Safety through automation?

Ensuring that automated and connected driving contribute to a safer transportation system

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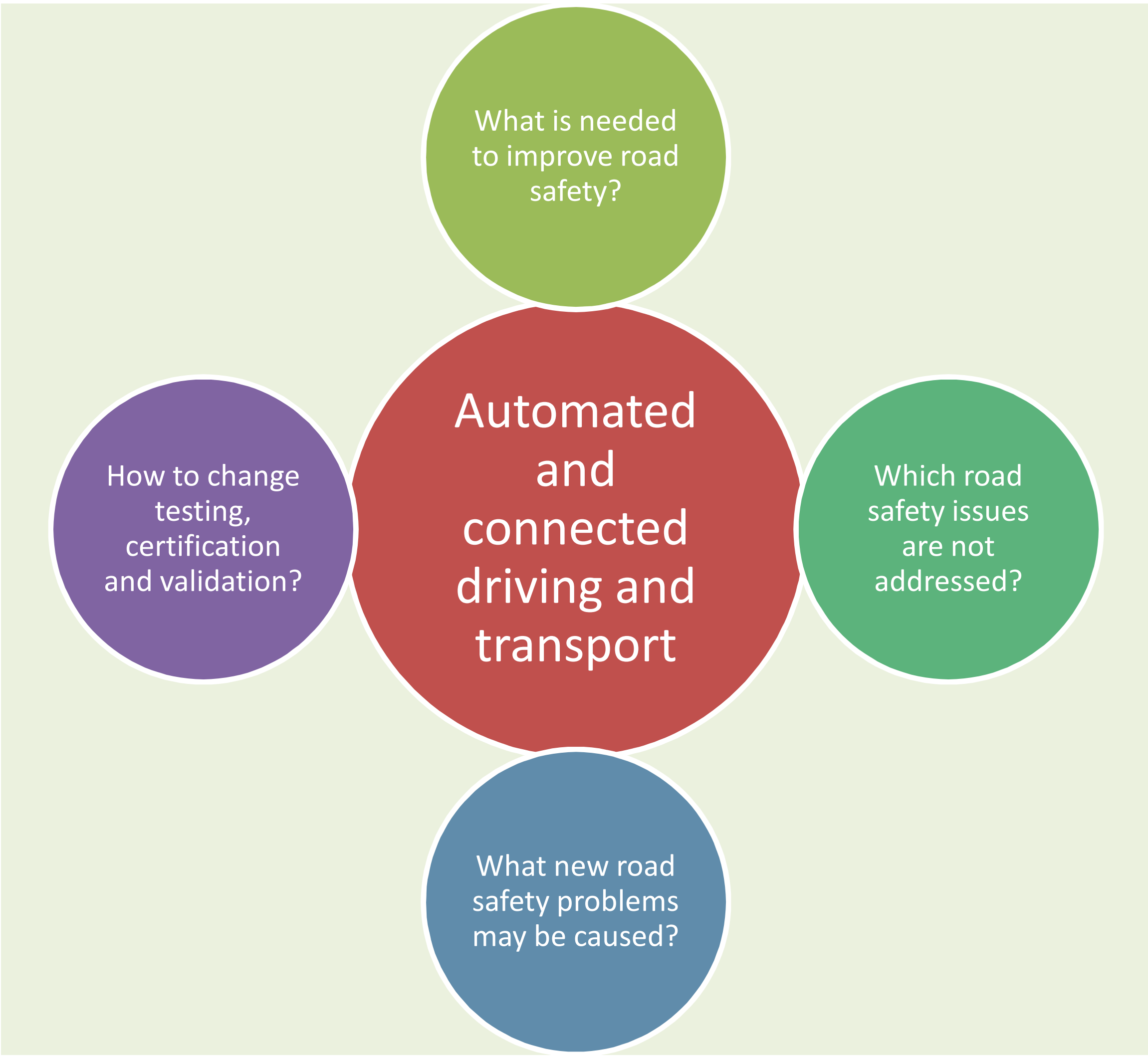
FERSI Position Paper – January 19, 2018



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FERSI Code of principles for "Safety through automation"

1. **Human Factors at the core**
   "Human-Centred Design" shall be put the core of development to prevent new risks of new levels of automation and to render unbiased acceptance by users.

2. **All potential user profiles**
   Drivers of all types, backgrounds and ages should be catered for by systems designed in such a way that all drivers experience automation as safe and comfortable.

3. **Safety in mixed traffic**
   Given the expected increases of traffic situations where users of non-automated as well as of automated vehicles of various levels will share road space, it is necessary to adapt infrastructure, vehicles and driving education, to reduce safety risks caused by mixed traffic.

4. **Safe communication between automated vehicles and providers of services**
   Effective, secured, and error-free communication channels between automated vehicles and providers of services (vehicle manufacturers, mobility services, fleet operators, road administrations, infrastructure operators, etc.) must be established and maintained to ensure safe interaction between all types of road users and the connected road environment.

5. **Safe communication between all road users**
   Safe and secured communication among drivers of partially as well as fully automated vehicles, as well as with other road users – especially vulnerable and unprotected groups – needs to be in place.

6. **Safety and automation benefits for vulnerable road users**
   It must be ensured that vulnerable road users (VRUs) – pedestrians, cyclists, and riders of powered two-wheelers (PTWs) – also benefit from automation and that, where feasible, specific connectivity- or detection-based solutions are developed to increase the safety of these groups.

7. **New training & testing**
   All drivers of automated vehicles are to be well trained, tested, and licensed, in order to cope with driving in modes with different levels of automation, and, when required, be capable of resuming manual control. Automated vehicles should be able to establish whether the driver is fit to drive and to stay in control.

8. **New tests & tools**
   Test procedures and tools (both virtual and physical) are to be set in place that cover the comprehensive set of scenarios needed to evaluate, validate, and certify automated systems – and updates and technical inspections are to be integral part of that process.

9. **Policy mechanisms for incorporating safety considerations**
   Policy mechanisms are to be set in place to ensure that automated and connected driving development takes safety and human factor considerations into account – and brings about substantial safety benefits in a timely manner for all road users.

10. **Impact assessment**
    Evaluation methods and models are to be established to measure the impact of automation – and information from crash investigation as well as data from automated vehicles and their use both in tests and operation, should be made openly available to impartial research for the sake of further improving safety.

N.B. that even if these principles may seem self-evident and straightforward, the underlying questions that need to be solved are complex and hard, and will require considerable effort, and, even so, for many of them there will still not be satisfactory solutions for many years.

The potential of automated and connected driving and intelligent transport systems

Purpose

In its 2014 position paper *Towards safer roads in Europe. Nine key challenges for road safety research for the next decade*, FERSI stated that, despite considerable earlier improvements in road safety across Europe, the number of road fatalities is no longer decreasing to the extent necessary to reach national and European targets. In some countries, the number of seriously injured is even increasing, in particular among vulnerable road users (VRUs) such as pedestrians and cyclists.

Two rapidly developing areas which are likely to have a large impact on European road safety over the coming decades are the fields of automated driving and intelligent transport systems. The recent rate of technological developments in these areas, coupled with the large degree of uncertainty regarding several key aspects of this development and its effects on traffic safety, has therefore motivated FERSI to draft a new position paper, building on previous statements, on the key questions related to traffic safety, automated driving (AD), connectivity and intelligent transport systems (ITS). This position paper has been prepared during the fall of 2017 by a designated Working Group consisting of leading experts from the FERSI member organizations.

The paper first gives a background to the problem and then lists a number of questions which are of primary concern to FERSI, and which have implications for traffic safety.

The paper ends with a summary of our recommendations. For sake of simplicity, and to efficiently convey the position of FERSI on this matter in a condensed format, our main concerns are also summarized in bullet-form in the section *FERSI Code of principles for ”Safety through automation”* at the beginning (page 3) of this document.

Background

Vehicle manufacturers and suppliers – but also other actors from the information technology (IT) industry and fleet operators – are currently racing to introduce and implement advances in AD, connectivity-based solutions and ITS technologies. Industrial actors intend to gain shares of what is expected to become a large and completely transformed transport market dominated by partially or completely automated and connected vehicles, covering the whole range from light ***person*** or ***goods*** transport, via automated ***public transport*** “pods” or buses, to ***heavy goods vehicles.*** In this line of reasoning, AD and ITS are expected to lead to optimization of road use, to improvements in traffic flows, and to reduction of congestion due to shorter inter-vehicular spacing as well as reduced pollution and fuel consumption (Fagnant & Kockelman, 2015; Willemsen, Stuiver, & Hogema, 2015). This should be the result of either centralized transport route optimization, or more de-centralized decision making in distributed platforms. In both scenarios transport planning will operate by mechanisms that better match transport supply and demand, and e.g. by supplying mobility as a service (MaaS) to complement the current public transport offering (first and last miles, transport ser-vices in rural areas).

Some also envision that a transport system with fossil-free, self-driving small “pods” covering **the “first” and “last” mile** – thus complementing other forms of more rapid public transport – will make private cars for commuting far less attractive. On a similar note, in increasingly congested cities, shifting **store deliveries** to automatized night-time operation could potentially solve issues of both congestion and traffic safety during the day.

There has been **remarkable technical progress** over the past few years regarding the sensors and artificial intelligence (AI)-related algorithms required to enable increasing levels of automation, beyond today’s driver support systems. Mixed-traffic medium- or large-scale trials with AD vehicles are being planned or already underway particularly in Europe, Asia, and North America.

In the public debate, it is often claimed that automated driving has the potential to **improve road safety.** This reasoning is partly based on estimates indicating that, presently, human errors cause or contribute to more than 90% of crashes (Singh, 2015; Thorpe, Jochem, & Pomerleau, 1997). Consequently, if the driving task could be shifted to optimal, error-free systems for automated driving, thus removing elements of human error from the operation of vehicles, risks for collisions should be reduced, and, ultimately, eliminated. Perhaps, however, a more realistic view is that we may be replacing at least partially crashes associated with human error by crashes caused by imperfect automated systems in the intermediary stages, when "mixed traffic" likely will prevail.

Another potential contribution to road safety, enabled by large-scale **cloud-connectivity of vehicles**, will be the possibility to instantaneously propagate more precise, detailed individualized and thereby relevant information, which can be used by the driver or the vehicle itself to take actions to improve traffic safety (e.g. by lowering speed, avoiding obstacles or accidents, allowing free passage for emergency vehicles approaching, etc. One example would be providing crowd-sourced and critical incident, hazard, or road condition information to other road users (Eriksson, Lindström, Seward, Seward, & Kircher, 2014) via low-latency ITS solutions (NordicWay consortium, 2017). While the potential for positive traffic safety effects stemming from digitalization and vehicle connectivity could be large, one cannot expect such services to emerge spontaneously, and even if some do (e.g. driven by commercial interests), others which are perhaps more traffic-safety or society-oriented will perhaps not be included. Work with both connectivity-based and infrastructure enablers and these types of services must therefore be actively pursued, while at the same time of course taking all actions necessary to eliminate risks of misuse, fraud, or information/data quality problems.

If combined with fossil-free propulsion technology and the electrification of road infrastructure, it is also envisaged in the public debate that a combined development of shared mobility by virtue of self-driving and connected vehicles is a way of cutting the proverbial Gordian Knot of future mobility solutions in a single blow.

Potential development and unknown factors

There are **large uncertainties** remaining regarding several of the fundamental factors conditional for the development described above. An important factor that needs consideration is *if* and *how* pre-existing vehicles and road infrastructure could (and should) mix and co-exist with ITS solutions and vehicles capable of varying levels of automated driving. Even if technology development is rapid, infrastructure changes and vehicle fleet renewal will still take decades. Therefore, this type of **mixed traffic** will likely dominate over the next several decades. Many questions related to traffic safety need to be addressed in practice during that time, for instance by technology development, by introducing of new types of rules and regulations, and through education. Whilst an immediate uptake, and substantial reduction in accident rates may not be feasible at low adoption rates of automated vehicles, there could still be significant benefits to be reaped from uptake rates as low as 2–5%, as well as from partial automation of particular driving tasks. Some claim that such benefits include improved traffic flow and a reduction in phantom traffic jams (Fountoulakis, Bekiaris-Liberis, Roncoli, Papamichail, & Papageorgiou, 2017; Ioannou, 1998; Roncoli, Papamichail, & Papageorgiou, 2015). Other researchers, however, have shown that in certain scenarios, energy use and greenhouse gas emissions will be nearly doubled with high levels of AD penetration in the vehicle fleet (Wadud, MacKenzie, & Leiby, 2016).

Part of the reason for these apparently contradictory predictions, is that a key determining factor is the extent and individual **willingness of sharing** transport (Pernestål Brenden, Kristoffersson, & Mattsson, 2017). If there is an advantage and a willingness to share transport, automated driving will result in improved traffic efficiency, fewer vehicles and less congestion – sometimes known as *automation heaven*, a scenario in which most people transport becomes "public transport" and where "mobility as a service" prevails and provides optimal use of transport resources. However, if shared mobility does not increase, the technological development may lead to the exact opposite outcome, known as *automation hell*: since vehicles in a future scenario drive themselves, possibly at low running costs due to electrification, this will allow vehicle "occupants" (since they are technically not drivers) to do other tasks while queueing in individual, self-driving cars. Some of these cars could even be completely empty – causing more traffic – with potentially more incidents, accidents and increased congestion.

Yet another fundamental issue to be solved concerns the interaction between automated vehicles on the one side, and **regular vehicles** and **vulnerable road users,** on the other. Fundamental questions are for instance how to indicate to other road users whether a particular vehicle is self-driving or not, or how to communicate to a pedestrian or cyclist that they have indeed been "seen" by the self-driving vehicle.

Other major questions in need of solving are related to physical and digital road infrastructure, road stretch designation, legal and policy regulations, allocation of insurance costs and liability, driving/riding licensing and training as well as traffic safety questions regarding the human interfaces to AD and ITS systems.

And finally, the view that traffic safety could be improved by **removing the human driver from "the loop", is overly simplified.** As pointed out already by Bainbridge (1983), automation of industrial processes may sometimes aggravate rather than reduce problems with the human operator. This is particularly true if you resort to the "standard" approach of leaving the operator with responsibility for abnormal conditions, which is precisely what so-called level 3 systems, according to the SAE scale[1] for AD, attempt to do. Assistance systems at the lower end of the SAE scale (levels 0 – 3) can all be said to require active supervision, since they rely on a human driver remaining ultimately responsible for the driving task at all times, whereas the highest levels (4 – 5) should not require manual intervention, and can be termed ***un-supervised.*** However, due to the way level 5 is specified, it will likely be unattainable in the next decades, and only of theoretical interest, since it requires dealing with *any* situation and environmental condition *manageable* by man[2]. Consequently, the highest level of automation attainable – at least from an immediate and practical standpoint – will be the SAE Level 4. It must also be noted that a rapid transition from Level 2 to Level 4 automation for the entire traffic system is impossible, as state-of-the-art Level 2 vehicles are to date typically limited to motorways or other particular road environments where traffic is less complex. Indeed, a similar approach of successive introduction will likely be necessary for Level 4 systems. Initial systems for level 4 AD are likely to only function in specific environments, for instance, on motorways only, whilst collecting data in areas outside of their operational design domain (ODD) until reliable behaviors can be ensured in an extension of the ODD.

If AD technology was already **perfected,** the potential for vehicles under the truly unsupervised levels of automation, Level 4 with an extensive ODD or full (level 5) automation, would theoretically be significant. The general argument is that, unlike humans, AD systems do not become **tired** or **distracted**, or lose **attention**, nor do they drive under the influence of **alcohol or drugs.** They would be programmed to always keep within **speed limits**, keep a **safe distance** to the vehicle in front and never overtake unless margins are well on the safe side. Sensor placement can provide continuous data flow with 360-degree views, and sensor technology furthermore allows AD systems to use frequency ranges (and combinations thereof), well outside human perceptive abilities, such as RADAR, LIDAR and IR.

In addition, recent advances in contemporary AI algorithms have already led to a situation where detection and control systems are trained on globally acquired visual and other sensory training data which represents **many orders of magnitude more data** than any individual human driver could ever encounter during a lifetime. On-line proliferation of updated decision schemes, based on newly encountered and resolved situations, so-

[1] See https://www.sae.org/news/3544/

[2] This does not mean that every human handles every situation well – only that some humans indeed cope where others fail – nor that the AD system must always cope.

called fleet learning, is another way forward. Advanced algorithms are capable of way shorter reaction times than human drivers and can easily base decisions on multiple data sources (both on-line and historic, as well as correlations). Furthermore, communication and connected ITS systems could enable several road **safety-enhancing** services, such as sharing of road friction or road temperature information, coordinated emergency braking, early and directed warnings for queues, incidents and hazards up ahead which can consequently be avoided (Eriksson, Lindström, Seward, Seward, & Kircher, 2014), etc.

In general, however, the actual performance levels of AD and ITS systems beg further scientific scrutiny, and **research efforts** should be directed towards **ensuring the levels of safety** of automated systems, as they develop in terms of their ODD. One proposed method is to specify minimum performance levels in selected scenarios. This is by no means easy: to improve on human drivers, an AD system must typically have a fatal crash rate better than one fatality in billions of kilometers, making testing and verification of performance a difficult or even impossible task (Kaira & Paddock, 2016). This may indeed become a bottle-neck for the development of AD, since we currently lack the methods to specify and assess safety levels of AD systems. Until such methods, for instance based on formal mathematical proofs (Shalev-Shwartz, Shammah, & Shashua, 2017), are developed, we are unlikely to see the improvements expected by society. Another specific aspect related to the data-driven schemes currently dominating the algorithmic side of AD systems is that of bias in the data, and the risk that excessive amounts of training data on one type of road or situation, will still not be helpful or carry over to other road types (or other situations).

What is stated above and elsewhere in this document may seem to stand in contrast to more technology-positive messages in the media from large actors who claim they will have completely automated vehicles in regular operation on a large scale in major cities of the world shortly. Our fear is that this view is tainted by the **economic driving forces** of these actors and that several of the **concerns** in this paper are too **easily overlooked** by those actors as well as others who share and propagate similar views.

Main concerns from the point of view of FERSI

This FERSI position paper focuses on four key questions:

I. How can automated and connected driving and ITS improve road safety? What conditions should be met, and which actions taken?

II. Which road safety issues will likely not be solved by AD, connectivity and ITS? In particular, are there groups of road users which could benefit from AD and ITS, but are unlikely to do so unless special action is taken?

III. What road safety issues may be caused by AD, connectivity and ITS? What actions can be taken to avoid this?

IV. How should testing, certification and validation methods be adapted and how should "best performing" AD/connected systems and ITS best practices be identified?

Each question is briefly discussed and then followed by a proposal for research topics that need to be addressed over the coming years. **For FERSI it is crucial that these questions are tackled for AD, connectivity and ITS to successfully contribute to a smart, green, and integrated transport system which is also *safe.***

How can AD and ITS improve road safety?

Considerable safety gains can already be achieved with contemporary technologies and systems at the lower end of the SAEJ3016 scale[1]. This scale is used to define the level of automation of vehicles. It ranges from 0 ("no automation") through 5 ("full automation"). For instance, systems for Automated Emergency Braking (AEB, a **Level 1** "driver assistance" system), could save lives and have been shown to reduce injuries, by intervening and reducing the speed of or even stopping a vehicle completely when collision with a solid object is imminent and/or unavoidable. For instance, at speeds below 50 km/h, AEB was shown to halve the risk of being the striking party in injury-inflicting rear-end crashes (Rizzi, Kullgren, & Tingvall, 2014).

Level 2 "partial automation" systems, for example adaptive cruise control (ACC), when used in combination with lane keeping assistance (LKA) and optionally with lane departure alert (LDA) are already in operation in many vehicles. They are expected to help avoiding rear-end collisions and lane-change crashes caused by human inattention and/or human inability to visually observe and constantly monitor vehicle surroundings. However, no clear such effect has been observed in the Field Operative Trials (FOTs) carried out so far, sofurther studies are needed to verify that this is indeed the case. Another level 2 technology which is more promising is Intelligent Speed Adaptation (ISA), which is known to reduce accidents and their effects, also on VRUs (Carsten & Tate, 2005).

Level 3 is a rather special case in the "supervised" category, called conditional automation, where the vehicle operates autonomously under many conditions, but where control could be returned to a human driver within a moment's notice, e.g. when automation fails. Level 3 automation vehicles are highly automated and drive themselves under specific, but not all, conditions. They allow the driver to take both feet, hands, and eyes off the driving task, but may still require manual intervention, at short notice, in situations which the vehicle cannot handle. Traffic safety researchers have shown that the faith put on human capabilities, specifically on attention and readiness are overestimated, thus introducing novel and unacceptable accident risks in traffic. Prior knowledge regarding human behavior, and in particular the human inability to stay alert and respond adequately at short notice (as would be the case) has given rise to several recent studies on simulated, as well as on-road, interaction with AD systems, showing that **reaction times** are comparatively long, typically in the order of 4-6 seconds (Eriksson & Stanton, 2017), and the ability of drivers to react appropriately in the driving situation is severely diminished during long stretches of time, and increase even further when the driver is engaged in a secondary task. FERSI has therefore concluded, as have several major car manufacturers (Level Three Automation Could Be Skipped, 2017; Davies, 2015; Why Every Car Maker Should Skip Level 3, 2017; Volvo to skip Level 3 autonomous mode, 2017), that *level 3 automation is unrealistic,* and should for the practical and traffic safety purposes in this position paper be disregarded.

Indeed, Level 2 systems are already presenting problems, since **drivers overestimate** function, range and reliability. Some research indicates that most drivers do not really understand how systems work and whether they are engaged or not (Banks, Eriksson, O'Donoghue, & Stanton, 2018).

Another *potential* benefit of AD and ITS is that these technologies may provide safe driving solutions to groups which are either unauthorized (due to lack of a driver's license), unable (e.g. due to physical inability, old age or other types of impairment) or unfit to drive (e.g. due to alcohol consumption, sleep deprivation, or under the influence of prescription drugs). Higher levels of AD could potentially (albeit perhaps only theoretically) provide **mobility solutions** for some (or all) of these groups.

However, the above reasoning effectively compares the *present* safety performance of humans who are driving in an imperfect state against the *possible* safety level of a *perfect* Level 4 system. Unfortunately, one can safely assume that – at least for decades to come – Level 4 systems will likely be restricted to very **specific ODD's** where complexity is low and there is a negligible risk of failures, whilst potentially continuing to operate at a Level 3 stage, which is neither perfect, nor capable of ideally operating in all scenarios.

Consequentially, it is far from obvious that the promising AD-related safety prospects will ever fully materialize, especially since comfort and mobility improvements seem to be the main driver for the AD and ITS developments, along with the expected associated sheer economic gains. The current version of the ERTRAC automation road map (ERTRAC Working Group "Connectivity and Automated Driving", 2017) predicts imminent development in parking and highway technologies, whereas road safety priorities across Europe rather target VRUs in urban areas, and people in vehicles and on powered two-wheelers (PTWs) in rural regions. It is therefore recommended for **policy makers** and other stakeholders in road safety to specifically **identify and promote** certain areas in need of development. Otherwise we run the risk of these areas gaining insufficient attention, and of the resulting development affecting traffic safety adversely.

Questions to be solved for positive traffic safety effects to occur include the following:

1. How to ensure that AD and ITS development incorporates relevant and appropriate safety and human factor considerations? It is necessary that **societal actors, legislators, and traffic authorities** have a proper understanding and decision-making power to steer the development of AD and ITS into the desired direction. In scenarios where commercial forces in the vehicle and IT industry assume control over the development of AD, ITS and mobility services, some of the benefits for society, e.g. improved safety for other road users, risks not being addressed adequately. We therefore need a mechanism for policy-makers to direct advanced driver assistance systems (ADAS) and AD system development so that they bring substantial safety benefits in a timely manner. Operational definitions will need to be defined with regards to safety levels – should it be as safe as the average driver, as the top 10th percentile of drivers or defined according to the ALARA (as low as reasonably achievable) principle?
2. How to adapt and develop in-vehicle technology as well as urban and non-urban infrastructure, so that AD and ITS enhancements lead to substantially increased safety levels? There is no point in promoting AD for the happy, select few, limited to a number of stretches such as straight motorways, where road safety is already high and not much is to be gained in this respect. There is need for more research into the necessary adaptations of the **road infrastructure** for optimal use of AD and ITS, e.g. by connected traffic lights, proliferation of warnings, coordinated emergency braking and many other enhancements made possible by recent technology developments.
3. How can information from other services be integrated and harmonized with AD functions? What requirements should be put on data and **information sharing** between operators of mobility services, between vehicle manufacturers, fleet owners and operators, owners of digital and physical infrastructure? What could be the role of IoT (Internet of Things)? Research is needed on how to combine AD functions with the booming area of IoT, towards enhancing the level of automation and facilitating the interaction with road users and the road environment, always in the benefit of road safety.

Which road safety issues will likely *not* be solved by AD and ITS?

Most AD and ITS development focuses on car and truck drivers and passengers. Quite some effort is also put on automation of relatively slow-moving public transport “pods”. Several **groups of road users** will likely **not benefit** at all, or only in a limited way, from the introduction of such vehicle automation and connectivity-based “intelligent” solutions in the transport system. These include large groups at risk among vulnerable road users, which constitute the bulk of the remaining challenge to reach the European road safety goals. Already today, VRUs are more numerous than car passengers amongst the traffic victims that are hospitalized. Unless specific focus is given, cyclists, pedestrians, motorcycle, and moped riders (i.e. VRUs) are not likely to gain immediate benefits from AD and ITS technology, or at least not to the same extent as car and truck occupants. The same holds, for instance, for people driving on rural roads – where it might be too expensive to adapt the road infrastructure, for elderly – who can no longer adapt to new “driving modes”, and for young people – who will have to learn to drive in different modes (which might be more challenging than is currently the case). Due to the larger cost of AD vehicles (and vehicles equipped with advanced ADAS systems), they will initially be bought by older rather than younger people, resulting in an age bias in the user base for quite some time before these vehicles eventually become common on the second-hand market.

A conservative estimate of the share of accidents which cannot be avoided by virtue of AD, ITS or similar technology can be made based on in-depth research and crash statistics. Based on such data (ACEM, 2009; ERSO, 2008; Schepers, Stipdonk, Methorst, & Olivier, 2017) we estimate that in 10% of road fatalities in Europe no motor vehicles that can be automated are involved as victim or crash opponent. Of these, around 4% are cyclists and 6% PTWs. For severe injuries this share is hard to quantify but is likely substantially higher.

Also, looking to traffic situations, there are many conditions and types of events that might not be addressed by the industrial vehicle automation actors, at least not initially, since they are costly and difficult to solve. Among these are several dangerous traffic situations such as snow, heavy rain, roads with poor-quality or no road markings, difficult intersections and crossings, narrow and curved roads etc.

Questions to be solved therefore include

4. How to make sure that different types of VRUs will also reap the benefits of AD and ITS developments geared towards cars and trucks? There is a strong need to intensify **traffic safety research regarding VRUs,** both in general but also specifically related to the interaction between representatives from these groups with vehicles featuring differing levels of AD.
5. What specific AD and ITS developments are needed for cyclists, moped drivers, motorcyclists, and pedestrians? How can VRUs benefit from **ITS or connected vehicle solutions**, or how could the latter be enhanced or modified to yield customer utility also for specific VRUs?
6. How to ensure that both **older and younger** drivers will fully benefit from connected and automated driving and ITS, and not experience it as an obstacle for safe and comfortable driving?

What road safety issues may be caused by AD and ITS?

Under the supervised levels (up to SAE level 3) of AD, there are many issues related to the interface (human-machine interface or HMI) between the human rider/driver and the vehicle.

These systems are intended to aid the driver and ease the process of safely driving his or her vehicle, but could at the same time place **additional demand** on human performance, specifically on **attention and readiness,** and may therefore introduce new risks in traffic (Banks, Eriksson, O'Donoghue, & Stanton, 2018). These need to be further studied, and it may well be the case that specific and additional driver training is needed for supervised levels (0 – 3) of automation to be acceptable. Even for level 4 systems, if there are limitations in operation defined by restrictions in the vehicle’s ODD, users need to be aware of these and understand their consequences.

An AD vehicle will also need to **interface with other (physical) road users,** both other vehicles and vulnerable road users such as pedestrians and cyclists. Both users of AD vehicles and other road users may need to acquire a deeper comprehension of how different levels of automation work and behave, in order to understand the automation features of the vehicles they encounter and to properly interact with such vehicles. Indeed, even discerning between AD and regular vehicles may be difficult enough. There is a definite need to investigate the advantages (and disadvantages) of differentiation between different types of vehicles, either by clear visual features (adapted for human perception) and/or electronically (for AD vehicles, and the connected road infrastructure). It is obvious that this will be a complex and long process that will not follow smoothly and hence will lead to dangerous situations that may, in turn, lead to crashes.

In addition, any AD vehicle is likely to interact not only with a single connected service, but with several which may reside in **different vehicle "clouds"** related to the specific vehicle, brand, or fleet, or to independent information suppliers. From all these sources, information needs to be extracted and possibly harmonized or at least allowed to co-exist with information from other channels. While this is a prerequisite for developing efficient mobility solutions, it adds a yet unseen level of complexity to the transport system which may of course cause conflict and possibly errors. Such harmonization, quality assurance and standardization of information flows may be essential to achieve many of the advantages of automated and connected vehicles and ITS.

Drivers must also be **aware of the limits** of the ADAS and/or automated features of their cars such that they do not rely too much on these features – and hence risk to lose control. A concrete example is that current Lane Keeping Assist (LKA) systems will not work properly when there are no lane markings; when the speed of the vehicle is too low; when the curve is too narrow; when something is blocking the camera that detects the lane markings; when snow or leaves cover the lane markings; when there is too much rain, or fog, etc. for the camera-based computer vision system to detect the markings. More specifically, drivers must know that systems have both technical limitations limited range or domain of competence (ODD), which may result in sudden loss of AD capability.

As mentioned previously, human limits in staying alert and acting as fallback when system automation fails may in fact preclude the introduction level 3 AD systems completely, which would coincide with FERSI's general view. While several of the traditional vehicle manufacturers advocate skipping level 3 altogether (Davies, 2015; Level Three Automation Could Be Skipped, 2017; Volvo to skip Level 3 autonomous mode, 2017; Why Every Car Maker Should Skip Level 3, 2017), other actors promote level 3 strongly, and make claims regarding their almost imminent introduction. This could lead to public and/or political **demands requiring drivers to practice "handover skills",** although these skills are likely not possible to train. Instead the systems need to adapt to human thresholds for resumption of control, (Eriksson & Stanton, 2017). All this could make **driver training more complicated and expensive.** For established and particularly older drivers, this can be quite some challenge since they have become accustomed to a certain type of driving, using human-vehicle interfaces predominantly designed for direct and immediate manipulation in traditional manual driving. Even if contemporary user interface design in AD vehicles should be self-explaining and intuitive to use, chances are that the mode of operation is still qualitatively simply too different for large groups.

As previously mentioned, there will be a **lengthy transition phase** while the number of automated systems on the road is increasing and at the same time the capabilities of those systems will be rapidly expanding. Separation of AD vehicles from non-AD vehicles by use of designated road networks (or separation in time) is a luxury few regions in the world can afford, so during a foreseeable time, we will have a **mixed fleet.**

While there has been some simulation work to examine the network level impacts of a mixed fleet, the capabilities of existing microsimulation models to accurately represent both the functionality of automation systems and the detailed kinematics of road user manoeuvres are very limited. This is an area needing further attention.

The extensive transition phase will provide opportunities to improve safety but there will also be new risks introduced. As yet, we have little idea about how we should manage the process to get the **greatest road safety gains as quickly as possible.** There is an urgent need to start developing suitable strategies for that, rather than allowing development to be driven solely by other forces in operation today. The latter obviously include technological advances, but also consumer demand, e.g. for the comfort of being chauffeured. On the business side the vehicle industry has a strong urge to increase sales by introducing new models with new features, while actors originating in the IT and communication technology sphere aim at developing new business by providing new types of mobility services which are profitable, perhaps taking market shares from the traditional vehicle industry.

It should also be added that **alcohol and drugs consumption** may increase if (and when) unsupervised levels of AD are introduced, if intoxication under automated transport is not regulated. Aside from obvious negative health effects of such a (tentative) consumption increase, there are also general road safety risks with an increased share of individuals under influence of alcohol or drugs in the transport system. In addition to this, there are also specific risks that a "driver" or passenger under impairment can misuse AD and ITS systems, or, for example resume vehicle control when intoxicated (even if it may be unlawful). In critical situations where for instance an automated vehicle ends up outside its ODD, an intoxicated person will be even **slower to react,** or even fail to do so, and is of course more prone to respond inappropriately or perform erroneous and dangerous or even fatal actions.

For the above reasons, a set of questions which would need special attention are:

7. How to manage the **transition to automated driving** while guaranteeing **road safety,** and ensuring that **mixed traffic conditions** do not lead to increased safety risks? One radical, but likely expensive, measure would be to separate automated vehicles from other road users - either permanently by designated and barred-off lanes, blocks or regions - or temporally, by only allowing their use on designated road stretches during specific times of the day. At the other extreme, where completely mixed traffic would be allowed, research must instead focus on somehow verifying the road safety aspects of interaction between AD vehicles and all other types of road users in a multitude of locations, situations, road, light and weather conditions.[3]
8. How to support the driver's **automation mode awareness** in view of decreasing accident risks? Research is needed regarding how difficulties in understanding the level or state of automation (both for drivers and other road users) relates to accident risks, and what remedies are at hand, e.g. by virtue of HMI solutions or training.
9. What changes are needed for **driver training,** both initial driving training courses and upgrade courses later in life? Drivers of vehicles featuring supervised AD will need to learn to drive in "non-automated mode", and in different "assisted modes". What is the role and responsibility of **car dealerships** in this respect?
10. How to ensure that the **resumption of control** by drivers of supervised AD vehicles happens smoothly and does not create additional risks? Research is needed on how to support resumption of control, in critical situations as well as under more normal conditions (Eriksson & Stanton, 2017; Eriksson & Stanton, 2017). A specific issue lies in how the system should establish that the driver is actually in a state where he or she is fit to drive (and not, for instance, drowsy, sleepy, fatigued, agitated, distracted or even intoxicated).
11. How to adapt the **driver licensing** system and driver license categories to take into account the variety of situations (with consequences for liability) resulting from development in ITS, automated and connected driving? More research is needed in this area and policy-makers need to discuss this at European or prefer-

[3] This is indeed a challenging task, since recent estimates state that automated vehicles need to be driven between 1.6 million and 11 billion miles (depending on the safety thresholds), taking up to 500 years for a fleet of 100 vehicles, to statistically assess the safety of automated driving technology (Kaira & Paddock, 2016)

ably even at global level. How will AD affect **professional drivers,** and the legislation and other regulations regarding **driving and resting times?** What new types of **professional driving license categories** may be needed? What will be the license and training requirements on the driver of a **rented car or a car-pool vehicle?**

12. How to ensure that drivers will still be able to handle extremely critical or unforeseen situations while driving under supervised conditions? How to avoid that extensive support systems and partial automation use will lead to less concern for accidents? Automation-induced **inattention, unawareness, or unfitness** to act are areas in need of investigation. So-called **selective de-skilling** may also be a potential hazard: relying heavily on ADAS or AD functionality may over time encourage drivers to forget key skills, especially in critical or stressful situations, when they may lose situational awareness or vehicle control.
13. How to make sure that road users with different levels of automation communicate appropriately with each other in view of avoiding traffic conflicts? Research is needed regarding how to prevent accidents due to inappropriate actions by others (particularly vulnerable road users) and, in particular, how to handle their **communication and interaction with AD vehicles.**
14. How to ensure that unmanned vehicles can **communicate appropriately with vulnerable road users**? Which specific requirements (in terms of speed, road paths, safe stopping distances, communication/alert systems) are to be defined to make sure that they do not endanger the safety of road users? Research is needed on such requirements and also on how these could (and should) be enforced.

How should testing, certification and validation methods be adapted, best-performing AD systems and ITS best practices be established?

AD and ITS systems will form an integral part of the traffic system in the future and several such systems (both old and more recent) are already in fact doing that, e.g. satellite navigation systems and radio data system (RDS) traffic announcements, with the important distinction that the latter are channeled through a physical person driving.

AD systems will consist of a physical vehicle, its sensors, the connected information sources, and the algorithms designed to detect, understand, and drive in relation to all the information at hand. Therefore, several **issues regarding testing, certification and validation** become considerably more complicated and need to be examined anew.

In addition, technical validation and system certification is only one side of the coin. The other concerns human users of AD systems (Kyriakidis, o.a., 2017). As mentioned earlier, with different levels of automation, the **role of the human** in the frame of AD vehicles changes from "a driver driving", a person in charge of "driver monitoring", to ultimately being only one of the "passengers/driver not driving" in a vehicle of tomorrow (Banks & Stanton, In press). As has been discussed above, specific (and differing) risks are related to these three different options, and research is required regarding how humans will take on, potentially accept, and perform their tasks and liabilities in these different roles.

Since the highest levels of AD do not really exist on the road today, one way to anticipate their future use by humans is by performing **virtual simulation** based on human models, as well as **driving simulations** with the "human-in-the-loop". Indeed, even if an AD system is technically validated, a remaining challenge is to understand how this system will be used (or misused) by human beings, and what types of interaction will take place with other vehicles as well as with humans inside or outside the vehicle in question. Consequently, virtual testing methods and/or new types of integrative simulation tools – including both the simulated AD systems and human model(s) of the future users – need to be developed and used before introducing real AD systems on the public road. They are essential in predicting potential difficulties or risks for end users, and to prevent new types of accident likely to occur, much as was the case when automated systems were introduced in aviation. One additional application of such simulation tools is to help increase future acceptability of AD at the individual and societal levels. Virtual testing should be understood in a wide meaning, incorporating vehicles, systems, humans, physical as well as digital infrastructure etc. During a forseeable future (until virtual testing and purely mathematical proofing takes over), it must also be accompanied by field testing and longish periods of naturalistic driving.

The above also means that **driving licenses** may take on a new meaning, with new levels or pre-conditions attached to different types of licenses.

Furthermore, from a transport system point of view, the boundaries between AD testing and traffic safety development are by no means closed, but in fact interdependent. When running, AD systems and connected vehicles generate huge amounts of data on traffic situations, interactions, and incidents, both within and beyond the ODD which the systems are designed to cope with. **Machine learning tools** may be used to improve existing algorithms and the performance of "virtual drivers" in preventing and coping with serious incidents. The same tools also provide the obvious way of successively extending the operating domains of AD systems. Therefore, the potential is high to make **large traffic safety improvements** at early stages of the learning curve, if the proper requirements for **data gathering and sharing** between different stakeholders is accomplished.

However, this also raises issues related to the timely **validation and certification** of these improvements (into new vehicles) as well as the methods to their integration in existing vehicles – in order to limit vehicle diversity that may be detrimental to traffic safety.

Such development also has strong implications for related questions regarding safety and security, cf. questions i-iv on page 15.

Primary questions in need of investigation are the following:

15. What are the **new testing methods** and/or tools to be specifically designed, developed and used to support vehicle automation systems evaluation, validation and certification? How can the wide set of scenarios experienced in normal driving (the high frequency events) be represented? How can the scenarios that result in crashes with human drivers (the high-risk scenarios) be represented? How can the scenarios which become more challenging for an automated system be represented?
16. What **human user models** are required in order to evaluate future use (or misuse) of AD systems?
17. How can a **"Human-Centered Design"** of vehicle automation be used to prevent new risks when introducing AD? How can the same type of approach be used to increase acceptance and facilitate deployment?
18. What will be the role of **virtual testing** and what will be the role of physical testing? What are the consequences if, as predicted, the former will become more prevalent than the latter?
19. Once a vehicle is validated, how will **vehicle updates**, especially of software, be handled in terms of **validation and certification**?
20. What will be the role of the periodical **technical inspection**, and who will assume responsibility in an increasingly shared mobility eco-system? If vehicle fleets are mostly leased to operators or individuals, this question may potentially be handled among the market actors themselves, as is already the case in other fields of product safety.

21. Should the **driving license** be linked to the level of automation, and if so – in what way? (This is paralleled today by licenses being conditioned in certain member states e.g. on using an automatic rather than stick-shift gear-box, or requiring the driver to wear corrective glasses or contact lenses to compensate for poor eye-sight.

22. How can we measure the **real-world impact** of connected and automated vehicles (CAVs)? Current accident investigation structures tell us very little about the effectiveness of crash avoidance technologies since a good system will avoid crashes. Currently vehicles with state of the art ADAS are relatively rare in the vehicle fleet and even when they do crash they are not likely to fall into representative accident sampling schemes. This means that the need for the analysis of stored data describing the operation of the system is even more essential, but such data is likely to be encrypted and proprietary, making investigation and evidence-based system improvement virtually impossible. Both direct and indirect impact needs to be considered (Milakis, Van Arem, & Van Wee, 2017). One solution would be to fund **independent evaluation by the research community** of industry's innovations, starting immediately as they reach the market. Such an evaluation program should have the purpose of classifying which AD, ADAS and ITS solutions yield the best effects, and which AD, ADAS and ITS practices should be promoted.

23. How can we ensure that AD testing and validation data as well as the huge amounts of streamed live **data** from AD and connected vehicles come to **optimal use**, from a traffic safety perspective? Large volumes of AD sensor data from different traffic situations, interactions and incidents are continuously generated, and machine learning tools may profit on these to improve existing AD algorithms to prevent and cope with serious incidents. What are the proper requirements for data gathering and sharing between different stakeholders to ensure the maximum traffic safety benefits?

Related and important questions

The 23 questions brought up above are those which are of primary concern to FERSI, given our organizations focus on traffic safety. It should however also be mentioned that several other necessary questions need to be answered and prerequisites met for public AD and ITS acceptance to reach sufficient levels, and for public safety an integrity to be guaranteed ***Among these auxiliary but important questions FERSI finds the following of special interest:***

i. How to address the **privacy issues** caused by data sharing and proliferation, both for recorded and real-time data-streams? What requirements can and should European and national traffic administrations put on vehicle manufacturers, fleet operators and individual vehicle owners? Obtaining higher safety levels may come at the expense of privacy. However, perceived problems with privacy may reduce public trust in AD vehicles to the point where users refrain from adopting automation altogether. This in turn would mean missing out on the traffic safety benefits AD promises to bring. Such data may typically also be (mis-)used for marketing purposes, leading to further distraction and negative effects on traffic safety. It is necessary to find a new equilibrium regarding availability and access of data regarding individual movement and behaviour on the road.

ii. How to protect road users from **fraud and hacker attacks**? Of primary concern is that connected vehicle systems are not compromised, and vehicle and traffic safety can be guaranteed. In addition, users must have confidence in automated safety systems, otherwise these will not be adopted. Further investigation and consequence analysis is needed to ensure effective positive benefits on traffic safety.

iii. How can society protect its citizens from AD and ITS being used as tools for acts of **terrorism**? In recent years, terrorists have resorted to using vehicles in several attacks across the world, and un-manned vehicles would make for ideal weapons. Similarly, the more centralized traffic control becomes (which may be necessary for efficient and effective traffic control and steering), the more vulnerable it becomes to any form of hostile attack, e.g. with the purpose of causing crashes or blocking traffic.

iv. What is the **cost-efficiency** of automated driving systems? Is there a point of increasing automation where the marginal costs of further improvements exceed the benefits of improved casualty reduction, reduction of congestion, increased mobility or reduced environmental impact? How does **user acceptance** influence take-up of AD systems and affect cost-efficiency?

FERSI assumes that questions i-iv will primarily be driven by other organisations, but since these questions border on traffic safety, their solution will likely also need involvement from FERSIs member organizations.

Summary of recommendations

Automated Driving (AD), along with connected driving and Intelligent Transport Systems (ITS) are likely to transform the European scene as regards transportation of both people and goods. Many strong industrial and political driving forces exist, but improving road safety gets insufficient priority in relation to current development.

In this paper, FERSI points out 23 separate questions, for convenience grouped into four areas (I – IV as described on page 7), towards which pre-normative research and policy actions should be directed already now, given the rapid rate of technical development in the area. FERSI concludes that for each of these questions, more research (and possibly subsequent regulation) is needed for AD and ITS to lead to significant steps forward in road safety on our European roads. If left unattended, development with regard to these questions may in fact lead to set-backs in road safety. FERSI therefore recommends that, at the European level, action is taken to ensure

- the prioritization of research funding addressing the 23 questions listed here,
- the development of policies that take research findings into account,
- the establishment of a scheme for evaluating industry's innovations by the research community to establish and proliferate best practices/best system knowledge among member states, and
- the promotion of involvement of other stakeholders, e.g. insurance companies, road administrations/owners, municipalities/cities, representatives for law enforcement, the research community as well as organisations representing different groups of (for instance) vulnerable road users. This is a much-needed complement in addition to the vehicle and supplier industries which are currently the main actors, pushing development and policy making.

It is the firm belief of FERSI that this is necessary for AD, connectivity and ITS to successfully contribute to a smart, green, and integrated transport system which is also *safe.*

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About FERSI

FERSI, the Forum of European Road Safety Research Institutes (FERSI) is a not-for-profit association in the area of road safety research.

The Association acts as a flexible network of European road safety research institutions. It unites partners from 21 European countries who have a mandate of their governments to implement a pre-normative road safety research. That means that FERSI participants develop road safety solutions to be translated in legislation and norms, offer consulting to national and European road safety authorities while implementing these solutions and evaluate effects of implementation.

FERSI is open for cooperation with any road safety research institute or organisation, both in exchanging research knowledge and in seeking opportunities for collaborative research. Road safety research entities form outside Europe could join FERSI as associated partners.

FERSI acts on behalf of its partners as their representative vis-à-vis the European Commission, European Parliament, European Council while promoting road safety research agenda and research results and acquiring funding for research projects.

FERSI represents its partners and their reconciled opinion in the dialogue with other international organizations contributing to the road safety improvement, e.g. OECD, UN, professional unions and branch associations.

The association supports its partners in disseminating the knowledge generated by them and is actively involved in knowledge and information exchange.

FERSI mission and objectives

The primary *mission* of the Association is to promote or coordinate high quality research on road safety issues, consult on implementation of research results and scientifically evaluate implementation outcomes.

The *objective* of the Association is to contribute to road safety research and enhance the road safety by ensuring that the relevant problems are addressed by best available experts and that solutions recommended by researchers are implemented in the most effective way.

In particular, FERSI may engage in the following (not exclusively) activities:

- enhancing the scientific quality of road safety research;
- proposing road safety topics for EU and national Research Agendas;
- developing road safety research recommendations and proposing them to competent national and European authorities;
- organizing seminars and meetings on road safety issues;
- participating in road safety research work conducted by EU or other international organizations;
- encouraging the international exchange of researchers;
- awarding prizes or scholarships financed by its resources to road safety researchers.

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