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A Human Factors Perspective on Automated Driving

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Automated driving can fundamentally change road transportation and improve quality of life. However, at present, the role of humans in automated vehicles (AVs) is not clearly established. Interviews were conducted in April and May 2015 with twelve expert researchers in the field of Human Factors (HF) of automated driving to identify commonalities and distinctive perspectives regarding HF challenges in the development of AVs. The experts indicated that an AV up to SAE Level 4 should inform its driver about the AV's capabilities and operational status, and ensure safety while changing between automated and manual modes. HF research should particularly address interactions between AVs, human drivers, and vulnerable road users. Additionally, driver training programs may have to be modified to ensure that humans are capable of using AVs. Finally, a reflection on the interviews is provided, showing discordance between the interviewees' statements—which appear to be in line with a long history of work on human factors research, and the rapid development of automation technology. We expect our perspective to be instrumental for stakeholders involved in AV development and instructive to other parties.

Keywords: Automated driving; Levels of automation; Human Factors challenges; Interview study; Experts vision

Relevance to Human Factors/Ergonomics theory: Automated driving could fundamentally change road transportation and improve quality of life. However, the role of the human driver within the automated vehicle is not yet clearly established. This work presents the results of an interview study among 12 HF scientists involved in automated driving research. A consensus was revealed among the researchers regarding the HF challenges that need to be resolved prior to the deployment of AVs on public roads. Such challenges include the synergy between the human driver and automation, potential changes in driving behaviour due to automation, and the type of information that the human drivers shall be receiving from the automated driving system. On the other hand, a disparity was identified between the researchers' concerns regarding the AVs development and deployment and the AVs technological advances: although the researchers expressed that AVs should not be introduced unless proven safe, reality shows that industry is now close to the introduction of Level 3 and Level 4 AVs on public roads.

Introduction

Automated driving technology has the potential to fundamentally change road transportation and improve quality of life. Automated vehicles (AVs) are anticipated to reduce the number of accidents caused by human errors, increase traffic flow efficiency, increase comfort by allowing the driver to perform alternative tasks, and ensure mobility for all, including old and impaired individuals (Fagnant and Kockelman 2015; Mui and Carroll 2013).

AVs can be classified according to their technological capabilities and human engagement, ranging from manual driving, where the human driver executes all of the driving tasks, to fully automated driving where no human interaction occurs. In this paper, we adopt the SAE levels of automation (SAE International 2014; 2016) shown in Table 1, which is arguably the most well-known and broadly used taxonomy in the field of automated driving research (International Transport Forum 2015; NHTSA 2016).

Table 1. Levels of automation as defined by the SAE International

Monitoring of driving environment	Level of automation	Description
Human driver	0: Driver only	The human driver performs all aspects of the dynamic driving task
	1: Assisted automation	A driver assistance system performs either steering or acceleration/deceleration, while the human driver is expected to carry out the remaining aspects of the dynamic driving task
	2: Partial automation	One or more driver assistance systems perform both steering and acceleration/deceleration, while the human driver is expected to carry out all remaining aspects of the dynamic driving task
Automated driving system	3: Conditional automation	An automated driving system performs all aspects of the dynamic driving task (in conditions for which it was designed), but the human driver is expected to respond appropriately to a request to intervene
	4: High automation	An automated driving system performs all aspects of the dynamic driving task (in conditions for which it was designed), even if the human driver does not respond appropriately to a request to

		intervene
	5: Full automation	An automated driving system performs all aspects of the dynamic driving task under all roadway and environmental conditions

There are suggestions that Levels 3 and 4 automation could be deployed by 2020 (ERTRAC Task Force and Connectivity and Automated Driving 2015), while Tesla announced the introduction of an automated feature that will allow individuals to summon their vehicles from a distance by 2018 (Blum 2016; Korosec 2015). Moreover, a recent study suggests that the public expects Level 5 (full) automation in more than 50% of vehicles by around 2030 (Kyriakidis, Happee, and De Winter 2015).

Along this accelerating evolution of road vehicle automation, Human Factors (HF) research scientists have warned for a long time that the mere fact that you can automate does not mean that you should (Fitts 1951; Hancock 2014). As early as 1983, Bainbridge (1983) presented several 'ironies of automation' and explained that "the more advanced a control system is, so the more crucial may be the contribution of the human operator." Similarly, Parasuraman and Riley (1997) explained the importance of studying how humans may misuse, disuse, and abuse automation technology, and also argued that humans tend to be poor supervisors of automation. With respect to AVs in particular, up to Level 4 automation, human drivers will be a key component, because they should operate the vehicle in conditions not supported by the automation, and will be expected (Level 4), even if not liable (Ref for Volvo), or even required (Levels 2 and 3) to resume manual control when needed.

Studies indicate that many challenges pertaining to the interaction between human drivers and automated systems are yet to be resolved. Such challenges include the impact of automated systems on drivers' mental workload and situation awareness (Brookhuis et al. 2008; De Winter et al. 2014; Kaber and Endsley 2004; Merat et al. 2012; Salmon, Stanton, and Young 2012; Stanton and Young 2005; Whitmore and Reed 2015), as well as the human drivers' levels of acceptance (Brookhuis et al. 2008), trust, and reliance on the automated systems (Coelingh 2013; De Waard et al. 1999; Fisher, Reed, and Savirimuthu 2015; Verberne, Ham, and Midden 2012).

Further challenges are associated with potential changes in human drivers' behaviour due to automation (Gouy et al. 2014), the necessary skills that the humans should retain to perform the driving task manually (Vlakveld 2015), and the role of the humans in the case of an emergency such as when automation fails or exceeds its functional limits (Levitan, Golembiewski, and Bloomfield 1998). In addition, research has yet to clarify the required level of supervisory control and cooperation (who is performing what part of the driving task) between human drivers and automated systems (Banks and Stanton 2016; Coelingh 2013; Hoc, Young and Blosseville 2009; Lu et al. 2016; Marinik et al. 2014).

Research challenges also comprise the estimation of the minimum time required by human drivers to resume manual control when instructed by the automated system (Gold et al. 2013, 2016; Merat et al. 2014; Mok et al. 2015; Radlmayr et al. 2014; Schieben et al. 2008; Zeeb, Buchner, and Schrauf 2015), and the interaction between AVs and other vehicles and road users (Martens and Van den Beukel 2013, Merat and Lee 2012; Merat et al., submitted; Madigan et al., 2016). Finally, as argued by Hancock (2015, p. 139), "one empirical question that necessitates vital research at this present time is the establishment of appropriate epidemiological baselines for the dimensions of current, manually-operated vehicle performance such as transit time efficiency, system downtime, injury and fatality".

Therefore, HF research can critically contribute to the development and deployment of AVs, by working towards a synergy between the human driver, vehicle, and environment. This paper presents the findings of an interview study with twelve researchers in the field of HF and automated driving. The aim of the study was twofold: first, to define the most critical HF challenges related to AVs, and second, to indicate similarities and distinctive perspectives among the researchers.

The remainder of the paper is organised as follows. First, we will describe the methods of the study, with subsequent sections providing a summary of the researchers' opinions in the form of twelve narratives. Finally, we discuss parallels and idiosyncrasies regarding the opinions of the interviewees, and provide concluding remarks and suggestions for policy makers and other stakeholders.

Methods

Using a 35-item questionnaire interview (provided in the Appendix), the twelve researchers articulated their expectations, concerns, and vision about AVs. The questionnaire was designed to reflect the researchers' experience and expertise, and it addressed four main areas of interest associated with the development of AVs: (1) challenges from a HF perspective, (2) potential strengths and benefits, (3) deployment scenarios and likely changes in the status of road transportation, and (4) public acceptance and expectations. The background and expertise of the participants is provided in the Section “About the authors” and helps the readers to interpret the twelve narratives. The questionnaire was built on past research that explored the public and subject matter experts' opinion on automated driving (Begg 2014; Casley, Jardim, and Quartulli 2013; KPMG 2014; Kyriakidis, Happee, and De Winter 2015; Payre, Cestac, and Delhomme 2014; Schoettle and Sivak 2014a, 2014b; Sommer 2013; Underwood 2014).

The twelve researchers are currently involved in research activities associated with HF and AVs, and they all have more than 10 years of experience in the field (mean = 19 years). Nine of the researchers participate in the EU project Human Factors of Automated Driving (2014d). To increase diversity, three additional researchers contributed to the study. One of them is involved in the EU projects AdaptiVe (2014a) and CityMobil2, the second in the UK project GATEway (2014c), and the third coordinates the EU support action Vehicle and Road Automation (VRA) (2013).

The interviews were carried out individually in April and May 2015, with their duration varying between 45 and 90 minutes. Based on transcripts from audio recordings of each interview, an initial narrative was generated to describe the researchers' main insights regarding the four addressed areas of interest. Building upon these narratives, the researchers then recomposed and finalized their statements, as presented in the next section.

Researchers' opinions

Neville Stanton

Decades of research have shown that humans are not particularly good at tasks that require vigilance and sustained attention over long periods of time (Warm, Parasuraman, and Matthews 2008). Today, one of the major challenges in the design of AVs is the expectation that drivers will monitor the system constantly and appropriately intervene when required (Stanton, Young, and McCaulder 1997). Experience from other industries, such as aviation, has shown that automation may actually cause as many problems as it solves. For example, the disconnection of the autopilot on Air France Flight 447 from Rio de Janeiro to Paris (which crashed on 1 June 2009, BEA 2012) failed to communicate the nature of the situation (the blocking of pitot tubes with ice crystals) effectively to the human pilots. The resultant inputs from the pilots led the aircraft into an aerodynamic stall, from which it did not recover. The black box voice recorder makes for chilling reading, as the pilots struggled to regain control of the aircraft.

There is concern that AVs could cause similar confusion in drivers, where the drivers' understanding of the situation is at odds with reality (Stanton, Dunoyer, and Leatherland 2011). Whilst in aviation, people are beginning to wise up to the fact that automation is causing confusion in pilots (which has been called a 'mode error' in the technical literature (Sarter and Woods 1995), there is still an assumption that the driver will be the last line of defence in AVs. Despite two decades of research on AVs, there is still much to be learnt. HF research can play a substantial role in the development of our understanding of driving AVs by reproducing a range of situations in simulators. Here we can observe how drivers are likely to behave as well as get feedback on their experience.

Research should be focusing on maintaining the communication and interaction between AVs and the driver. Unless a system can be designed that requires no human input at all (and has no controls within the vehicle) we need to design automation that supports, rather than replaces, human drivers. To some extent, supportive automation is already with us, such as Antilock Braking Systems, Lane Keeping Systems, and Electronic Stability Control (Stanton and Young 2005). These systems can be thought of as a background automation rather than foreground automation (where the latter takes over the driving tasks). Background automation allows the driver to drive the vehicle, but watches over them in case of trouble (Young, Stanton, and Harris 2007). If the driver brakes too hard, strays out of the lane, or steers too hard, the automation will intervene in an attempt to save them. Automated Emergency Braking Systems are an extension of this philosophy, and will brake if the sensors detect an impending accident without any intervention from the driver.

As a cautionary note, with creeping automation taking a more active role in driving, there are some very salient lessons to be learnt from aviation. This can be illustrated using the difference between the automation philosophies in Boeing and Airbus. In Boeing the pilot is king. Although there is a protective layer of automation, this can be overridden by the pilots. By way of contrast, in the Airbus the computer is king, and the pilots cannot override this protective layer of automation in normal law mode. Whilst it is acknowledged that the automation does protect pilots, it can also cause problems as shown with the AF447. In this incident, the aircraft entered alternate law mode (although the pilots did not realize this mode change) (BEA 2012). In addition, the flight controls in the Airbus do not have any feedback (they do in the Boeing), so do not move at all when the autopilot is in control (whereas they do in the Boeing). Each pilot did not realize that the other was making control inputs. This would be equivalent to the steering wheel not moving in a car that is being driven automatically, certainly not something I would advise to vehicle manufacturers.

Overall, automated vehicles are meaningful only if drivers are freed from the driving tasks, are not anticipated to supervise the system, and are not liable for it. We are, however, rather far from reaching this point (Walker, Stanton, and Salmon 2015). Accordingly, it might be more beneficial for the society if research focuses on background automation, until foreground automation has matured sufficiently.

Thierry Bellet

Almost twenty-five years ago, the US Automated Highway System (AHS) program was launched to conduct long-range research on the design of future Intelligent Transportation Systems aimed at aiding driving, enhancing the capacity and efficiency of the highway system, and assisting transportation agencies in managing their facilities and controlling traffic (Bement et al. 1998).

One of the program’s main findings was the unclear extent to which human drivers would accept reduced manual control of their vehicles or be willing to travel in automated vehicles at close following distances, on narrower lanes, and at higher speeds (Bement et al. 1998). The program also showed that improving road safety and increasing road capacity might not be mutually compatible unless society accepts the idea of “automation responsibility” in the case of accidents (Bellet et al. 2003). If not, the human drivers may be required to remain alert and take back the control of their vehicles in the case of critical situations. Subsequently, increased safety margins and a reduction of vehicle speeds are required to allow drivers to rebuild their situation awareness and adequately resume control of the driving task. However, this would mean that AVs, compared to manual driving, would actually reduce road capacity. Therefore, the program concluded that although there are no technical showstoppers for the overall success of an automated highway system, legal and societal challenges may be more difficult to resolve, including rejecting the founding paradigm of the driving task, where responsibility lies with the human driver (Lay, McHale, and Stevens 1996). Recent developments in AVs have changed the situation. AVs, although in limited numbers, now exist. It is not a question of whether it is possible to have AVs on the public roads. It is a question of how, when, and under which conditions they should be introduced. Of course, the famous Bainbridge's (1983) 'ironies of automation' remain exactly the same, but now the time has come to propose solutions to these ironies. Today the main challenge is not to consider the future, but to think about the present. Facing this challenge, HF research has to clearly define the role of humans in AVs (is the human still technically a driver), and to support accordingly the design of a human-centred automation. Synthetically, three main options seem promising: (1) developing co-piloting systems supporting the driver rather than replacing them, (2) designing solutions to keep humans in the loop of control during automation, in order to support situation awareness, (3) defining dedicated areas for full automation without any responsibility of the driver (e.g., dedicated lane on highways, or platooning for long tunnels).

However, to support such human-centred design of automation, new simulation tools are required, from realistic AV simulators allowing full-scale immersive tests, to traffic flow simulations including realistic human driver models that are able to predict the road safety effects of AVs (Bellet et al. 2012). Such simulation tools could allow us to test different types of AVs, support decision-making regarding policy and legislation, and finally permit the introduction of AVs on public roads and their potential deployment during the next 20 years.

Bart van Arem

The deployment of automated vehicles will eventually change road transportation as it stands today. However, AVs that are able to drive in all situations and at all conditions, without requiring any human supervision or intervention, will not be introduced into the market any time soon.

Nevertheless, I believe that within the next 10 years AVs could be deployed on public roads for specific scenarios (e.g., highway driving). The human drivers in those vehicles will then be supervising the system and intervene if required.

Research, therefore, should aim at ensuring that the human drivers remain alert and situational aware, even when they are not actively controlling the steering wheel and pedals. This level of automation, however, will not allow the drivers to be engaged in a large variety of non-driving tasks. This means that the benefits for the consumers as well as their acceptance and willingness to buy such AVs are limited.

Thus, our resources should be focusing on highly automated driving, which will enable a driver to engage in non-driving tasks, and which is equipped with fail safe strategies, including a feature that brings the car to a minimal risk condition (cf. SAE, 2016).

Karel Brookhuis

Human beings notoriously get bad marks in (low frequency) vigilance tasks, that is, detecting occasional mishaps. The poor human ability to monitor and supervise represents a major weakness of automated vehicles in general, and specifically at the SAE Level 2, since it will be mandatory for human 'drivers' to keep monitoring the system and the environment. Since human drivers should primarily be supervising the system, rather than engaging in any other activities, the benefits of AVs and in turn their acceptance and the public willingness to use them, let alone buy them, are debatable, whilst driver training and licensing will change dramatically. In order to maintain driving skills, human drivers should keep having the opportunity to drive manually, probably requiring AVs to stay fully equipped.

As system failures cannot be excluded, additional research should focus on four topics: (1) to define the way in which human drivers should be informed in case of a system failure, (2) depending on the type of failure, what the human driver is able and allowed to do, (3) to optimize the safe interaction of the new technology with human drivers, and (4) to ensure public acceptance and trust in automated vehicles.

The deployment of SAE Level 5, operating without any human intervention in all situations and at all conditions, might even never happen, as people are reluctant to accept any potential harm caused by a machine operating independently. A realistic and fast way to deploy AVs is by employing segregated lanes, which will be controlled and maintained by a separately managed infrastructure. In these lanes only authorized AVs operating at SAE Level 4/5 will be allowed.

In conclusion, I am expecting AVs within the next 10 years, but only in a segregated manner such as low speed vehicles on designated tracks for the transportation of goods. For this to happen, the safety levels should be clearly demonstrated, while any potential side effects that may arise from their deployment are adequately communicated to the people involved and to society in general.

Marieke Martens

Automated vehicles in the next couple of years will have operational limitations, being able to operate only under the specific conditions they can cope with. Once we can prove that AVs are always able to cope with situations in an acceptable, safe, and comfortable manner, the AVs may take over control, and the human drivers will become passengers. Subsequently, liability issues could also be resolved, with the drivers remaining liable for as long as they are in control of their vehicle, and the original equipment manufacturers (OEMs) becoming liable once automation accepts the control of the vehicle.

However, if AVs cannot cope with a situation, they will either hand over the control to the human driver or they will come to an alternative solution such as a transition to a minimal risk condition. This may include AV coming to a standstill (e.g., safe stop), which may be dangerous if the AV does not explicitly communicate its intention to other road users or does not come to safe stop in a predictable manner or at a predictable location.

HF research should specifically focus on the transitions from automation to manual driving, in order to ensure that the human driver will appropriately respond to the request of their vehicle to take over control. Additionally, HF research should identify the behaviour of AVs vehicles when automation is in control, in order for the passengers to understand the vehicle's actions and to feel comfortable (i.e., no motion sickness; cf. Diels and Bos 2016), and for other road users to understand and predict the AVs intentions. This will ensure the maximal benefits in terms of safety, efficiency, comfort and acceptance.

By elaborating current technology, the deployment of SAE Level 3 or AVs operating on highways will be feasible within the next 5 years. I do not believe in SAE Level 2 (driver monitoring the environment), since drivers are not able to pay attention to the road and automation status across long periods. SAE Level 2 is suitable for testing and research purposes, with expert drivers or technicians assessing the reliability of the automation, in order to verify readiness for SAE Level 3. Yet, a lot of testing is required to confirm the safe operation of AVs in different types of conditions, and to understand the operational envelope of automation. SAE Level 2 systems as we currently see introduced on the market will only work well if their reliability is actually 'Level 3 ready'.

The deployment of SAE Level 5 in mixed traffic conditions may never happen at acceptable levels. AVs may have to operate at very low speeds in order to meet appropriate safety requirements, making these vehicles particularly slow in city environments. However, such AVs could be introduced for specific scenarios and types of operation, such as public transportation.

Klaus Bengler

Automated driving should not become a hype topic; its presentation nowadays sometimes may be too visionary and confusing/distorting for the public. It is rather unrealistic, for example, to expect SAE Level 5 automated vehicles soon on public roads. However, it could indeed be possible to introduce fully automated driving vehicles operating at low speeds in segregated lanes supported by infrastructure for specific scenarios. Examples of such applications can be found in public transport or the transportation of goods.

It is important, therefore, to clearly define the functionalities and the range of applicability of automated vehicles. Based on the current technological and infrastructural capabilities, automated driving could only be a fraction of individuals' daily mobility. At present, SAE Levels 4 or 5 AVs can only be applied in very specific scenarios, such as low speeds and specific areas.

In the future, AVs may be able to operate at higher SAE automation levels. In such vehicles, the mode of driving can be selected based on the situation and conditions at each particular time of the operation. In other words, the human drivers could remain drivers, supervisors of automation, or passengers, depending on the mode of automation. In those vehicles, new families of input elements can be introduced, yet steering wheels have many advantages, such as clear visual feedback regarding direction.

AVs will be designed to obey the traffic rules in all cases, and therefore the fluency of their interaction with other vehicles and road users, as well as their acceptance by the public, is a big topic.

Within this context, HF research has four main tasks. First, to define the acceptance criteria of human drivers regarding the automated driving functionalities. Second, to determine the individual capabilities of human drivers when using AVs (e.g., situation awareness, reaction times), and in turn to ensure safety while changing driving modes. Today, for instance, humans driving manually are able to look outside their windows or to the dashboard for a small period of time without a problem. It is unrealistic to expect that human drivers will constantly monitor the automation system. Rather it could make sense, to define a period that the drivers could divert their view away from the automated system. Third, to provide design solutions regarding the interfaces installed in AVs and their interaction with the human drivers. Finally, to investigate the interaction and communication between AVs and conventional cars and other road users. AVs will be deployed on the market only if they are proven to be safe, and all the relevant liability issues are resolved.

Jan Andersson

Automated vehicles can eventually change the status of road transportation, including the use and ownership of vehicles. From a safety, mobility, and traffic perspective the focus on developing and directly deploying SAE Level 5 AVs would be the most beneficial, as the majority of the human factors and legal challenges associated with the SAE Levels 2, 3 and 4 AVs would be avoided. Yet, it is more realistic to expect a gradual deployment of SAE Levels 2, 3 and 4 AVs, which will introduce different levels of functionalities and applicability.

The main weaknesses of these automation levels, however, are the expectation that human drivers intervene upon a request by the automation, in addition to the liability uncertainties. Who would like to use automation if they remain liable at all times for a system that they partially cannot control?

HF researchers need, therefore, to understand how people will be using the automated functionalities, in order to ensure a smooth process for the human drivers to regain control of the vehicle. Research has proven that people are poor in monitoring a technological system (e.g., Endsley 1996), or staying alert when not being engaged to the driving task, and we should be aware of this when the liability criteria are determined by legislators. It is crucial, therefore, to define the minimum time requirements for human drivers to return back in the control loop, for several different driving scenarios. For this, research would first have to define the human driver's mind-set, and whether bringing them into the loop is a cognitive or a decision-making aspect. Furthermore, it is important to define the type and frequency of information that human drivers should be receiving in order to facilitate and maintain their situation awareness, primarily when they are not engaged to the driving task.

In addition, HF research must determine how people using other transport modes or conventional vehicles, and vulnerable road users will be interacting with AVs, and to confirm that the human drivers and all road users are aware of the automated systems' capabilities and limitations.

Natasha Merat

The main concerns and worries towards deployment of automated vehicles are currently associated with automation SAE Levels 2 and 3. All relevant stakeholders agree that it is very difficult to establish and ensure whether or not a human driver is aware of the automated system performance, and research suggests that humans may generally be poor supervisors of automation in such circumstances (Parasuraman 1987). Subsequently, it is hard to define the appropriate time that humans need to regain control of a vehicle during a specific situation, and to confirm that upon regaining control they respond in a safe and appropriate manner (Merat et al. 2014). As long as the design of AVs allows human intervention, the impact on safety of road transportation is debatable.

The general public should also be aware that we are far from ready to deploy AVs capable of operating in all environments and scenarios without any human intervention. It is therefore more likely that the first AVs will only be operating in dedicated lanes, for specific driving scenarios.

One of today's biggest challenges is to verify that the human drivers are aware of the AV's limitations, in order to resume control when required, whilst also remaining free to engage in other activities, beyond driving. Otherwise, if drivers' main task in an AV is to observe and monitor the vehicle and its operation, the benefits of automation to consumers are minimal.

Therefore, for the next 5 to 10 years, research is likely to focus more on providing solutions for maintaining human drivers' situation awareness, mainly when they are not engaged in the driving task. In addition to ensuring that AVs (including their computers and sensors) are functioning reliably, improvements in the design and performance of HMIs are required to establish the type and amount of information that drivers should receive in order to cope with any unexpected situation (Merat and Lee 2012).

The long-term potential benefits of AVs on safety, time and traffic efficiency, mobility, and pollution can be enormous. Yet, all relevant stakeholders have to be modest and avoid confusing the public by raising unrealistic expectations. Indeed, it might be possible to have vehicles with automated functionalities on public roads within the next 10 to 15 years. However, it is rather likely that the cost and maintenance of such vehicles will be quite high, which will be a major barrier towards their deployment and acceptance by the majority of the public.

Nick Reed

Today, challenges towards the introduction of automated vehicles are associated with levels of automation that rely on the human drivers. Although it is feasible to deploy conditional automated driving vehicles (SAE Level 3), the expectation that a human driver can remain alert and rapidly regain situational awareness following a request by the system is unrealistic. However, if AVs become capable of safely dealing with a human driver failing to respond to a request to intervene, then fully automated vehicles cannot be far behind. Research has first to determine a safe and effective process for re-engaging the driver back in the loop. Second, to educate human drivers on system capabilities and expected actions; and thirdly, to explore tendencies for drivers to use automation and adapt their driving behaviour to particular circumstances of a journey.

Current technology suggests that deployment of low speed automated vehicles operating without human intervention on dedicated routes for specific purposes, such as public transport, may be possible within three years. Once the technology is mature enough to support fully automated vehicles, car ownership and vehicle usage patterns will change. Today, a car is often the second biggest investment a person makes yet will typically be parked the majority of the time. There is also a trend for younger people to reject car ownership or license acquisition, probably associated with high insurance costs for driving. SAE Level 4 and (eventually) Level 5 AVs make mass car sharing models much more viable. As an on-demand service, people could choose a vehicle that is appropriate for each individual, specific journey rather than owning an individual vehicle that is compromised across an owner's various mobility needs. These shared AVs present additional HF challenges such as how to design AVs that provide an enjoyable, personalized travel experience for diverse customers and how vehicle interiors should be redesigned to make journeys comfortable and pleasant without compromising occupant safety.

Maxime Flament

The automation levels have been formulated as a common language. As technology is advancing, we need to keep a critical eye and avoid getting stuck at an intermediate level of automation. Indeed, today's HF research raises serious doubt as for the handing over of the driving task associated with SAE Level 3. It is human nature that a driver, who is relieved even briefly from their driving task, will engage to other distracting tasks. From a liability standpoint, the industry will not introduce such a distracting system unless the automation can bring the vehicle to a minimal risk condition if no driver response is detected. For this reason, the SAE Level 3 AVs may just never come to the market.

Adding confusion to the definitions, the same vehicle, depending on its environment and its access to reliable information, could allow more than one level of automation. The HF challenge in this case will be to clearly inform the driver about the possible levels of automation at any given time and place, and why this is so. This will lead to trust and acceptance of automation, but, too much trust may cause over-reliance together with unintended use, misuse, and even abuse. In fact, the difficulty may come from other road users: manual drivers, cyclists and pedestrians; knowing the AVs' capabilities, they may take advantage of AVs in mixed traffic. The challenge for AVs will then be to keep their place in traffic while guaranteeing reasonable safety. This should lead to innovative ways to indicate the driving intentions to other road users.

AVs should firstly address critical situations caused by boredom and drowsiness, as well as construction sites, intersections and other stressful areas. AVs could be on the market within less than ten years, first on highways then gradually on other main roads, supplemented with valet parking.

Marjan Hagenzieker

The role of human drivers is one of the main challenges when discussing automated driving vehicles. In vehicles where human drivers are expected to intervene, the human has to be both a driver and a supervisor. However, these two roles require different training and skills, while they are not in tune. For instance, the less human drivers are manually controlling their vehicles, the more their driving skills will deteriorate (e.g., Dragutinovic et al. 2005), which can be critical especially in the case of an emergency.

Therefore, HF research should determine the required skills of humans in order to operate AVs, and to identify any changes in their driving behaviour. Moreover, research has to define the necessary (re)action times for the types of situations and interventions that drivers will be asked to perform.

In addition, research should assist in redesigning the current driver training programs. On the one hand, the new programs have to ensure that human drivers are always capable of performing the driving task. On the other hand, they must instruct human drivers how to supervise automation, and to maintain their supervisory skills.

HF researchers also have to determine ways of communication between AVs with human drivers, other vehicles, and vulnerable road users. In addition, research has to determine the consequences of behaviour of AVs, which is potentially very different compared to the manual driven vehicles. Such large differences in the behaviour of AVs may impose additional demands on people who do not drive or use AVs. This could raise questions on whether we should allow AVs to induce such demands to those who do not own, drive, or use this technology.

For fully automated vehicles that do not require any human intervention, research should focus on proving them safe and reliable. However, it is too optimistic to believe that such vehicles will be able to operate in large scale mixed traffic in the foreseeable future. Nevertheless, the deployment of AVs of SAE Levels 3 and 4 on specific stretches, dedicated areas, and driving scenarios, such as highways, is feasible and could in the mid and long term improve the safety of road transportation.

Riender Happee

Are we ready to deploy automated vehicles on public roads? Certainly not, as we still have to prove them safe. On the one hand, the role of the human driver in AVs has not been clearly defined. On the other hand, neither vehicle technology nor the infrastructure is proven to be ready to support the deployment of automated vehicles safely operating in real world traffic conditions.

Proving safety requires on-road and virtual testing to rigorously assess not only the technology but also the human interaction with automation. The critical aspects of HF to date have almost exclusively been tested in driving simulators (De Winter et al. 2014). Undoubtedly, driving simulators are valuable for gaining insight in human behaviour, especially in safety-critical scenarios that cannot be easily tested on the public roads. Yet, the results derived from simulator experiments do not necessarily reflect reality. It is essential, therefore, to compare the behaviour of drivers in simulators with equivalent studies on the public roads, in order to eventually build evaluation methods combining simulator and on-road studies.

Testing procedures are required for sensing and control systems in order to determine whether they operate reliably in complex real world driving conditions. HF research should focus on establishing procedures to test and determine the safe interaction between human drivers and automation, not only during transitions of control, but also regarding the interaction of automated vehicles with other road users.

Hands-free driving is already commercially available with restrictions, and eyes-off-road driving may be possible and legal in the near future, in particular for highway conditions. AVs can provide transitions to minimal risk condition (e.g., safe stop) if human drivers do not take over when this is requested by the AV. Such minimal risk strategies can prevent mishaps in the hopefully rare case that drivers are unfit to resume control. However, as long as such take-over requests exists, and as long as drivers have options to resume manual driving, we need to incorporate human factors analysis in the safety assessment of automated driving.

Discussion

Comparison of the interviewees' statements

The interviews revealed a consensus regarding HF challenges that need to be resolved prior to a wide-scale deployment of AVs on public roads, with a number of distinctive remarks.

In line with recent position papers (Casner, Hutchins, and Norman 2016; Norman 2015; Poulin et al. 2015; Trimble et al. 2014), the experts highlighted a complex interaction between human drivers and SAE Level 2 and 3 automated vehicles. The interviewees stressed that any automated system that removes the human from the driving task, yet requires the human to monitor and supervise the system and regain control when necessary, could be unsafe. In other words, one should not expect that human drivers will always be able to regain control of their vehicles in a safe and appropriate manner. Moreover, SAE Level 2 and 3 systems may not be welcomed by drivers because the range of the permitted secondary tasks will be limited (e.g., NHTSA 2012). Thus, drivers may not be able to benefit from automation to a significant extent (cf. Naujoks, Purucker, and Neukum 2016).

The researchers underpinned the importance of additional research on public acceptance and trust in automation, the interaction of the AVs with other vehicles and road users, and the amount and type of information that the human drivers shall be receiving by the automated system. Finally, they referred to the need for additional experiments to study human driver behaviour while operating in automated mode and during transitions from manual to automated mode and vice versa, and to validate findings from simulator experiments with equivalent studies on public roads.

Besides areas of wide agreement, the twelve researchers expressed distinctive statements on different aspect of AVs, including legislation, cost of AVs, and type approval challenges. The role of human drivers in AVs was discussed, and it was suggested by several of the researchers that unless AVs (permanently) take over all functions of the driving task, drivers should remain ‘in the loop’. The issue of driving skill degradation due to automation was raised, stating that training programs will have to be modified, teaching human drivers about the automation’s capabilities and expected actions.

The issue of responsibility in the cases of accidents is a critical factor in AV deployment, yielding a conflict between roadway capacity and roadway safety. Specifically, it was stressed that when human drivers are expected to regain control of their vehicles, large safety margins (i.e., separation between vehicles) will have to be adopted, while engineers are developing platooning systems that operate with short inter-vehicle headways. Nevertheless, it was stated that AVs could be broadly deployed within the next 10 years with an operational design domain confined to highways and similar roads, with the expectation that human drivers will resume manual control when leaving the operational design domain.

It was stated that automation levels were formulated as a common language, but that in reality the same AV (depending on its environment and access to reliable information) may allow more than one level of automation. Finally, it was pointed out that there is a need for testing procedures regarding sensing and control systems, in order to determine whether AVs operate reliably in complex real-world driving conditions. To this end, the Dutch Type Approval Authority has introduced an amendment to the Exceptional Transport (Exemptions) Decree to facilitate testing and development of autonomous vehicles on public roads (RDW 2014).

Comparison of the interviewees' statements with the current state of AVs deployment

In the interviews conducted in April and May 2015, the twelve researchers commented extensively on HF related safety implications of Level 2 and 3 AVs, and some specifically expressed that AVs should not be introduced on public roads unless proven safe. However, reality shows that SAE Level 2 automation systems, and even systems that are close to SAE Level 3 automation, have now been deployed. For example, in October 2015 Tesla introduced an Autopilot feature that allows for minutes of hands-free driving, whereas as of October 2016, new cars are equipped with full self-driving hardware (Tesla, 2016). These observations illustrate that industry marches forward and that there is a disconnect between academic research and industrial research and development. Furthermore, it shows that even experts who work in the field of AVs may underestimate the pace of development in some industries, regarding the introduction of AVs on the market.

The interviewees agreed that we are far from ready to deploy fully (SAE Level 5) automated vehicles on public roads, with several researchers claiming that fully AVs may never operate at acceptable levels (Shladover 2016). Instead, SAE Level 4 vehicles could be introduced on specific routes, under certain conditions, and for distinct applications, such as segregated areas, low speeds or high speeds on highways only, transport of goods, or public transport. In agreement with the reviewers' expectations, the projects CityMobil2 (2014b), GATEway (2014c), and WEpods (2014e) are currently demonstrating the integration of autonomous transport systems into complex real world urban environments. Such integration, however, may pose questions concerning the interaction of vulnerable road users with AVs (Lundgren et al. 2017; Núñez Velasco et al. 2016; Rothenbücher et al. 2016; Merat et al., submitted).

Concluding remarks

AVs have the potential to substantially reform road transportation by increasing safety and traffic flow efficiency (SAE Levels 3 to 5), and ensuring mobility for all (SAE Level 5). It is no longer a question of whether it will be possible to have AVs on public roads, but rather a question of how, when, and under which conditions. This paper presents the perspective of twelve researchers in the field of HFs and AVs.

Findings indicate that, currently, the main challenge for the deployment of AVs is the expectation of the human driver to intervene, after a period of not controlling the steering wheel and pedals. Thus, research should focus on (a) designing AVs that can inform their occupants about the vehicle's capabilities and operational status, as well as about upcoming situations that the vehicles cannot solve. In addition, research should (b) concentrate on defining the automation functionalities that the human drivers would accept and use, and (c) determine the interaction between the human driver and automation during transitions of control. Furthermore, research needs to (d) establish procedures to test, determine, and ensure safety while changing from automated to manual mode, and (e) investigate the interaction between AVs and human drivers, conventional cars, and other road users such as cyclists and pedestrians. Finally, research should (f) explore the modification of the current driver training programs so that drivers are instructed how to use automation in a safe and acceptable manner. We expect that these findings can be instrumental for stakeholders involved in the development of automated driving technology and instructive to other parties.

For long-term successful deployment of the AVs all the relevant stakeholders including the automotive industry, research institutes, policy makers, and governmental bodies should work together to facilitate a safe deployment of AVs, not only taking technology into account but also the human factors and the end user's perspective. As Cummings (2016) stressed, the relevant policy makers and governmental bodies shall provide leadership to overcome today's inadequate testing and evaluation programs of the robotic self-driving cars. Cummings suggested that the automated driving community could learn and follow practices from other domains, such as aviation. The Federal Aviation Administration (FAA), for example, has explicit certification processes for certifying aircraft software, and they would never allow commercial aircrafts to execute automatic landings without verifiable test evidence. Similarly, road transport governmental bodies worldwide may have to deny certification to self-driving cars, until the industry provides greater transparency and reveals how they are conducting the testing of their cars. Such an action, may hinder short-term deployment and innovation, but could be essential for the long-term deployment and subsequently for the overall safety improvement on public roads.

It may be argued that our concerns and recommendations hardly differ from early HF lessons learned from aviation and other automation domains (e.g., Bainbridge, 1983; Fitts, 1951; Parasuraman, 1987; Wickens et al., 1998). For example, an early report on HF for future air traffic control stated: “men, on the whole, are poor monitors. We suggest that great caution be exercised in assuming that men can successfully monitor complex automatic machines and ‘take over’ if the machine breaks down” (Fitts, 1951, p. 11, see also De Winter and Dodou, 2014), a statement that closely mirrors the interviewees’ statements. Why HF researchers seem to convey the same message for decades is a question that deserves further consideration. Does it mean that HF is making little fundamental progress while technology advances apace, or does it mean that HF scientists have a consistent yet crucial role in warning and advising prior to the introduction of disruptive automation technology?

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Thierry Bellet has 3 master degrees (in Cognitive Psychology, University of Lyon, 1990; in Ergonomics, University of Paris, 1991 and in Artificial Intelligence, Telecom ParisTech, 1993), and received his PhD in Cognitive Ergonomics in 1998 from the University of Paris 5. His research interests mainly embrace cognitive modelling and simulation of the human driver (i.e., COSMODRIVE model) and cognitive engineering for advanced driving aids and vehicle automation. From 1998 to 2008, he collaborated with UC Berkeley (PATH) on the driver modelling issue for Automated Highway. Since 2000, he also participated in 20 National and European research projects dedicated to Situational Awareness modelling, embedded systems for driver monitoring, Human-Machine Cooperation simulation and the Virtual Human Centred Design of Intelligent Co-Piloting systems.

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Klaus Bengler graduated in psychology at the University of Regensburg in 1991 and received his Doctorate in 1994 in cooperation with BMW. After his diploma he was active on topics of software ergonomics and evaluation of human-machine interfaces. He investigated the influence of additional tasks on driving performance in several studies within EMMIS EU project and in contract with BMW. Multifunctional steering wheels, touchscreens, and ACC-functionality are examples of his research topics. In 1997 he joined BMW. From several projects he is experienced with experimental research with different kind of driving simulators, as well as field trials. At BMW he was responsible for the HMI project of the MOTIV programme, a national fellow of the PROMETHEUS program. He was work package leader in an actual EU project Speechdat Car, dealing with voice recognition in vehicles. Within BMW Research and Technology, he was responsible for projects on HMI research. He was active as a sub-project leader for subproject 2 “Evaluation und Methodology” within the EU funded integrated project AIDE. He is active member of ISO TC22 SC13 WG8 „Road vehicles - Ergonomic aspects of transport information and control systems“ and chairman of the German delegation. Since May 2009 he is leader of the Institute of Ergonomics at Technical University Munich which is active in research areas like digital human modelling, human robot cooperation, driver assistance, automated driving and human reliability. Among intensive industrial cooperation the Institute is engaged in the funded Projects DH-Ergo on Digital Human Modeling and ECOMOVE on anticipative driving and H-Mode or D3COS on highly automated and cooperative driving. He is project leader in the German research initiative UR:BAN that investigates the potential of driver assistance and active safety systems in the urban area.

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Appendix

A Human Factors Perspective on Automated Driving - Questionnaire

Instructions

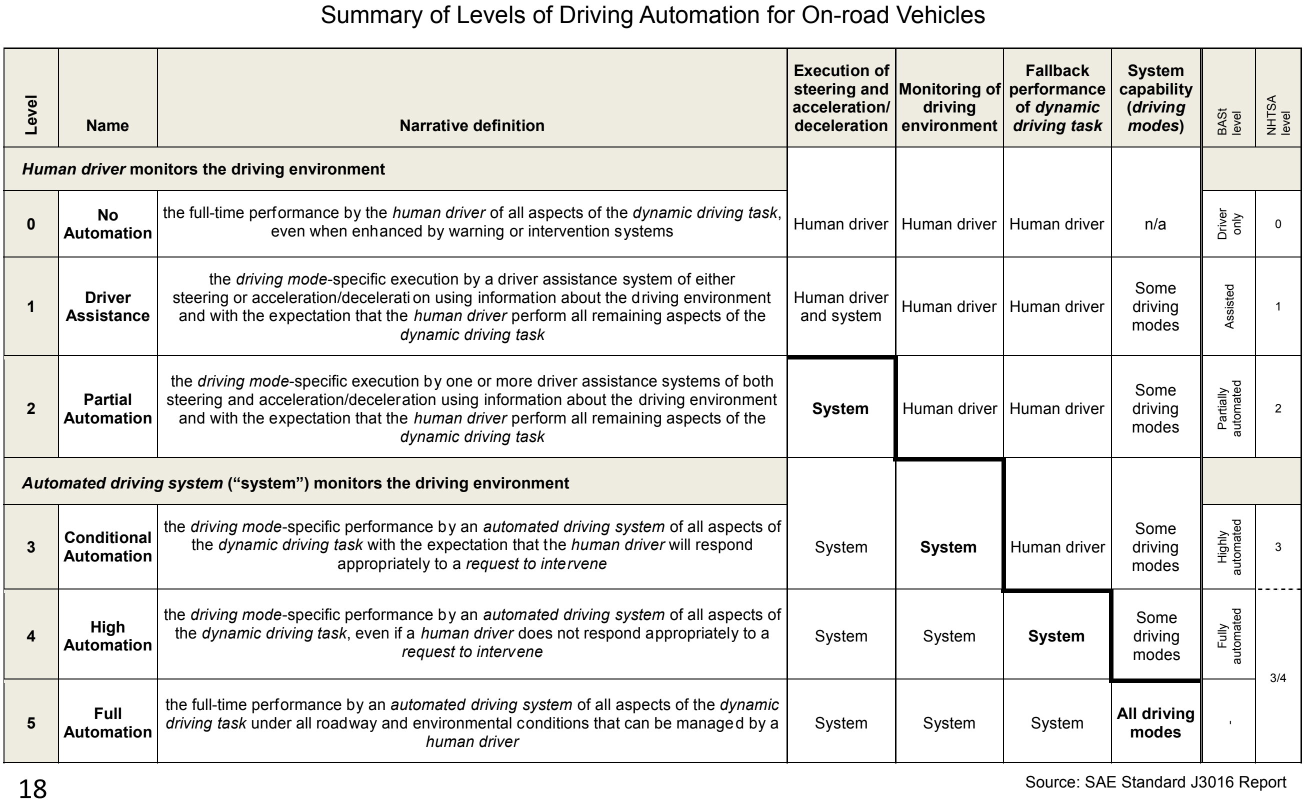
In these interviews we are investigating expert opinions and vision on automated driving focusing on Human Factors challenges.

In the interview we are adopting the SAE levels of automation, as shown in Figure 1.

This interview will discuss strengths, weaknesses, opportunities and threats of automated driving, as well as your vision on the deployment of those vehicles.

Short term period: Up to 2020, Medium term: 2020 to 2030, Long term: Beyond 2030.

Figure 1: Levels of automation as defined by the SAE International



Summary of Levels of Driving Automation for On-road Vehicles

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* (“system”) monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Source: SAE Standard J3016 Report

Questions

The first set of questions relates to SAE levels 3-5 of automation (strengths, weaknesses, threats)

(1) In automated vehicles where drivers are expected to respond appropriately to a request to intervene, what would you consider as the main strengths and weaknesses (threats)?
(2) In automated vehicles where drivers are not expected to respond appropriately to a request to intervene, what would you consider as the main strengths and weaknesses (threats)?
(3) What are your safety expectations of automated driving? How do you vision public acceptance concerning safety expectations of automation - induced accidents?
(4) What are your expectations in law changes regarding automated vehicles? When do you think that such changes will take place?
(5) How much would you expect that an automated vehicle would cost, on top of the price of an average vehicle?
(6) If we assume that all legal issues about automated driving are resolved tomorrow, are we ready to deploy automated vehicles? Which Level?

The second group of questions relates to all levels of automation (vision on automated driving technology)

(1) When are you expecting highly automated driving vehicles to be deployed on public roads?
(2) When are you expecting most of the cars to be driven fully automated on public roads?
(3) In which driving scenario are you expecting the first automated vehicles to be introduced (e.g. highways, parking, maybe asking about passenger cars or trucks)
(4) When are you expecting highly (and fully) automated vehicles to be operating in cities?
(5) How do you vision the role of drivers in the future? Supervisor, driver, passenger?
(6) Do you think that the highly levels of automation are needed? Why not jumping directly to FAD?
(7) What do you think on Google's decision to directly introduce FAD vehicles?
(8) The Vienna Convention on Road Traffic requires that 'every moving vehicle or combination of vehicles shall have a driver' and that 'every driver shall at all times, be able to control his vehicle'. The Convention is currently in the process of being amended to allow a car to drive itself so long as the system can be overridden or switched off by the driver. Do you think that this amendment is sufficient? Do we need the Vienna Convention? Do you think that we could abolish it (after all the US or the UK have never ratified it).
(9) AVs have the potential to reduce crashes and improve roadway efficiency significantly. Yet, AVs will occasionally be crashing and being involved into accidents. Subsequently, a number of ethical dilemmas arise, e.g. what decision a FAD will take when detecting an imminent, unavoidable accident? How should such dilemmas be addressed? For instance, should a HAD or FAD vehicle stop before hitting a cat, even if this could be dangerous for its passengers?

(10) Do you consider the Human Factors research important for the development and deployment of automated driving vehicles? Why do you consider it important? Why don’t you consider it important?

(11) What would you consider the most important Human Factors issues for the different levels of automation? Why?

(12) How could HFs science contribute to overcome the legal barriers towards the deployment of AVs?

(13) Towards the deployment of AVs, which are the most critical challenges, the technological or the HFs? An example?

(14) In automated (non-fully) vehicles should drivers be allowed not to supervise their vehicle for more than a defined period of time? Could you define this period?

(15) How should a driver be informed about a failure in the system of an automated? Should the car directly come to a stop?

(16) Today, simulation studies investigate the behaviour of drivers for the different levels of automation. Do you think that results from those studies replicate the behaviour of drivers on real life traffic conditions? How could we overcome this problem?

(17) How the HFs science should tackle the issues about driver's workload in CAD and HAD modes? How to deal with high-workload to boredom and complacency?

(18) How HFs scientist can define the sufficient time that a driver needs to safely take over control at any situation? Do we need to precisely define this time before deploying AVs on the public roads?

(19) Once fully automated vehicles are introduced would we need HFs scientists any longer? Why? Why not?

(20) In fully automated vehicles would steering wheels be necessary? If yes, how do you vision wheels design, e.g. round or F1 type wheels? Should the wheels be moving or staying still? If not, what could replace the steering wheels?

(21) In highly automated vehicles what kind of secondary tasks could drivers be engaged in? What kind of secondary tasks should not be allowed?

(22) In fully automated vehicles what kind of secondary tasks could drivers be engaged in? What kind of secondary tasks should not be allowed?

(23) While driving in a fully automated vehicle could we be sleeping? Or being drunk? Or should people under 18 or over 90 be allowed to drive them?

(24) Would you send your fully automated vehicle to pick your kid up from school?

(25) Should a fully automated vehicle have any marks to indicate its level of automation?

(26) Do we need complex dashboards in fully automated driving vehicles? Could a "Function" / "Non function" indicator be just sufficient? Any other suggestions?

(27) How would you expect the status quo of the current car ownership to change in the short / medium / long term? Will people continue buying vehicles when fully automated vehicles are deployed or will sharing?

(28) Do you think that people will ever be ready to completely relinquish the “control” over their vehicles to a computer?

(29) What do you think of the current description of automated driving in the media?

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