-pittsburgh-trial

Waymo which stands for *A new way forward in mobility*[41]. The new company will focus on further development of automated driving and its application to various mobility solutions. Waymo are testing self-designed cars in California and Texas in different traffic environments, including urban driving.

Waymo have also a partnership with Fiat Chrysler that has developed 100 automated Pacifica vehicles that will join the rest of Waymo's automated vehicle fleet in 2017. The vehicles are plug-in hybrids that have undergone a series of adaptations, from electronics to powertrain, chassis and physical design to enable integration of the new hardware and software. Various Pacifica prototypes have been tested at Fiat Chrysler's proving grounds in Michigan and Arizona, as well as on Waymo's testing facilities in California. The testing has also included 200 hours of driving in extreme weather conditions.

10.13 Baidu

The Chinese technology company Baidu, which until the middle of 2016 had a partnership with BMW on automated driving, has at the end of 2016 received permission to test automated driving in real traffic in Wuzhen, China[42]. The testing takes place on a predefined route of about 3 km. Test cars can independently change lanes, navigate intersections and make U-turns. They have a maximum speed of 60 km per hour and there is a driver behind the steering wheel of each vehicle. The cars come from the domestic manufacturers BYD, Chery and BAIC. In addition, the company has permission for testing on public roads in California. Baidu plans to launch its self-driving vehicles in 2018 and to achieve mass production by 2021.

11 Assessment: interaction design principles

This section presents an synthesis of the review with the focus on advanced driver assistance system that support drivers in lateral and longitudinal control of vehicles.

11.1 Name of system and vehicle type

It is common that advanced driver support systems with similar functionality (lateral and longitudinal control) have different names. In addition to that, the names are often to self-explaining and do not give a clear view of system's capability. This is, from user perspective, an important parameter to consider as it may create confusion, and also discourage users from using these systems.

The analysis shows also that advanced driver support systems are mainly available in selected luxury vehicle models. Also, they do not come as standard equipment in vehicles, which limits their contribution to improved safety.

[41] http://www.reuters.com/article/us-google-autonomous-idUSKBN142223
[42] https://techcrunch.com/2016/11/17/baidus-self-driving-cars-begin-public-test-in-wuzhen-china/

11.2 Functionality and operational domain

There is a discrepancy in the functionality of seemingly similar systems. This includes also differences in their operational domain. For instance, systems that assist drivers in traffic jam scenarios operate in different speed domains, depending on the manufacturer (e.g., BMWs Extended Traffic Jam Assistant System operates in speeds up to 60 km/h, while GMs Super Cruse works even in higher speeds). Also, some of these systems detect merging traffic while some others do not detect merging traffic. Similarly, some lane keeping systems have a centering function, while other not. These functionality discrepancies, in combination with insufficient function names, may constitute a challenge, especially when considering users who use vehicles from different manufacturers.

11.3 Activation and deactivation of the functions

The analysis shows that the activation and deactivation of system functions differs largely between different manufacturers and models. The controls are rather scattered and unstandardized, both regarding their placement (e.g., on the left-hand side of steering wheel, on the right-hand side of steering wheel, center console) and form (e.g., buttons, paddles). It is also common that users need to select certain functions in a menu. This is illustrated in *Figure 34* where we show the activation principles used by four manufacturers for a system that takes care of lateral and longitudinal control of vehicle.

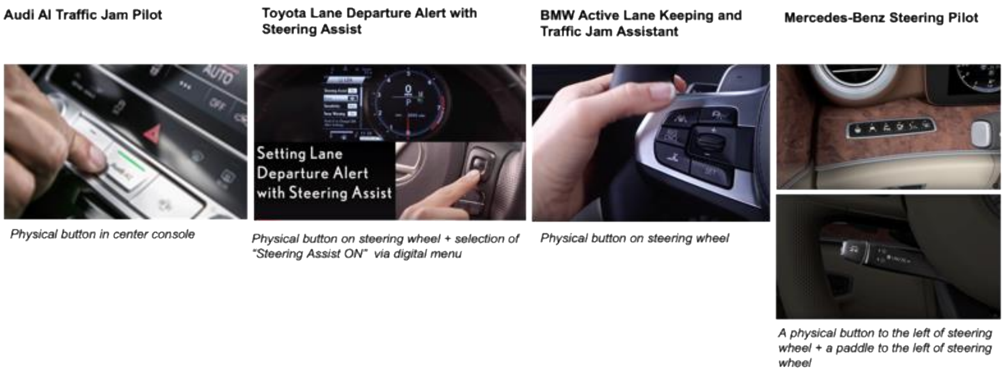

Figure 34 Systems with similar functionality differ in names as well as activation strategy.

11.4 Driver engagement

Many manufacturers are developing their version of hands-free systems (systems that allow drivers to take hands off the wheel), something that has been a big selling point for upscale brands like Tesla, Cadillac, Mercedes-Benz and Nissan. The review shows discrepancy when it comes to e.g., how drivers are made aware of this functionality, for how long they can take their hands off the steering wheel, how drivers are reminded to take hands back to steering wheel etc. In addition, there is also variety between manufacturers in whether they allow drivers to have both their hands off the steering and eyes off the road. That is, some manufacturers allow both while some other require that the driver keeps his/her eyes on the road. The amount of time allowed for having eyes off the road varies, however, it is from literature difficult to know exact numbers. In addition, different manufacturers use different methods for detecting driver engagement; some manufacturers (e.g., Mercedes) use a pair of capacitive-touch buttons on the steering wheel while some others use camera-based detection (GM). It should also be noted that these systems are only available for certain markets and operate within a certain design domain (e.g., limited-access highways with physical barriers to oncoming traffic).

11.5 Feedback to the driver and display clarity

The review shows that design of feedback to drivers is scattered from various design perspectives. To start with, there is a difference in type, modality and frequency of information provided to drivers. For instance, in their *Audi AI Traffic Jam Pilot*, Audi provides feedback to drivers in three modalities: visual (color, text), audio (abstract sound, lowering volume in cabin), haptic (pretention in seatbelt). On contrary, in their *Extended Traffic Jam Assistant System*, BMW uses only visual and audio feedback. Placement of the feedback information is on a high level similar between different manufacturers; visual feedback is used as a base and is commonly presented in the instrument cluster. However, when it comes to details there are large discrepancies between manufacturers; different information is presented in different parts of the cluster, different form factors and colors are used. This makes the information displays cluttered, which might make them difficult to grasp.

12 Conclusions

A general conclusion from the study is that there are currently large differences in design of advanced driver assistance systems (ADAS), both when it comes to products available on the market and products that are in conceptual phase. The use of different naming for similar functions is one of most urgent issues since it serves as a direct touchpoint towards the user. Another urgent issue, especially when it comes to ADAS that support drivers in both lateral and longitudinal control of vehicle, is that seemingly similar functions have in fact different functionalities and request different level of engagement in vehicle control from drivers’ side. On top of that, manufacturers tend to use different human-machine interaction principles when it comes to activation and deactivation of the functions as well as to provide feedback to drivers. This becomes even more urgent if considering that several different functions and systems co-exist in one and same vehicle. Altogether, this review shows a clear lack of standardized approaches for design of ADAS and highlights a need for creating a more harmonized interaction with drivers across different systems and across different manufacturers.

Table 1 Differences in design principles: Summary

Category	Summary of results [systems on the market]
Name of system	Different names for same or similar functionality Names are not self-explaining
Vehicle type	Advanced systems are typically available on selected (luxury) vehicle models
Functionality	Merging traffic is not always detected in traffic jam scenarios Lane keeping is some cases centering, in other not
Operational domain	Differences in operational speeds between systems with same functionality
Driver engagement	Some systems allow drivers to have hands off the steering wheel, others not
Activation/deactivation	Controls are scattered and unstandardized Menu-principle used by several stakeholders
Feedback to the driver	Same colors used to indicate different features Systems do not reliably inform driver of a failure
Clarity of display	Displays are not easily understood in a quick glance

13 RISE Viktoria AB

RISE Viktoria AB is an independent and non-profit research institute focusing on sustainable mobility through the use of information and communication technology (ICT). The overall aim is to contribute to global development addressing the major challenges for the vehicle and transport sector. These challenges are oil dependence, traffic accidents, congestion and impact on climate and the environment.

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