ENVIROMENTAL, SAFETY, LEGAL AND SOCIETAL IMPLICATIONS OF AUTONOMOUS DRIVING SYSTEMS

Anders Eugensson
Mattias Brännström
Doug Frasher
Marcus Rothoff
Stefan Solyom
Volvo Car Corporation, Sweden
Alexander Robertsson
Chalmers University of Technology, Sweden
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ABSTRACT

The concept of autonomous driving opens up for many opportunities but, at the same time, raises concerns and issues for discussion that need to be analyzed and penetrated before a more broad roll-out of autonomously driven vehicles on public roads can be attempted.

Among the obvious potential benefits for the society is improved fuel economy, enhanced safety and reduced congestion. There are, however, also potential benefits in offering mobility to the physically challenged, reduced need for infrastructure investments, more efficient use of the urban landscape and individual benefits with more efficient use of the time spent in the car. Driving in autonomous mode opens up for using the time for other useful occupations, e.g. working, relaxing, eating, etc.

Many obstacles remain before autonomous driving can be a part of transportation on public roads. In Europe an intense debate is discussing the implications of the Vienna Convention, which governs the framework for the requirements on the driver, and the legality of not having the driver in control of the vehicle. In the US, activities within the states are opening up for autonomous driving testing on public roads under certain provisions, but there is an obvious risk of causing fragmentation by creating deviating requirements.

Sorting out the liability issues will be one of the major challenges before autonomous driving on public roads can be a reality. Present national laws in some countries do require a person in form of the driver to be liable in the case of an incident or a crash. For higher levels of autonomous driving, liability needs to rest with the manufacturers or another entity not in the form of a person and should be reflected in national liability legislations.

INTRODUCTION

During the last decades, driving a car in a modern urban area has, globally, turned into following a slow moving traffic for a considerable amount of time without neither the pleasures of maneuvering an advanced modern vehicle nor being able to use the time for a more useful activity. The concept of autonomously or semi-autonomously driven vehicles would potentially open up for a number of possibilities attractive to the future car buying customers and occupants. Being able to use the time in the car for other things than monitoring traffic and driving and instead being able to find the ride relaxing and efficient could potentially improve the work-life-balance for many people in densely populated areas. There is, however, a deep-rooted and, for many reasons, well justified concern among both governments, manufacturers and the public that there will be huge obstacles in the path of the technological development and in relation to the perception and behavior of humans that will efficiently prevent fully autonomous vehicles.

The development of various levels of driver assistance systems has been very rapid during the last decade. These systems also have various levels of autonomy, i.e. the vehicle assumes the responsibility from a driver, for a shorter or longer duration and can be viewed as necessary steps in the development towards semi- or partial autonomous systems and eventually fully autonomous systems.

It is generally accepted that, in about 90-95% of all incidents and crashes, human behavior is partially or fully responsible. In the push towards reaching the goal of zero serious injuries and fatalities there is a clear need in having the vehicle assuming more of the
responsibility from the drivers either in assisting or taking over the control of the car in a critical situation. The debate is currently running high on the legality and desirability of having the car fully or partially assuming the control, or if the driver should always be in control. For many of the involved parties, however, in assessing what is needed for reaching very low numbers of casualties, there is a shared view that more advanced assistance systems leading towards autonomous driving are desired or needed in reaching this goal.

The legal implications and constraints will have a major influence on the speed of the development, the applications and the directions of autonomous driving in different countries and on different continents. The legal framework affecting the development of autonomous driving concepts varies considerably between the US, Europe and the rest of the world. It even varies within Europe and within the US.

Autonomous driving also, potentially, opens up for possibilities for improved fuel economy, reduced problems with congestions in urban areas, more efficient use of land for city planning, reduced emissions and driving possibilities for the physically impaired.

It is clear to most safety stakeholders that autonomous driving, on some level, is very much part of the future. The technology level has already reached a stage where initial tests are possible. However, dealing with the legality, liability, infrastructure usage and driver acceptance issues will be critical in order to make this truly a part of the future.

DEFINITIONS OF AUTONOMOUS DRIVING CONCEPTS

When discussing autonomous driving the different levels of automation can be identified as:

- Driver Assistance
- Partial Automation (or semi-automation)
- High Automation
- Full automation

**Driver Assistance Systems (DAS):**

Driver assistance systems are systems geared towards assisting drivers by giving information essential or useful for driving and, when a situation is beginning to become critical, giving clear and concise warnings. Examples of DAS are Lane Departure Warning (LDW), Forward Collision Warning (FCW) and Blind Spot Information Systems (BLIS).

**Partial automation systems:**

Partial automation systems are systems that autonomously intervene when the driver fails to act despite warnings. Examples of this are Automatic Emergency Braking (AEB) and Emergency Lane Assist (ELA).

**High automation systems:**

Systems that have the main focus on assuming the control from the driver for a shorter or longer time, but still with the driver supervising the driving.

**Full automation systems:**

Systems that do not need a driver but instead have all occupants in the vehicle performing other activities and not supervising the driving. This level of automation opens up for activities such as computer work, relaxing, different forms of entertainment, etc.

High automation, Full automation and to some extend Driver assistance Systems will have the possibility to offer clear advantages to reduce congestion and to improve safety, fuel economy and comfort.

Communication between vehicles, a.k.a. Vehicle-to-Vehicle communication (VtV) will be an important component for High automation and Full automation systems. VtV opens up for reducing the distance between the vehicles, and thus reducing congestion, since the vehicle behind will be aware of, e.g. braking actions, before when they occur. Braking can therefore occur simultaneously and with no added distance needed for reaction time.

VtV will also help to improve safety since the communication between vehicles will be essential in the decision making of the autonomous vehicle. VtV may also be used to link up vehicles in car trains (platooning) or in smaller units. Such road trains may potentially have a positive influence on improving fuel economy.

Another way of differentiating the levels of automation can be made focusing on the human participation. At the first level the human monitors constantly and is expected to immediately interact, which provides independency whether or not requests. At the second level a human is present and constantly monitoring the driving and when requested by the vehicle, after some time, the driver interacts and provides direction and input. In the third level, a human is present and provides input to the driving as and when desired and at the forth level no human at all is present in the vehicle.
For the forth and third level, and partially also for the second level depending on the time allowed for the human to respond and provide input, the vehicle systems need to have redundancies so as to rectify and cover up for any malfunctions, misinterpretations or any mistakes made by the systems. This may also be performed in a way as to get the vehicle safely off the road (in a limp-home manner). Any deployment of such systems would require careful evaluations of Failure Mode Efficiency Analyses (FMEAs) before being deployed on public roads.

There are also other ways to differentiate autonomous systems. One way is between the level of automation, speed and length of time the autonomous system is active. The National Institute for Standards and Technology (NIST) describes ‘contextual autonomy’ according to three dimensions: the complexity of the mission assigned to the system, the complexity of the environment in which that system performs its mission, and the degree to which that performance is performed without human involvement.

In the discussions linked to the discussions on the upgrade of the Vienna Convention, The German auto makers’ organization VDA (Verband der Automobilindustrie) has proposed, in addition to the groups for levels of automation: driver only, assisted, partially automated, highly automated and fully automated, two subgroups: driver assistance systems and driver authorization systems. The proposed definitions are:

**Driver assistance systems**
A driver assistance system is a system integrated into the vehicle. It supports the driver in his driving task by providing information and warnings, and – if designed to do so – actively intervening in the driving process. The driver must specifically activate and deactivate the system. The driver can override the driver assistance system at any time.

**Driving authorization systems**
A driving authorization system is either a passive or an active system integrated into the vehicle which, using one or more stages of authentication, either once or repeatedly grants fully, restricts or prevents access to the vehicle or to a function. A driving authorization system is designed such that the driver cannot override it.

The definition of the subsystem ‘Driver Authorization systems’ could open for various types of autonomous systems assisting in moving the vehicle and its occupants to a safe haven in the case of the driver being incapacitated, e.g. intoxicated, excessive drowsiness, sudden severe illness, etc., and where it is not desirable for the ride to continue in spite of the intentions of the driver.

**SAFETY IMPLICATIONS OF AUTONOMOUS DRIVING**

Many governments worldwide have adopted long-term safety goals and targets, eventually ending up in zero fatalities and serious injuries. Among those is Sweden who, in 1997, adopted its Vision Zero, which aimed at future goal of zero with respect to casualties in traffic. Governments have set up action plans for making the traffic system robust and forgiving, such as reducing the number of intersection and replacing them with roundabouts, separation of vehicles and vulnerable road users, preventing head-on collisions, etc.

Many manufacturers have also adopted targets and plans for reaching zero injuries and fatalities. Volvo Car Corporation has adopted a target of zero serious injuries and fatalities in a new Volvo vehicle by the year 2020. All of these are, of course, very ambitious and far-reaching goals. The big question then arises; can this be done only by relying of the Haddon Matrix approach, i.e. that traffic safety is depending on the interaction between drivers, the infrastructure and the vehicles?

It is an established fact that in about 90-95 % of all incidents and crashes human error is partly or fully responsible. Eliminating human error therefore offers the largest potential in reaching the target of zero casualties. The development of preventative or active safety, forming the basis for autonomous driven vehicles, has already proven the safety potential for supporting this important target. Since the launch of the first advanced active safety system (the Electronic Stability Control system) in the late 1990s, a whole set of systems, aiming at avoiding or mitigating crashes in a number of scenarios have been developed and launched. These systems reflect different levels of autonomy and are completely or partially taking over the responsibility of correcting a critical situation from the driver. The systems all depend on various sensor technologies for establishing the conditions around the vehicle in making the right decision. Examples of used technologies are laser systems, radar, cameras and positioning technologies separate or in combination.

Among the examples of proven benefits for active technologies is the effect on claim rates for the Volvo
City Safety system, installed on the Volvo XC60 since 2010 and on all Volvo models since 2012, a system that brakes automatically for rear impact at low speeds when the driver is not paying attention. The Insurance Institute for Highway Safety (IIHS) in the US evaluated the City Safety system in a study using data from about 80% of the insured vehicles in the US. The study showed a reduction of claims for the Volvo XC60, compared to other luxury SUVs by 22%. The reduction in bodily claims is about 51%. [1]

For other types of assistance systems similar effects on the reduction of the number of crashes or casualties have been proven or estimated. For instance, the reduction of the number of fatalities with a system detecting and braking autonomously for pedestrians has in a study [2] been estimated to 24% as compared to cars without the system.

During the last decade the issue of distracted driver, especially in connection to the use of devices brought into the vehicle, such as hand-held or hands-free cell phones, has been high up on the list of priorities for actions for reducing the number of traffic casualties. In the US, some studies indicate that the number of traffic fatalities related to drivers being distracted may be as high as 5,000 of a total of 33,000, i.e. about 15%. Measures discussed are including permanently shielding off the vehicle for incoming calls, not using cell phones, hand-held or hands-free, while driving and reducing the ability for manual-visual interaction with a nomadic device brought into the vehicle.

We know that being connected is very much part of the everyday life for modern people. Many of the young generation, the digital natives, may view the driving time, not being connected, as a distraction from the desire of being connected. Shielding off the time spent in the car from connections with the outside world would not appear to be a viable strategy. Having the car supporting the driver during heavy workloads and adapting the assistance to the driver accordingly would be a strategy in-line with a more realistic approach.

Some of the systems available today already point at possibilities to discover distraction or lower attention levels among drivers. E.g. in studies made of the Euro FOT data [3] about 56% of the drivers were distracted shortly before the warning from the alertness system, in about 20% of the cases the drivers were both tired and distracted and in about 20% the drivers were only tired. The development of systems detecting distraction and balancing the driver workload is anticipated to be part of the future for vehicle safety.

These systems can be a stepping-stone for a continuation into partially autonomous systems, systems that can temporarily assume the driving responsibility from the driver during a situation when the attention level of the driver is not considered to be sufficient. Building on these examples it is believed that the evolution of more efficient assistance and autonomously activated system have the potential of, in practice, eliminating traffic casualties.

Up to this point in time, assistance and autonomously activated systems have acted basically with only limited support from the infrastructure. Lane departure warning systems, lane keeping aid systems and some driver alertness systems use the lane markings for establishing movements within the lanes and correcting and warning when the car is deviating from the right path or that driver is showing signs of drowsiness. A number of projects are, however, under way to align the interface between the infrastructure and the vehicle assistance systems. Road signs, lane markings, vehicle-to-infrastructure communication systems (VtI), locations of obstacles, traffic lights and wild life fences, locations and shape of pedestrian and bicycle crossings, all play an important role in making it possible for the in-vehicle systems to make the right accessions and decisions.

For some manufacturers and governments, there is a belief that Vehicle-to-Vehicle communication systems (VtV) will play a major part in reducing the number of crashes with the next couple of decades. However, the penetration of these systems is a major factor and issue. Unless the penetration becomes very high rather quickly, there is an obvious risk that real life benefits will take time to show effect.

Cooperative technologies
It is foreseeable that the technologies for communication between vehicles and infrastructure, Vehicle-to-Vehicle (VtV), Vehicle to Infrastructure, (VtI) and other applications called VtX, will have a large impact on the development and implementation of autonomous vehicles. These technologies will not only allow for distributed sensing, where information from different vehicles sensing platforms will be used in the own vehicle, but will also allow for cooperative decision making and control, where vehicles will act depending on other neighboring vehicles in order to reach a common goal. One such example is that of vehicle platoons, where cooperative control is necessary in order to keep short following distances.
A road train with cars equipped with automatic braking systems that communicates with other vehicles will always brake faster and more efficiently than a line of cars guided by normal drivers. This can be illustrated by the following example. If a road train with 8 vehicles is driving in 90 km/h with a gap of 5 meters the distance between the cars will be more or less the same after an emergency braking, as shown in Figure 1 and 2. This can be compared to the case of 8 vehicles in ordinary highway driving in 90 km/h, as shown in figure 3. Here the human driver is assumed using a time gap of 2 seconds, i.e. a 50 m following distance. All drivers respond quickly (reaction time less than 1 sec), however the last vehicle will stop 25 meters behind the vehicle in front. If someone in the line will have a less quick reaction time the cars will likely crash into each other.

The controller shown in Figure 3 is tuned to resemble a responsive driver with a fast reaction. In the considered example the controller will lock the wheels to 1g, in the last vehicles in order to regulate to its desired gap, however this might not be possible if e.g. the road friction conditions are not optimal, resulting in the last vehicles crashing into each other.

**Figure 1.** Inter-vehicle spacing during automatic braking in a platoon. The inter-vehicle spacing is changing insignificantly during the braking. This is due to actuator delays. It is interesting to note that the intervehicle spacing error is decreasing downstream the platoon, i.e. the spacing error is greater between the lead vehicle and the first follow vehicle than between the last and next last follow vehicle. This property of comes from the controller algorithm and it is refered to as string stability.

**Figure 2.** A vehicle platoon with one lead vehicle LV, and 7 following vehicles FV is braking. The LV is initiating a manual braking, the FVs are braking almost instantaneously, resulting in similar deceleration amplitudes and profiles with almost no loss of inter-vehicle spacing.

**Figure 3.** Typical, human driver-like behaviour during braking on highway from an initial following distance corresponding to 2 s time gap. The first vehicle brakes with 5m/s², the following vehicles brakes each after a reaction time of 1s. The controller simulating the human driver will lock the brakes in most vehicles avoiding an accident in case of a good road friction conditions, i.e. 1 g considered in the example above.

**Systems handling temporarily incapable drivers**

In a not too long distant future it can be expected that there will be systems developed that can very accurately assess the state of the driver, whether being drowsy, intoxicated, subject to sudden illness or in some other way unfit to carry out the responsibilities of driving. For the automation systems where the driver is still in the loop, or for systems where the driver is able to switch off the autonomous driving mode, it will not be desired to allow the driver to keep on driving or assume control of the vehicle. Systems that can safely guide the vehicle off the road into a safe haven at the roadside will be a desired for avoiding misjudgements by incapable drivers. The development of such systems may, however, be impeded by legal restrictions requiring that the driver should always be able to make an override of...
the autonomous system under all circumstances. In the discussions on the amendments to the Vienna Convention strong voices are raised that clarifications should be made that the driver should always be able to switch off the autonomous systems at all times. There are, however, amendments being proposed that overrides should not be possible when this endangers safety.

LEGAL IMPLICATIONS

The existing legal framework for regulating the requirements on motor vehicles, on the driver and on the infrastructure offers many challenges on the way towards autonomous driving. When this framework and most of the base work for the regulations were created, autonomous driving was unheard of or something displayed in films and cartoons as visions for the future. Given the rapid technological development and the opportunities for developing and implementing technologies of various levels of autonomy, the legal framework needs to be restructured and revised in order not to be a hindering obstacle towards reaching the objectives envisioned by autonomous driving. In the analysis of the legal framework on different continents, obvious differences appear in the attitude of the lawmakers.

As a general statement, the US lawmakers, either on federal or state level, tend to be looking for removing obstacles for performing testing and field operations eventually leading up to the possibility of a broad roll-out of autonomous driving, whereas the European lawmakers struggle with the definitions and concepts of the level of autonomy that are to be allowed in the future.

The legal framework with implications for autonomous driving can be divided into four major parts:

1. The Vienna Convention
2. The Geneva Convention
3. US State Laws
5. Product Safety
6. Product Liability

When analyzing the laws and regulations that have a bearing on autonomous driving a difference in approach is soon apparent. In some countries it is considered that everything is prohibited unless permitted by law. In most countries, however, everything is legal unless prohibited. This becomes an important fact when analyzing the US state laws and the national rules and regulations.

I. The Vienna Convention

The Vienna Convention or Convention on Road Traffic (8 November, 1968) was adopted by United Nations Economic Commission for Europe, UN-ECE under its Working Party on Road Safety (WP1). This working party focuses on preventing crashes by adopting international uniform traffic rules. These rules are focusing rules for the general behavior in traffic specifying the requirements on, among other things, sign and signals, traffic education, speed and distance between vehicles, instruction by officials and the drivers physical and mental condition and ability, skill and alertness.

In Article 8, Drivers, it is specified that:

1. Every moving vehicle or combination of vehicles shall have a driver.

2. It is recommended that domestic legislation should provide that pack, draught or saddle animals, and, except in such special areas as may be marked at the entry, cattle, singly or in herds, or flocks, shall have a driver.

3. Every driver shall possess the necessary physical and mental ability and be in a fit physical and mental condition to drive.

4. Every driver of a power-driven vehicle shall possess the knowledge and skill necessary for driving the vehicle; however, this requirement shall not be a bar to driving practice by learner/ drivers in conformity with domestic legislation.

5. Every driver shall at all times be able to control his vehicle or to guide his animals.

The last paragraph: ‘every driver shall at all times be able to control his vehicle or his animals’ is, at the moment, the subject for intense discussion within the regulatory community. How should the line ‘be at all times being able to control his vehicle’ be interpreted? In view of the fact that this convention is adopted by WP1 and its authority to regulate general rules for traffic and that it does not have the authority to specify requirements on vehicle performance, the most common view is that this paragraph only concerns the state of the driver and does not restrict how the control of the car can be handed over to the vehicle systems.

There is, however, an interpretation that this paragraph specifically restricts the possibility to hand over the
control of the vehicle from the driver to the in-vehicle systems. The consequence of the latter interpretation is that the Vienna Convention must be amended to accommodate for the already introduced driver assistance systems that do temporarily assume the control from the driver. This interpretation in practice also illegalizes Partial and Fully Autonomous Systems until an amendment has been made to this article.

The discussions on the interpretation of this article are being, at the moment, very intense in Geneva. Some governments, such as the Swedish and Belgian governments are supporting the first view, i.e. that Article 8 only makes specifications for the state of the driver, whereas the German government supports the latter view, i.e. that the driver must always be in control and that Highly Automated or Fully Automated system are violating this paragraph in the Vienna Convention.

Since no homologation is linked to this convention, it is up to each country that has ratified the Vienna convention to interpret the wording in Article 8 in relation to automated systems and their legality. This means that we can end up in a situation where the Highly or Fully Automated systems are legal in some countries but not in some others.

In line with the interpretation made by some countries, i.e. that the Vienna Convention does not allow for handing over the control to the vehicle and the fact that driver assistance systems already do this, the discussions in Geneva are now focusing on how to amend Article 8. The countries that see no conflict believe that the Vienna Convention does not need to be amended.

Proposals are now being put forward suggesting sub paragraphs for allowing a temporary hand-over to the vehicle. These sub paragraphs are specifically including requirements that the driver should always be able to over-ride the system. Similar requirements would efficiently prevent the introduction of future systems sensing that the driver is unfit to perform his or her task as a driver and direct the vehicle in a safe manner off the road into a sheltered spot near the roadway. This could then be the case for a very tired driver or an intoxicated driver where such pullover or limp-home function may be in contradiction to the intentions of the driver but clearly in line with traffic safety.

With all the proposals and amendments to the Vienna Convention that are being discussed there is a risk of imposing major restrictions for the future technological developments needed for reaching the levels of High Automation and Full Automation and consequently not achieving all the benefits from automated driving.

Restrictions for the development based on assessments and hesitations made when evaluating the progress of the present level of technology and all existing uncertainties can easily end up in the similar historical mistakes made in relation to other areas of technical progress, e.g. airplanes and computers. Regulators are therefore strongly urged not to, at this time, set limits for the development towards autonomous driving but rather regulate individual systems and set performance standards as needed as the technologies continue to being developed.

Within the regulating community there exists a certain resistance towards the concept of not having the driver always in control of the vehicle. This resistance is not, however, compatible with the ambitions and targets of reaching zero fatalities and serious injuries. As explained in the safety chapter of this paper, for the vast majority of crashes, human error plays a role. This fact can never be eliminated purely by other measures such as driver education and infrastructure improvements. Having the technologies taking over the controls from the driver and guiding the vehicle will be necessary for reaching the low casualty levels.

2. The Geneva Convention

The Convention on Road Traffic signed at Geneva in 1949, a.k.a. ‘The Geneva Convention was established with the intention of establishing uniform rules for international traffic. 95. Visiting motorists would then be familiar with the basic rules for travelling in a foreign country.

Article 8 reads:

1. Every vehicle or combination of vehicles proceeding as a unit shall have a driver.

2. Draught, pack or saddle animals shall have a driver, and cattle shall be accompanied, except in special areas which shall be marked at the points of entry.
3. Convoys of vehicles and animals shall have the number of drivers prescribed by domestic regulations.

4. Convoys shall, if necessary, be divided into sections of moderate length, and be sufficiently spaced out for the convenience of traffic. This provision does not apply to regions where migration of nomads occurs.

5. Drivers shall at all times be able to control their vehicles or guide their animals. When approaching other road users, they shall take such precautions as may be required for the safety of the latter.

The commonly accepted interpretation of this based on the history behind the Geneva Convention is that this concerns unsupervised animals but not unsupervised cars. The conclusion will then be that the Geneva Convention does not restrict the use of automated vehicles.

3. US State laws
Under the common law approach, as applied by the states in the US, anything is allowed unless prohibited by law. Since no specific state laws restrict the licensing of autonomous vehicles no principle barriers exist that would prevent automakers from receiving such licenses. However, in order to facilitate testing on public roads, state law- and rule makers have been very busy preparing and adopting laws and regulations specifying rules for licensing automated vehicles.

Among the states that have passed laws, as of February 2013, are Nevada, California and Florida. Bills for licensing of automated vehicles have been introduced in, among others, Arizona, Hawaii, Michigan, Washington state and Washington DC. Only Nevada has so far, however, adopted regulations specifying necessary verifications for receiving a license.

Automakers fear that this state activity, although commendable in its ambition, may lead to a patchwork of laws of regulations that may complicate the introduction of autonomous vehicles on a 50 state level in the US. It is therefore recommended that the National Highway Traffic Administration, the federal agency regulating the performance and equipment on a motor vehicle, gets involved in creating a national proposed standard to be adopted by the individual states.

4. National Rules and Regulations
Many countries, states and provinces worldwide have restrictions in place regulating the general behavior of the driver in relation the road traffic circumstances. In addition to a general cautious and prudent behavior, there are specifications on the minimum distances to the vehicle in front. This is specified in some states to be between 100 and 300 feet. These requirements will be significant in relation to some applications of autonomous driving, such as road trains or when cars link up with V2V communications systems where the distance between the vehicles may be and need to be shorter than the distance considered necessary for a safe normal driving.

5. Product Safety
An automated vehicle, in full compliance with all applicable legal requirements and in compliance with the Vienna and Geneva Conventions, could, if it is considered that it, or its subsystems, presents an unreasonable risk of death or injury, be classified as ‘defective’. The manufacturer of this vehicle would then be obligated to inform its customers and send out a notice of a recall. All recalls are very costly and could tarnish a manufacturer’s reputation and brand image in addition to making its customers dissatisfied and lower their loyalty to the brand. A widely published recall of an autonomous vehicle could be devastating for the subsequent launches of similar vehicles.

The technological and behavioral challenges with autonomous driving entering, in many ways, uncharted territory will impose additional considerations in design and marketing. Any mistakes leading to crashes and subsequent recalls and bad publicity could seriously impede the progress of autonomous vehicles for years.

6. Liability
There are a number of challenges dealing with product liability in relation to autonomous driven vehicles. How will it be possible for manufacturers to design for any foreseeable misuse? How to distinguish between foreseeable misuse and system abuse? Requirements on instructions, redundancies and the design of the Human Machine Interfaces will be excessive and demanding. Will it be enough to prove that the system is sufficiently safer than for the driver-guided situation?

It is clear that manufacturers will have to put more efforts into deeper Failure Mode Efficiency Analyses (FMEAs) and other additional analyses of the systems. In some countries in Europe, and also in some countries globally, the national liability legislations specify that the liability must rest with an individual and not with a manufacturer or a supplier. This fact does make the liability issue for autonomous driving very complex and it, in practice, prevents High and Full Autonomous driven vehicles being applied for public road use in those countries. For other countries, without the specific need to assign the liability to an individual, this can
instead be distributed according the individual proportions of responsibilities between the driver, manufacturer, suppliers and other entities liable.

As long as the driver is required to monitor the situation, e.g. for systems such Traffic Jam Assist where the system will be switched off if there is insufficient driver surveillance, liability will fully or partly rest with the driver. However, for systems not requiring a driver monitoring, the manufacturer will be liable for the time period when the driver is out of the loop (unless the accident is solely caused by a third party or an override by the driver). In conclusion, as today, liability will probably be decided on a case-by-case basis.

Some special liability issues may arise for the case of platooning. Where does the liability rest in an accident between a vehicle in the rear of the platoon and an outside vehicle? If the crash is caused by the platoon but it was not possible to foresee this by the platoon leader since the end of the platoon is not visible from the front. If then the vehicle in the tail is in a highly automated mode just following the leader assigning liability will be complicated.

TECHNICAL ISSUES

A number of technical challenges remain before systems with higher levels of automation can be launched on public roads. Many issues remain that require more research and development of more advanced systems.

Among the challenges are how to properly assess to vehicle surroundings, the algorithms for the decision-making, how to consider actions from other road users, etc. Public acceptance levels for errors in decisions or for unmotivated activations, so called false positives, will be very low.

There is a common belief among manufacturers, governments, safety and policymakers that truly full automation will never be achieved. However, the only conclusion one may make from history is that technology very often exceeds the common conception of what is considered possible.

One area for concern linked to autonomous systems and also for driver assistance systems in general is what is commonly called Cyber security, i.e. the risk that external hostile sources penetrate the shield manufacturers are developing for advanced systems of autonomy. The integrity and protection of the systems have to be safely secured before any system launch. Customers will have a very low understanding of systems malfunctioning or acting improperly in traffic endangering the safety of occupants or other road users. One way of safeguarding against both Cyber security attacks and system misjudgments is to create redundancies, i.e. have multiple sources of information in support of the decision-making. Information from external sources, e.g. from infrastructure or from other vehicles, adding to the information created by the in-vehicle systems will be needed for a reliable and robust decision-making.

In order to restrict the challenges linked to a large variety of traffic situations, systems for autonomy may be certified only to be allowed on special road sections adapted for certain systems, e.g. on highways or for special applications such as parking. Such certification may require some regulatory framework for setting the requirements to be met on each section of road or for each application.

One issue that has been raised for systems of high automation or full automation is how to safeguard that the driver is back in charge when the system goes from automation to driver back in control of the vehicle. What would be the reliable ways to reactivate the driver, e.g. for a sleeping driver and how to check the alertness of the driver before handing controls over? This area is in need of extensive human behavior research in order to support the proper decision-making.

ENVIRONMENTAL IMPLICATIONS OF AUTONOMOUS DRIVING

The transport sector’s impact on health and the environment

The global burden of disease study 2010 [5] reveals that as many as 3.1 million deaths globally were caused by unhealthy air quality from air pollutions in 2010. To give a perspective, in the same study the number of traffic related fatalities were around 1.3 million globally.

The transport sector is one of the main causes of pollutants. In addition to the emissions contributing to the exceeding of air quality standards, carbon dioxide (CO₂) is one of the key pollutants related to global warming. The transport sector represented approximately 22% of the global CO₂ emissions in 2008, out of which road traffic caused 73% [6]. In the United States, this fraction was higher than the global average and the transport sector represented
approximately 31.1% of the total amount of CO₂ emissions in 2008 [7]. After electricity and heat generation, transportation takes the position as the second largest cause of CO₂ emissions [6].

Despite the accomplishments of reducing the environmental impact per vehicle, greenhouse gases (GHG) from transport as a fraction of the total amount of emitted GHG in the European Union, did in fact increase by 34% (including international aviation and maritime transport) from 1990 to 2008 [8]. This is an undesirable trend, but the percentages above must, however, be interpreted with consideration not only to the change of amount of GHG, but also with respect to the achieved reductions of emissions within the transportation sector in comparison to the achievements of reduction of emission of other polluting sectors.

The GBD 2010 study [5] further presents findings of “years of lost life” (YLL) and “years lived with disability” (YLD), which together is abbreviated to “DALY” (i.e. DALY = YLL + YLD). The study shows that particles in outdoor-air represented 76 million DALY in 2010, i.e. particles in the air take the position as ninth highest risk factor for DALY in 2010 globally [9]. This risk factor linked to particles is even higher in some regions, in particular in South East Asia. Overall, urban areas are most vulnerable and the emissions from local traffic as the main cause. This is worrying as the percentage of the population living in urban areas is estimated to increase, e.g. in Europe from 74% of the population in 2011 to approximately 85% of the population living in urban areas by 2050 [8].

**The process of reducing the transport sector’s emissions**

The transport sector’s high level of impact on health and the environment, an increasing population and growing needs of transportation, verifies the need of improvement. However, while discussing reduction of emissions during the vehicle operation cycle, rolling resistance, aerodynamic resistance, weight and the internal combustion engine are areas often mentioned. Although the progress of improving the vehicle design, internal combustion and the exhaust cleaning processes have been successful and will continue (it is estimated that a up to 30% CO₂ reduction for passenger cars can be achieved with present technology [8]), more rewarding and cost effective reductions are sought after. This is one of the main reasons why manufacturers and researchers are developing alternative energy propulsion systems for the vehicles of tomorrow.

Regardless if the vehicle fleets are driven by fossil fuels or by other energy sources, the benefits of improving the actual driving cycle are expected to have a significant potential in lowering energy economy, i.e. reduce emissions. Although educating drivers in “eco-driving” will help to improve fuel economy and reduce emissions, autonomous driving is expected to have a significant influence while reaching for a more energy efficient driving cycles. In addition, autonomous accident preventing systems could help to reduce emissions by avoiding accident related congestion and improving traffic flow.

**Autonomous system’s direct and indirect environmental impact**

In 2012 the European field operational test project, Euro FOT published its report [10] verifying that driver assistance systems significantly improve fuel economy. The project was conducted by a partnership of 28 companies and organizations in Europe between May 2008 and June 2012. It involved both trucks and passenger cars, focusing on investigating a number of driver assistance systems. In total (trucks and cars) around 1200 drivers drove the test vehicles on a daily basis, resulting in data for about 35 million kilometers of driving. Volvo Car Corporation, which was one of the participating car manufactures, collected data from 100 vehicles driven by 263 drivers for a total of 3 million km. Subsequently, the study provides a large amount data available to be evaluated of for example system performance, driver behavior and user acceptance in an ordinary real traffic environment.

Among the findings of the Euro FOT study is the potential of improving the fuel economy by using the Adaptive Cruise Control system (ACC). The ACC is designed to automatically adjust the distance to the vehicle in front, which is a stepping-stone on the way towards autonomously driven vehicles. Overall, the ACC was used on about 50% of the kilometers driven on motorways (tested over 780 000 km [11]) and the average fuel economy while driving with the system was reduced by 2.1% for cars [10]. ACC further reduced the average speed with 0.4% [10] and the targeted crashes (rear-end crashes) with 16-42% [11].

With the high driver acceptance of 50%, the targeted usage area and the benefits of the ACC, promising potential is provided from the statistic that about 63% of the car emissions in the European Union are related to non-urban roads and motorways (73% of the total kilometers of car travel) and that non-urban road travel represents 61% of the fatalities [8].

With the assumption that all passenger cars in EU-27 were equipped with ACC, the Euro FOT study
estimates that a total of about 693.9 million liters of fuel per years could be saved, resulting in a reduction of about 1.7 million tons of CO₂. Considering the total amount of the approximately 3.8 billion tons of CO₂ emissions in the EU27 in 2011, the one system could then potentially decrease the impact in EU27 with 0.0447%. [21]

The indirect traffic effects from the safety enhancement of the bundle of Forward Collision Warning (FCW) and ACC, i.e. the safety aspects contribution to reduction of subsequent congestion, is stated to be capable to lower the incidental delay with about 3 million lost vehicle hours in EU-27 [10].

A study of 437 urban areas in the United States, conducted by using measurements from 2005, presented a total congestion delay of 4.2 billion hours and 10.97 billion liters (2.9 billion gallons) fuel wasted due to congestion in those urban areas in 2005 [13].

The project, Safe Road Trains for the Environment, “SARTRE”, was completed in 2012 and showed findings of promising benefits of taking the human driver partially out of the driving-loop. The project aimed at investigating the potential from vehicle platooning with respect to enhanced safety, comfort and reduced environmental impact on normal public highways. Being funded by the European Commission under the Framework 7 program, the project was carried out by a partnership between Ricardo UK Ltd., Kraftfahrwesen Aachen (IKA), SP Technical Research Institute of Sweden, Volvo Car Corporation and Volvo Technology of Sweden.

By using Vehicle-to-Vehicle (VtV) communication the distance between the platooning vehicles was reduced significantly, producing beneficial aerodynamic conditions. On the same instance, the VtV communication implied a high safety enhancement as a professional driver leads the platoon and the following vehicles are interacting seamlessly with each other. In addition to the safety benefits (predicted to be as high as 50% on highways) and the consequence of reduced indirect traffic effects, the direct improvement in fuel economy was estimated to be around 10% [14].

**Autonomous systems potential to increase traffic efficiency and lower the environmental impact while expanding the infrastructure**

A study presented on the IEEE Vehicular Technology Conference in 2011 [15] suggested that autonomous systems could increase the highway capacity by 273%, if all cars had such technology. This is derived from the fact that just a few percentage of the road space is taken up by the car due to the safety distance required by the human driver.

To drive safely at a highway speed of 90km/h, a driver must hold a distance of around 75 meters to vehicle in front. In the SARTRE project platoons were safely driven in 90 km/h with just 6 meters of gap between the vehicles. This obviously proves the high traffic density and thus the traffic efficiency autonomous vehicle technology is capable of achieving.

Moreover, it is expected that road transportation will continue to be an important part of transportation in EU through 2050 (about 2/3 of total passenger transport) [8]. Without any changes, the traffic is predicted to increased with 34% by 2030 (51% by 2050) in the European Union and the cost of congestion will increase with approximately 50% in the European Union by 2050 (reaching almost €200 billion annually) [8]. With an increasing number of vehicles on the roads, a reduction of emissions-per-vehicle is required just to keep the same total amount of emissions from transport of today. The challenge of lower the total amount of emissions requires a multiplicity of technology enhancements.

The environmental benefit of autonomous systems goes beyond the driving cycle. With a higher traffic density, the required road space is less, thus less road infrastructure investments is needed to cope with the growing population and higher transport needs.

Although the environmental aspects of building roads are complex, less building implies environmental benefits, if the traffic efficiency and safety aspects are maintained (or improved). McKinsey & Co. have estimated that approximately $16.6 trillion worldwide (€1.5 trillion between 2010-2030 in the European Union [8]) is needed to be invested in roads through 2030 to match the demand for transportation with the global growth [16]. Road investments is the single largest investment of the total estimated $57 trillions needed to be invested in infrastructure all over the world though 2030. To give some perspective, $57 trillions are nearly 60% more than the infrastructural investments the last 18 years [16]. The approach of improving the vehicles to more effectively use the roads in a complementary manner to reduce the need of expanding the road infrastructure would also result in more representative economically circumstances. The cost of the necessary technology to achieve such efficiency would be paid by the road users (or owners of the vehicles) and as a result would the cost of the road infrastructure investments be
Environmental effect of reduced number of traffic accidents
Autonomous driving is expected to have an effect on reducing the environmental impact from traffic by avoiding or by a substantial reduction in the number of crashes, incidents and disturbances in traffic that already are being significantly reduced by e.g. automatic emergency braking systems. Autonomous driven vehicles will further enhance the efficiency.

In order to estimate the benefits following calculation can be made. Assume that a moderate rear-end collision results in a 30 minute complete blockage of 1 out of 2 lanes on a highway during rush hour. Furthermore, assume that this will temporarily reduce the traffic flow to 1/6 of the capacity during 30 minutes, (blockage of one lane forces the traffic into one lane with a 1/3 which means that the total capacity is about 1/6 of the original capacity) which in turn will result in a traffic jam. Assume that, during rush hour, the average time gap between vehicles is 2 seconds. Then the 30 minute blockage will result in approximately 30*60*2*1/2*(1-1/6) = 1500 vehicles initially being involved in the traffic jam. Further assume that the average front-to-front distance between two vehicles is 7 meters in a low speed traffic jam. Then the traffic jam builds up to 7*1500*1/2 = 5250 meters during the 30-minute blockage. Since the accident occurred during rush hour, the traffic jam will remain for the entire duration of the rush hour, e.g. 2 hours (since flow in = flow out during rush hour). In 2 hours, 120*60*2*1/2 = 7200 vehicles will endure the 5.25 km traffic jam before it is dissolved. Assume that the average fuel consumption for the vehicles increases with 1 L/10 km during the traffic jam. Each vehicle is thus consuming 0.525 L extra gasoline in the 5.25 km traffic jam, in comparison to driving with normal speed. In addition, all vehicles need to slow down and then accelerate again after the traffic jam. Assume that the average weight is 1500kg and the engine efficiency is 25%. The energy content of gasoline is 34.8MJ/L. The energy required to accelerate a 1500 kg vehicle from 0 to 72 km/h = 20 m/s is 1500*20²*0.6MJ, which is equivalent to 0.6/(34.8*0.25) = 0.07 L of gasoline. In total, the 7200 vehicles involved in the 5.25km traffic jam will consume approximately (0.525+0.07)*7200 = 4300 L of extra gasoline due to the rear-end collision in this example.

Furthermore, the traffic blockage in traffic is wasting excessive time for all occupants involved in this incident. Approximately 30 minutes per person is wasted, giving a total of 5000 hours time lost. The traffic jam also increases the wear and tear on all vehicles, but this is harder to estimate. The same thing applies to stress-related health issues created by being stuck in a traffic jam.

Figure 4. Estimates for the effect of speed on MPG [55]

SOCIETAL IMPLICATIONS OF AUTONOMOUS DRIVING
The path towards more advanced vehicle assisting systems and finally leading up to partially autonomous or fully autonomous driving will be challenging for all involved stakeholder including industry, governments, authorities, infrastructure developers, researchers, fleet owners and the general public. The deployment of the various level of autonomy will affect everything from urban and infrastructure planning and investments, legal adaption, technology developments, changing road user’s conception of traffic and driver education.

Investments in infrastructure
Investments in infrastructure impose huge costs to society. In the US it is estimated that the cost per mile for an urban highway is about 8 to 12 million USD per mile. [17] Over the next ten years the investments in roadways in the US are estimated to be in the order of 1.5 trillion USD. [18]

The question then arises, will autonomous driving concepts need larger infrastructure investments or will the need for infrastructure investments be reduced with implementation of autonomously driven vehicles? What supports the need for major infrastructure investments is if special lanes are required for deploying autonomous driving, lanes that have to be built and linked to this are investments in property, planning, constructions, etc. There are, however, a number of ideas and concepts that can be used when deploying autonomous driving and that can help to reduce the need for investments rather than increasing them. Concepts such as directional devices built into the
infrastructure may be used to direct an autonomously driven vehicle and keep it more centered to the center of the lane, which in turn can open up the possibility to reduce the width of the lanes. Those concepts may also have a number other directional uses such as indicating a safe roadside emergency location.

By reducing the width of a lane it would potentially be possible to add more lanes on existing areas used for highways, which would significantly reduce investments and increase savings.

Autonomous driving in urban areas can also potentially open up improved possibilities for more optimized use of the city landscape by improving traffic flow, more dense parking, reduced lane widths, etc.

**Personal and societal benefits**

In the continuous development of various levels of assistance systems leading up to fully autonomous systems there are potentially a number of possibilities for societal benefits.

From an individual perspective the main benefit from autonomous driving would be to recapture the true freedom behind the wheel, the freedom that cars defined a century ago. At that time freedom was defined by the possibility to go wherever you wanted with your own car. Today true freedom is defined in further dimensions, such as being able to travel and spending time as desired. A vehicle with autonomous driving capabilities could potentially offer the freedom to use time as desired when on the road, on top of traditional freedom.

In the modern society time has become one of the most critical factors of wellbeing. An autonomous driving vehicle could open up possibilities for other activities such as leisure, work and social interaction. Improved health status due to more time available for personal use is also a factor that may be added to the benefits as stated above.

Wasted time in traffic can be linked to a financial loss, this both from individual point of view and from a societal point of view. Being able to use time more efficiently when commuting to and from work can add valuable time to read mails, book meetings, prepare speaker notes and presentations etc. This will free-up time at work for more useful meetings and discussions where personal presence is necessary. The time in the car can also more efficiently be used for private matters, such as reserving time with a dentist, arrange theater tickets etc. which can be handled behind the wheel more efficiently, freeing up time away from work for social engagements.

Automated driving may have an equal opportunity factor by offering mobility to users that would normally not be able to drive. Blind, physically challenged or persons without driving licenses could potentially own and ride a car with autonomous driving features.

Clear benefits like time, and reduced fuel consumption, are required for a sustainable business case. The direct value of having vehicles with autonomous driving capabilities can be estimated based on time saved and reduced fuel consumption. The value for the driver is higher when adding comfort of travel and gained freedom.

Autonomous driving also could open up for benefits such as the possibility of using commuter lanes, bus lanes, reduced city tolls, access to certain restricted areas, using specially assigned parking areas, etc.

The event of a crash free society could open up for new opportunities for vehicle interiors and removing some restrictions for the occupants positioning in the interior compartment. If there is no crash risk occupants will not need to be belted and may have the possibility to move around freely inside the vehicle which would even further improve riding comfort.

If crashes and incidents can be avoided or reduced, the costs for insurance is likely to come down which if impact the total cost of owning a motor vehicle. Autonomous Driving systems will make it possible to utilize the available road space more efficiently. By coordinating traffic flow, i.e. speed and distance between vehicles, congestions can be reduced and the traffic flow through cities increased. With improved control of distance between vehicles the static distance can be reduced in slow moving traffic, but also reduced dynamic distance between vehicles in stop-start traffic scenarios. Traffic flow speed in congestion is often reduced by delays in stop start traffic, but also narrow sections and access points. If the speed can be increased by automated control in these sections an increased overall traffic flow can be reached. Reduced distances between cars and increased traffic flow speed require increased knowledge of the environment around the vehicle.

There are studies in the US indicating an efficiency increase for traffic with autonomous vehicles with up to 273% [17]. Although this figure appears to be on the
overestimated side it is clear that autonomously driven vehicles will help to improve traffic flow.

**Cost Savings from Avoiding Crashes**
It is evident that the societal savings from altogether avoiding crashes, as potentially being able to be delivered by the combination of autonomous driven vehicles and efficient driver assistant and automatic braking and steering systems, will be huge. The different studies of annual savings for road casualties fatality circle around a level in Europe of around 1.6 million EUR per avoided fatality, 70,000 EUR per avoided injury and efficiency benefits of avoided casualties (add on to road safety): 15,500 EUR per avoided fatality accident, 5,000 EUR per avoided injury accident [3]. In the US, in a study published 2011, the total cost for car crashes is estimated to be around 300 million USD with a cost per fatality of 6 million USD and 126,000 USD per injury [19]. In the same study the cost for road crashes per person in the US is estimated to be 1050 USD per year.

From the studies being released during the last couple of years, assistance systems have proven to yield a number of clear safety enhancements and reduction of both casualties and reduction of societal costs.

In one of the studies [20] the British motor vehicle research institute Thatcham has estimated the saved repair costs if all vehicles in the UK were equipped with an automatic emergency braking system similar to the Volvo City Safety system to around 1.3 billion Euros annually. The saved societal costs for avoiding around 150,000 whiplash injuries per year would be nearly 2 billion Euros.

**Benefits and Business Opportunities from Road Trains**
As described earlier autonomous driving can be defined and is expected to be offered on different levels. These levels may offer different levels of business opportunities. For the level of high automation, one application possible is platooning, also known as road trains or platooning. The EU project called SARTRE, SÀfe Road TRains for the Environment was finished in 2012 [14]. The target for this project was to investigate the technical, legal, environmental challenges and the business opportunities with road trains.

Results from the project indicated a fuel economy improvement of 14% for the following vehicles and 5% for the lead vehicle. Assuming add-on costs for necessary in-vehicle equipment at about 2,000 Euros, a small amount of administrative costs and a commuting distance of around 80 km per day, the break-even cost per car in the train would be about 55 Euros per month or 3.5 Euros per 100 km. If the lead vehicle is a truck, being in the road train will immediately be paying off. If the lead vehicle is a passenger car, the level where the road train will be adding income to the car owner would be 4-8 cars in the road train depending on the business model of monthly subscriptions or charge rates per distance.

It is clear that in the initial phase, however, there will be too few trains on the road to make the leading car business be sustainable alone but instead only as a secondary business (taxi, delivery services, etc.). There are also a number of inherent issues with road trains that need to be resolved before a broad rollout on public roads. Among those are e.g. the use of commuter lanes and necessary infrastructure investments, liability issues for conflicts between external cars and cars in the road train, liability of the driver in the lead truck or car, etc.

**DISCUSSION**
Systems with high levels of automation clearly have the possibility to offer many benefits both to individuals, the general public, and the transportation sector and to the society. At the same time it may profoundly alter the conception of driving and riding in an automobile, something that will be a major shift from a focus on the transportation as such to the usage of the time in the car. The question can then be asked, will the society be ready and will it adapt to the new possibilities? Will the expected business opportunities arise and in a timely manner? Will public skepticism overrule the possibilities opened up by automated systems?

The development of assistance systems and systems paving the way towards higher levels of automation is very rapid. Will this development be in tune with other developments such as infrastructure developments? Will the need for infrastructure investments to accommodate for autonomous systems be significantly higher than anticipated?

Given the obvious benefits from automated driving, can we expect governments and infrastructure authorities to step up to the challenge of supporting the development and progress of launching these systems on public roads? On key factor that may influence the development is the risk of failures on the way to highly automated systems that can seriously affect the trust and willingness by authorities and the general public to adopt the idea of the driver not being in control of the
vehicle. Cases of malfunctions and failures causing public distrust are well known in the automotive history. It is therefore paramount that manufacturers, suppliers and rulemaking bodies use caution and carefully examine each step on the way towards high or full automation.

CONCLUSIONS

The event of automated driving offers a number of possible benefits both on an individual level as well as to the society, such as improved safety and fuel economy, reduced exhaust emissions, improved traffic flow and reduced problems with congestions, mobility for the physically challenged, etc. There are, however, many obstacles and challenges left before the systems for high or full automation can be launched on a wider scale. Additional research, further technological development, adaptions to the infrastructure and to interaction with other road users, sorting out the legal matters, establishing business cases are a few of the critical issues that need to be addressed. Given the potentials and clear advantages it is likely that the development towards high or full automation will continue and in an ever more rapid pace attaining levels and producing new concepts in a not too distant future.

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