

# Definition of necessary vehicle and infrastructure systems for Automated Driving

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## Study Report

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## Executive summary and white paper

The vehicles we drive are becoming increasingly more complex and many electronic technologies that had once no link whatsoever with the automotive industry are changing nowadays our driving experience. Our cars have started to assess the situation in traffic much faster than humans can do thanks to many ingenious sensor-based driving assistance systems. Wireless communication inside the car or between cars, trucks, busses and conventional cellular base stations has become reality as well. As a next step, exchanging dedicated technical information between vehicles or between vehicles and the outside world is also within practical reach. Other participants in traffic like pedestrians and bicyclists could benefit as well if detected by in-car advanced driving assistance systems (ADAS) and avoided when an accident becomes imminent, or simply warned by wireless communications means.

All these technologies open up new business opportunities for car manufacturers and their suppliers, road administrators, telecom companies, etc. while raising legitimate questions of various backgrounds. The truth is that vehicle technologies evolve as we speak more and more toward assisting the drivers in difficult situations in traffic, achieving traffic decongestion, improving the safety on our highways and in urban environments, reducing the fuel consumption and exhaust emissions, and delivering a high degree of comfort while driving. Automated driving, in some sense, has become part of our life, although there is still a long way to go until most vehicles will feature ADAS-based intelligence. Nevertheless, the chain reaction has started and the automotive industry along with all other stakeholders, such as governments, are paving the way to increased automation on the roads while the drivers are still requested to stay in control. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies and applications will soon also become part of the automated driving experience and together with ADAS will form the automated driving ecosystem. Common understanding says that taking the driver out of the loop in the evolution process from automated to autonomous driving will not happen easily and probably will not happen at all. Nevertheless, since autonomous cars have already been proven in normal traffic and there are valuable opinions as well about opening dedicated lanes or corridors for autonomous vehicles, the far-fetched future may not lie too far ahead.



This report addresses the challenges that come along with the transition from the slightly automated cars of today, through an ecosystem of highly automated vehicles assisting the driver in practically any difficult situation. The report builds upon the state of the art in ADAS technologies and formulates answers that could guide the automotive industry in this transition process and could help the legislators, the road authorities, the consumers, and

the relevant industry define the healthy traffic environment of the future. Due to the imminent, large-scale penetration of ADAS and to a certain extent also of the V2V and V2I technologies, the main objective of the report is fairly limited to automated driving.

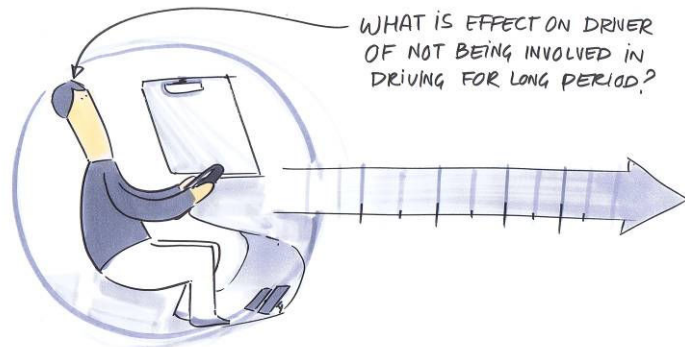
To begin with, the report defines the framework within which common definitions for automated driving, V2V- and V2I-based cooperative driving, and autonomous driving should be interpreted. It is important as well to understand how these technically-defined vehicle categories could populate our roads and for this purpose three scenarios are taken into account: mixed traffic on highways, mixed traffic in urban areas, and dedicated traffic corridors. The complexity of the vehicles on the road and of the supporting road infrastructure is intrinsically related to the characteristics of the traffic in these three scenarios.

Automated driving has led already and will increasingly more lead to business scenarios that affect the consumers while having an impact as well on the legislative aspect of the society and financial balance of the stakeholders. At increased purchasing costs of the vehicle and added costs for some key services, the technologies envisaged to become a common presence on our roads and improve so much our mobility may not return easily the financial investments. It is for this reason that the industry and governments need to compromise between benefits, user needs, technology penetration and acceptance, incentives, standards and last but not least, legislation. The report introduces these compromises and discusses them in relation to all involved parties.

It is essential to understand that automated driving, cooperative driving, and autonomous driving have not appeared overnight. Significant efforts spent by companies and public institutions, including governments, have pushed the technical developments forward and have created the necessary conditions to prototype intelligent vehicles, test the impact of the ADAS-based features in real traffic, and cooperate internationally to achieve the results of today. The report summarizes the most significant national and pan-European projects that have contributed or, if they have not finished, still contribute to the state-of-the-art intelligent transportation systems (ITS). There are, of course, unsolvable problems at present for which solutions are envisaged on short term or are being sought and expected within a larger timeframe. A summary of the most relevant technical impediments that are known to slow the progress on the intelligent, automated vehicles is included in the report.

Obviously, since driving our cars and trucks expose us to an interaction with the road signage, traffic monitoring systems, law enforcement systems, etc., it is appropriate to pay attention as well to the external world. The report gives also an overview of the available state-of-the-art roadside units (RSU), of the several European projects that focused on improving the infrastructure able to support the ITS of the future.

Yet another paramount aspect tightly related to automated driving at present and in the near future, and certainly related to autonomous driving in the long run, is the interpretation of the Vienna Convention. It will be shown in the report how this European legislation is commonly interpreted, how it creates the framework necessary to deploy on a large scale automated and cooperative driving systems, and what legal limitations are foreseen in making the new step toward autonomous driving. The report analyses in the same context other conventions and legislative acts, searches for gaps in the current legislation and makes an interesting link with the aviation industry where several lessons can be learnt from.



From another legal perspective, neither the automotive industry nor the other contributors to a roadmap in automated driving are loosening the discussions on liability issues. Several European projects touch the liability aspects already and a summary of these projects is tabulated in the report. The status of the civil liability in the European countries is briefly discussed in order to introduce the effects automated driving has at present and could have in the future upon various stakeholders.

Reliability of the ADAS-based automated driving and of the V2V- and V2I-based cooperative driving plays an important role in all discussions with manufacturers and legislators. Vehicles are becoming more sophisticated by incorporating large amounts of software to control the various subsystems on board. Will our vehicles be more and more prone to defects while driving or is the failure rate of the software close to that of electromechanical components, therefore guaranteeing a fairly safe transport carriage? This is central question that keeps the automotive industry, in special, busy on a daily basis with finding the right answers and solutions. The report gives an overview as well of the several reliability strategies under current implementation in the automotive industry and under attention of the relevant participants in the ecosystem of road transportation.

Given the increasing importance of software in the well-functioning modern vehicles, it was also appropriate to address the electronic control units (ECU) in report. More and more vehicles are commercialized with functions like steer-by-wire, brake-by-wire, etc. and these technologies will not cease to exist in automated driving. The new developments in these technical areas are reviewed along with the existing and anticipated standards, and with the research gaps that would need to be filled in toward a future-proof large scale deployment of automated vehicles.

One more topic that needs to be addressed covers the broad area of sensor technologies. Modern vehicles are able to assess extremely well their own dynamic behavior by measuring speed, acceleration, forces, rotation angles, distances to objects in front or behind, etc., and their location by means of global positioning systems (GPS). New sensors are being deployed in automated driving systems and their precision grows steadily in line with their complexity. Some automated driving features, like automated merging into on-going traffic, would require new automotive solutions of better accuracy that presently in use. The report lists possibilities, opportunities, improvement areas and indicates as well the requirements raised by the automated driving from the satellite-based navigation technologies.

Of course, an analysis of the road ahead in automated driving and cooperative driving extending toward autonomous driving cannot be complete without an overview of possible applications. This part of the report should be seen closely related to the technological progress made by key vehicles manufacturers and automotive suppliers. Many other organizations like universities or research institutions play a significant role as well in closing the gap between fiction and reality. It is not a laboratory dream anymore to safely lead a vehicle in an automated way toward the roadside if the driver faces suddenly health problems and becomes incapable to steer his or her car anymore. Adding vehicle-to-vehicle and vehicle-infrastructure communications to our cars will enable another dimension in traffic and will make a journey by car more safe, more comfortable, at less cost if we won't have to brake and accelerate so often, and more fluent if we can drive safely close to each other on busy highways (while all vehicles brake and accelerate at the same time).

Surely, we all have to take into account the human-machine interface (HMI) with which the intelligent automated vehicles of the future communicate with us or simply avoid communicating with us if that is not necessary. This particular section of the report provides insights in the HMI needs of the next-generation vehicles and, more importantly, in the perception exhibited by the drivers of such highly-automated, communication-enabled transportation systems.

### **Main conclusions**

The topics addressed in this report should lead the reader through a convergence process to several conclusions. It is, however, not easy to draw these conclusions because of the large spectrum of knowledge required in apprehending the topics discussed. The following conclusions drawn from a top-down perspective could help the reader arrive at a correct understanding about automated driving:

- 1) Some automated driving functions are already present in modern cars. With many automotive technologies advancing at a rapid pace, being driven as well by national and international projects, there is an increasing need for deploying the automated driving applications cost-effectively, at the right time, with the right partners, and maybe in a more pragmatic manner. It is necessary to create a short- to long-term plan that could efficiently lead the gradual introduction of automated driving applications in groups, categorized according to specific criteria and fulfilling categories of requirements (for example, mandating a certain level of safety at intersections by means of V2V communication).
- 2) Automated driving functions that interconnect with the road infrastructure continue to be regarded from the perspective of a chicken-and-egg situation: investments in the appropriate infrastructure are postponed or even denied until vehicle manufacturers take the lead to implement the related applications and the other way around. By acting in a more resolute manner at the legislative level it will be possible to break this issue into solvable situations, which could easily be agreed upon for the benefit of all participants in traffic, of the manufacturing industry, and of legislators as well.
- 3) Implementing a mandatory introduction plan for automated driving does not suffice if the appropriate standardization is not in place at the right time. Significant steps have been made in this direction especially in the area of V2V and V2I communications, but

the automated driving concepts are much more numerous and with complex implications. A more concrete standardization program will certainly help the industry, the regulators, and the road infrastructure owners to take the right decisions in due time and avoid thereby undesired costs introduced by uncertainties in their business models.

- 4) There are some missing links in the technology areas as well, although the world is moving toward filling the technology gaps along various roadmaps. Advanced automated driving will require more accurate global positioning of the vehicle along its path. A few solutions are known to become available, such as better satellite systems meant for public use. Other solutions come from better in-car sensors, better algorithms, faster electronic control units, etc. However, it has become a fact that electronic components exhibits much lower development cycles compared to the renewability cycles in the conventional automotive industry. This inconsistency may lead to serious problems during the exploitation time of the vehicle and has even the potential to create completely undesired situations if the vehicle as a system is not sufficiently protected against tampering. It is, hence, the task of the industry to cooperate seriously toward defining as soon as possible the technical in-vehicle environment that should remain safe under all circumstances.
- 5) Looking from another standpoint to the technical part of automated driving, it is the task of the regulators to already address any potential dangerous situation caused by vehicles failing to behave as in theory or by on-purpose breaching into the vehicle electronics. The legislators should embrace now the challenge of preparing in due time an adequate legislative framework that covers maybe more complex issues than liability alone, while allowing for sufficient innovation freedom to enable new technical developments and business models.

It seems appropriate to end this summary with a few remarks not directly related to the subject of this report, but worth in the process of thinking about automated driving, cooperative driving, and autonomous driving. The progress in the human history has systematically taken the path of the shortest resistance and has often bypassed governmental rules, business models, and the obvious thinking. At the end of the 1990s nobody was anticipating the prominent role the smart phone would have in 10 years, but scientists were busy planning journeys to Mars within the same timeframe. The latter has not happened and will probably not happen soon... One lesson humanity has learnt during its existence is that historical changes that followed the path of the minimum resistance triggered at a later stage fundamental changes in the society. *"A car is a car"* like David Strickland, administrator of the National Highway Traffic Safety Administration (NHTSA) in the U.S. said in his speech at the Telematics Update conference in Detroit, June 2011, but it may drive soon its progress along a historical path of minimum resistance.

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# 1 Introduction

This report describes the study results of the SMART 64 project. This study focuses on the identification of necessary vehicle and infrastructure systems for Automated Driving. First, the objective of the project and relevant definitions are given. This is followed by possible mobility scenarios for 2025 which are used as focus for the project.

## 1.1 Objectives and definitions

The tender objective, issued by the EC, DG INFSO, describes a list of aspects and questions to be addressed. The project consortium decided also to add human driver interaction, as this is seen as crucial for the successful deployment of automated driving systems. In addressing the 11 aspects, an overview of the current and possible future situation in the field of automated driving is given, together with key players and their roles. In the end, the study should lead to the identification of possible deployment strategies for automated driving.

The aspects addressed in the SMART 64 study are:

1. State-of-the-art
2. Vienna Convention
3. Liability
4. Reliability
5. Control units
6. X-by-wire/actuation
7. Sensor systems
8. Positioning and applications
9. (Potential) key players
10. Cross border driving/Standards
11. Human driver interaction

Automated driving, autonomous driving and cooperative driving are terms which are broadly used, however with a variety of different meanings. The same holds for automatic driving, often used instead of autonomous driving, and semi-automatic driving. Based on discussions within the project team, and with the project officers, the following definitions are agreed upon for the use within SMART 64.

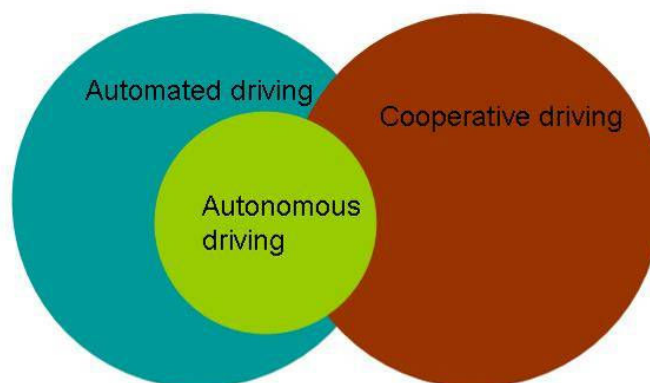


Figure 1: Areas and overlap for three types of driving

*Automated driving:* Driving enhanced by dedicated control, existing of autonomous (sub)systems that support the driver, while he/she is in control or able to timely get back in control and which is legally responsible throughout for carrying out the driving task. Automated systems can operate continuously (for example steer-by-wire) or can operate at specific moments when dedicated interventions become necessary (e.g. parking assist). Automation can cover a wide spectrum, from relatively weak support to highly automated driving.

*Autonomous driving:* The extreme end result of automated driving. In principle, no human driver needs to be active in operating the vehicle, although a driver can still be, but does not need to be in place. Autonomous driving is the extreme version of automated driving. This is out of the scope of the SMART 64 project.

*Cooperative driving:* Addresses automotive and road traffic systems that make use of information and communication technologies (ICT), in conjunction with automated or non-automated driving vehicles. These technologies are used to exchange specific information between vehicles (vehicle-to-vehicle communication, or V2V) and between vehicles and road infrastructure (V2I). ICT gives vehicles an additional input level that enhances their ability to make intelligent manoeuvre in traffic regardless of their level of automation; see also Figure 1.

In the above definitions, the word “vehicle” is chosen well-thought. The SMART 64 study looks into automated driving for passenger cars, public transport and also freight.

## 1.2 Scenario definitions for 2025

SMART 64 addresses the future of automated driving, with a timeline up to 2025. In searching for actions necessary to come to a proper and working deployment of systems and technology, it is essential to work with some realistic scenarios for 2025. This includes traffic environments, as sketched below. These can coexist but can also merge into more complex scenarios.

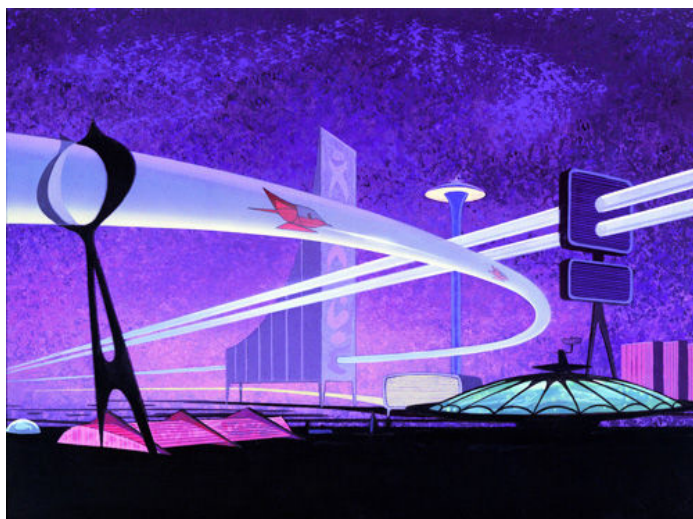


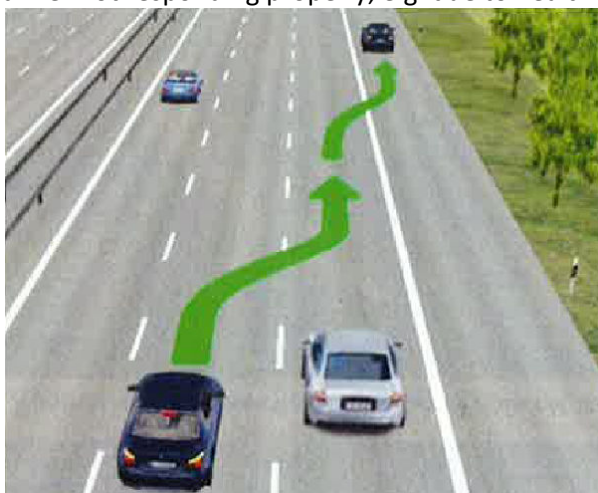
Figure 2: Mobility beyond 2025

Three basic scenarios are foreseen:

1. active government (section 1.3);
2. active private sector (section 1.4);
3. disruptive developments (section 1.5).

Within these scenarios, 3 typical traffic environments are identified in which Automated Driving can play a role. The possible environments for 2025 are described below:

1. **Mixed traffic on highways** (automated driving vehicles mixed with conventional vehicles on multi-lane highways). Applications include:
  - a. Safety pull over; a system that automatically takes over control, pulls over and stops the vehicle in a controlled and safe way, for instance, in the case of a driver not responding properly, e.g. due to health issues.

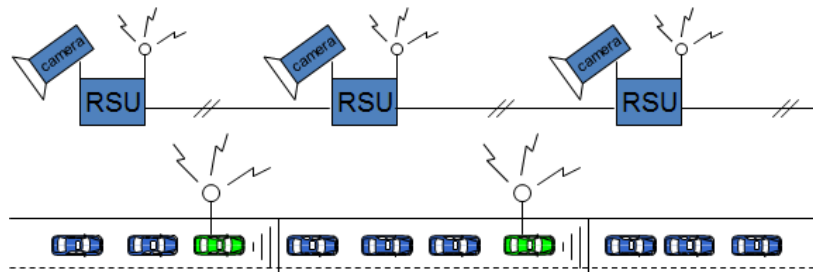


**Figure 3: Safety pull-over assistance, as experimentally tested by BMW under the name Emergency Stop Assistant**

- b. Automated lane keeping; a system to control the vehicle's lateral position towards the middle of a lane by applying gentle steering actions.
- c. Steering assist in case of e.g. road blocks; where very narrow lanes make driving challenging while maintaining a high throughput.
- d. Platooning by means of CACC (Cooperative Adaptive Cruise Control); a system that automatically adapts the vehicle's velocity to that of the surrounding vehicles in order to improve the traffic throughput and dissolve so-called shockwaves<sup>1</sup> in a safe way. There are several variations of platooning, with or without the use of a back office. Intermediate systems can be based on the use of Road Side Units (Russ, see Figure 4), which e.g. send a desired velocity profile to vehicles in order to improve traffic throughput.
- e. Active hazard detection around the vehicle; including pedestrian detection, complemented with collision warning and active hazard braking; a system that scans the surrounding area of the vehicle up to several tens of meters and automatically manoeuvres and brings the vehicle to a safe stop in case of imminent accidents.

<sup>1</sup> Shockwaves are disturbances which are caused by e.g. a braking action and which are enlarged by the upcoming traffic.

- f. Lane merging assistance; also for vehicles using the entry ramps which need to merge with the high-speed traffic already on the highway.
- g. Driver warning in case of drowsiness etc. that are used for and adjustment of the level of automation to the driver state.



**Figure 4: Mixed traffic in platoons, as experimentally tested during the SPITS project in The Netherlands**

2. **Mixed traffic in urban environments** (automated driving mixed with normal vehicles). Applications:
  - a. Emergency braking for vulnerable road users (VRUs); a system that automatically brakes in case a collision with another road participant. On-board sensors allow for sensing and prediction of trajectories of VRUs. See Figure 5.



**Figure 5: Pedestrian detection, as experimentally tested at Daimler Research**

- b. Parking: automated parking and parking spot reservations; automated guidance to the nearest parking spot at a given destination.
  - c. Contextual speed limit; a system which sets the optimal speed in a vehicle for safety reasons or in order to improve traffic throughput (e.g. also for crossings/traffic lights).
3. **Dedicated lane** (also referred to as Automated Highway Systems); a lane (possibly only temporarily in use) with additional infrastructure/sensors added to increase the reliability of Advanced Driver Assistant Systems (ADAS). On this lane only automated driving vehicles are allowed. Applications:
  - a. CACC, also based on sensors within infrastructure
  - b. Lane keeping
  - c. Road pricing possibilities to support desired (clean, efficient, safe) driving behaviour use of automated systems.
  - d. Fuel use optimization

These environments are summarized in Figure 6. The gray boxes are systems which do not contain an automated system on board of the vehicle which takes over one (or more) tasks of the driver. So the complexity of automation does not apply for these systems.

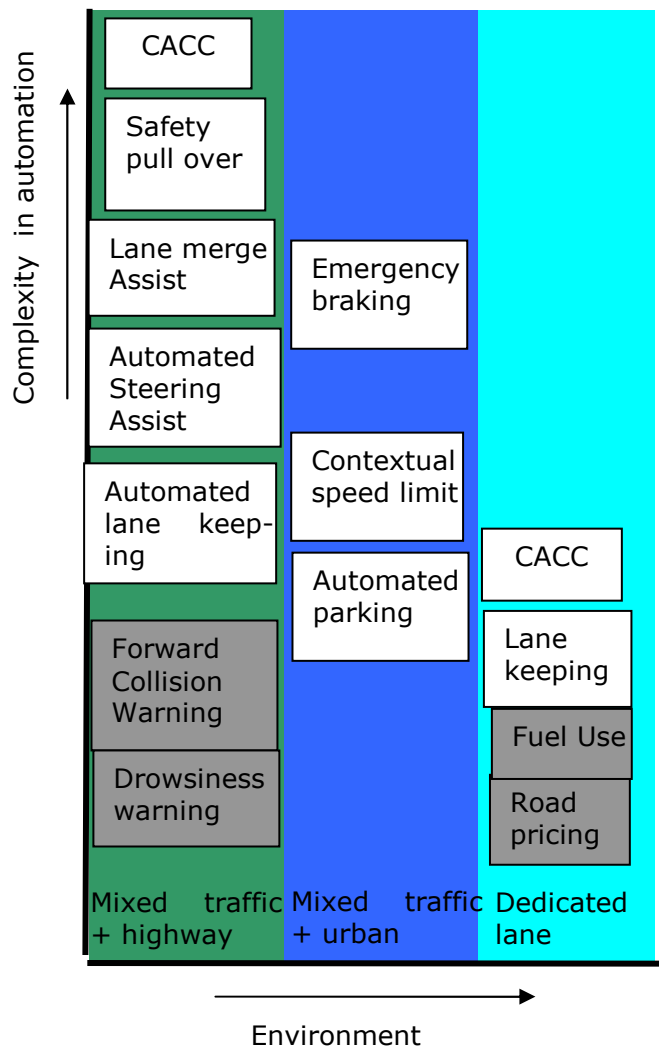


Figure 6: Focus applications with different traffic environments and complexity

### 1.3 Active government scenario

This scenario describes the situation in which governments play a very active role in the stimulation of automated driving. This scenario could be used in case manufacturers remain hesitant to deploy automated systems, whereas governments acknowledge their benefits. The section starts by discussing these benefits. After that, the possible roles and actions of the governments are explained.

#### 1.3.1 Benefits: drivers for governments

Governments can be divided into different levels that relate to the environments defined in section 1.2:

- Municipality responsible for urban traffic. (mixed urban)

- National or regional governments responsible for a traffic network that includes highways (mixed highways and dedicated lanes)
- European government responsible for the Trans-European Transport Network, known as TEN-T. (mixed highways and dedicated lanes)

These governments are usually responsible for both the roadside infrastructure operator and the organization responsible for socio-economic development within their region. The benefits of improved mobility systems can be summarized as follows:

- Traffic management, i.e. the responsibilities as a road operator
  - Reduce congestion / improve traffic efficiency, to reduce infrastructure costs
  - Improve safety / reduce accidents: both a decrease in medical and infrastructure costs and congestion
  - Reduce emissions (CO<sub>2</sub> but also other nuisances like sound levels)
- Reliable connection to key locations to enable economic growth. Specific infrastructure like a dedicated lane might be a way to ensure a good connection to a specific area, e.g. a business park or an industrial area.
- Stimulate innovation, to increase employment and create economic impact (e.g. create market leaders)

**Table 1: Examples of benefits for traffic management**

Examples of benefits from automated systems	Congestion	Safety	Emissions
Optimizing the road usage, e.g. by minimizing the headways (distance to vehicles in front) and minimizing brake actions that lead to shockwaves.	X	X	X
Limit the number and severity of accidents	X	X	
Better “behavior” of vehicles with uncertain drivers	X	X	
Parking assist	X	X	
Lane change assist	X	X	
CACC / platoon with short inter vehicle distances	X		X

Table 1 gives several examples of the benefits of automated systems for traffic management (on congestion, safety and emissions). For each of the examples listed in the table it seems that the merits of automated systems will only be evident when the systems become highly automated and when the penetration of these systems is deployed to a large extent. Of course, these remarks hold for cooperative systems as well. However, when cooperative systems become more and more widely deployed, the merits of automated systems could become less obvious. This especially holds when the envisioned connected car services becomes available. Consider rerouting as a means to prevent congested areas, road works warning, traffic jam warnings and so on. In that case, the additional benefits of an automated over cooperative systems decreases. However, with cooperative warning applications it is still the driver that remains the weakest link, which can be overcome by means of automation.

However, as stated earlier, governments are not only a roadside operator but also have socio-economic interests. Even if the benefits on traffic management are marginal, governments may nevertheless wish to stimulate automated systems because of other benefits that are more related to (socio)economic growth. For example, on an European level a reliable connection to key locations ensures that important European regions remain reach-



able, e.g. main logistic sites like airports and harbors and the TEN-T. Automated systems could help to better manage traffic in these situations. Innovation is another potential benefit that could help to stimulate European companies to become world market leaders.

### 1.3.2 Means: actions to stimulate

Governments typically have a variety of different ways to stimulate desired technology developments, as indicated in Figure 7. These include:

- Funding
  - Direct investment
  - Stimulate with economic means, e.g. tax incentives
- Facilitation
  - Help manage liability issues, e.g. via an insurance fund
  - Legal adjustments
  - Political commitment
  - User acceptance
  - Evidence of benefits (e.g. via studies)
- Technical involvement
  - Provide piloting grounds (e.g. via infrastructure)
  - Provide a common roadmap
  - Stimulate standards
- Roadside infrastructure adjustments

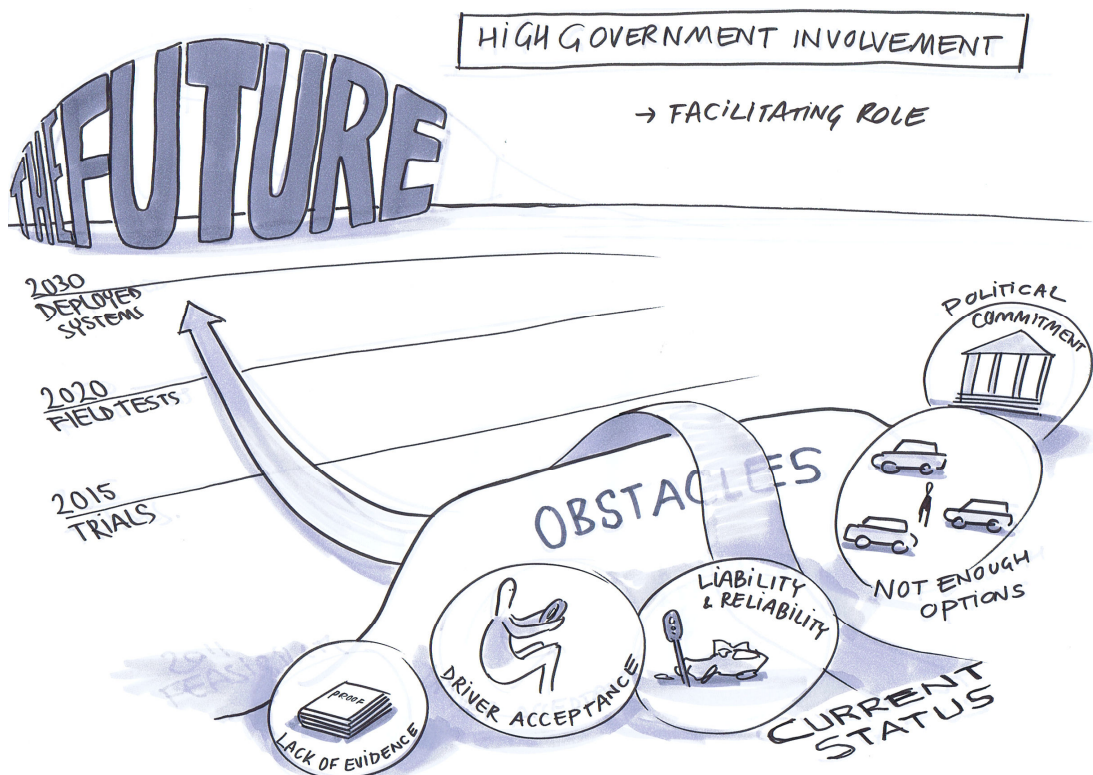


Figure 7: Facilitating role of governments

A special remark needs to be made with respect to liability. At the first stage of deployment, automated systems potentially have a high liability risk but a limited penetration.

That implies that the usual way of insurance, i.e. spread the risk over many users, does not apply. Governments could step in by e.g. introducing an insurance fund to prevent such a chicken-and-egg situation.

At the end of the day, the developed automated systems will operate in one of the three environments as defined in section 1.2. Therefore, this section elaborates what benefits and means an active government (in this case also a roadside operator) can have.

<b>Mixed highway</b>	
Goal	Network optimization
Issues	Traffic disturbances of entries, exits, lane changes and capacity
Applications	Platooning, merge assistant, lane change assistance, emergency stop
Actions to stimulate	<ul style="list-style-type: none"> <li>• Equip own fleet (e.g. public transport)</li> <li>• Prioritize equipped vehicles <ul style="list-style-type: none"> <li>○ Limit access of other vehicles (on location or on timing, e.g. odd/even days)</li> <li>○ Stimulate alternatives, e.g. improve public transport or road pricing</li> </ul> </li> <li>• Stimulate equipped vehicles via e.g. tax deduction</li> <li>• Stimulate standards</li> <li>• Insurance fund</li> </ul>
<b>Mixed urban</b>	
Goal	Network optimization.
Issues	<ul style="list-style-type: none"> <li>• Parking spaces</li> <li>• Congestion (large cities typically consists of several layers of retail/commerce, single dwellings, families, shopping malls, cheaper family homes, industry etc.)</li> <li>• Vulnerable road user safety at intersections</li> </ul>
Actions to stimulate	<ul style="list-style-type: none"> <li>• Limit car ownership with the aim to limit the number of vehicles on roads/parking spaces and more single points of entry to stimulate to buy up-to-date vehicles.</li> <li>• Provide alternatives, like personal rapid transit (PRT), rental cars and bikes, multimodal transport, V2V/V2I (e.g. intersection safety)</li> <li>• New business models, e.g. monthly fee for usage of all transport solutions, combination of infotainment, e.g. discount on museum entry fees</li> </ul>
<b>Dedicated lane</b>	
Goal	Increase capacity and/or prioritize vehicles
Issues	<p>Congestion and throughput</p> <p>The incentive to build a new lane is the same as usual: to solve congestion problems where access is crucial, e.g. industrial areas (could initially be tailored to trucks). People tend to use more lanes when they are built. Therefore, access control is required to prevent this from happening.</p>
Actions to stimulate	<ul style="list-style-type: none"> <li>• Stimulate usage, since it requires constructing new infrastructure.</li> </ul>

- Tolling could be an option. People need to get accustomed to use it (compare with London experiences). An additional role of governments is to ensure correct communication of travel times, since a pitfall of many normal toll operators is that they take a benefit in attracting people by providing incorrect information.

### 1.3.3 Conclusion

At first glance, from the perspective of a government (which differs from car manufacturers), the direct benefit to governments as roadside operators seems quite limited, especially when the potential is compared against cooperative systems (the connected car). However, traffic management could be an incentive to stimulate the introduction of automated systems, for example, to keep vital areas, i.e. key economic locations, reachable. Governments can also have other incentives to stimulate these developments, e.g. to stimulate economic growth by innovation.

On the other hand, governments have a variety of means to stimulate the development of automated systems, for example via funding, facilitation and other ways. Again traffic management could play an important role, e.g. via access control.

Translated to the three environments as presented in Section 1.2, the dedicated lane has the most direct link to automated systems. On the mixed highway, equipped vehicles can be prioritized, such as heavy duty trucks in road trains with platooning systems at key highway sections. For the mixed urban situation, an interesting idea is how to stimulate new business models to limit the car ownership.

## 1.4 Active private sector scenario

Besides an active government scenario, one could foresee a scenario in which governments play a relatively passive role and the deployment needs to be accelerated by the private sector. This means that not only the automotive industry, the automotive supplying industry, but also different type of key players as mentioned in Section 11.2, such as service providers, navigation system suppliers, telecom and insurance companies need to play a role.

The ideal situation is when both the public and private sector take an active role to accelerate the deployment of automated driving. Regardless of the role of the public sector, whether it be passive or active, technological developments need to come from the key players in the private sector and these will only happen when detailed business models are in place. This section describes the benefits for the private sector and the issues that typically should be under consideration by an active private sector, in order to speed up the deployment of automated driving.

### 1.4.1 Benefits: drivers for the private sector

Compared to the public sector, the motivation for the private sector is relatively clear: to have a concrete economic benefit, such as more market share, cost reduction, increased profit, etc. Depending on the size and role of the (key)players in the value chain of auto-

ated driving technology, in the end a business model is required in which all parties of the value chain receive benefits. This value chain includes the end user: the driver. In fact the driver is the most important player in the chain: he or she needs to buy the vehicle that supports automated driving because of direct benefits: safety, comfort, less fuel consumption, decreased (vehicle) insurance costs, etc. It is up to the (key) players to find the business models that are economically feasible and attractive for all the players within the chain. As stated above, it is clear that these players are not the traditional players within the automotive sector. Because of this, new types of agreements and business models and strategies will arise.

### 1.4.2 Means: actions to stimulate

The difference between a passive and active private sector lies in the role the private sector can take with respect to the non-technological issues such as legislation, standardisation and homologation, but also training of people that have bought the vehicles that allow for automated driving. The most challenging issue for the private sector is to find applications that bring value to all the players involved, from OEM and supplier, to e.g. fleet owner, insurance company and end user. Then, a quick uptake will happen and significant penetration rates of automated driving vehicles will arise. Besides the individual benefit of increased safety and fuel efficient driving, a significant penetration rate of automated driving vehicles will increase the overall benefit of traffic congestion reduction, reduced emissions and traffic safety.

To come to fast deployment of automated driving, an active private sector will be seriously involved in:

- Defining and adapting to new legislation (including standardization)
- Aligning with Societal and Political needs (traffic and vehicle safety, data privacy, training)
- Quantifying economical benefits (from the viewpoint of different stakeholders, players in the chain)
- Speeding up technological developments (reliable and affordable)

By means of working groups, task forces, etc. in which the different private (key) players are gathered and share each others viewpoint on an international level. Below these 4 aspects are described in more detail:

#### Legislation

An automated driving systems needs to meet the Vienna Convention (see Section 3, aspect 2). The private sector, especially those who are in the end responsible for the performance of the vehicle, should be involved in the discussion.

Regardless of the degree of automation, automated driving must be safe and comfortable. This requires reliable sensor, control and actuation systems, both from a hardware and software point of view. Standardization (for instance within ISO) of e.g. development and manufacturing processes of hardware and software for automated driving systems is needed, due to high complexity of interaction. One could imagine that homologation of these complete systems is required: OEMs and suppliers (in a broad sense) should be involved to come to the right procedures.

**Societal and political needs**

An automated driving vehicle can be enhanced by a cooperative system, which means to have the possibility to communicate with other vehicles (V2V) and/or to infrastructure (V2I). Another example is the black box in some vehicles, this stores vehicle performance data under specific conditions. Privacy is in both cases a key issue that needs to be taken into account.

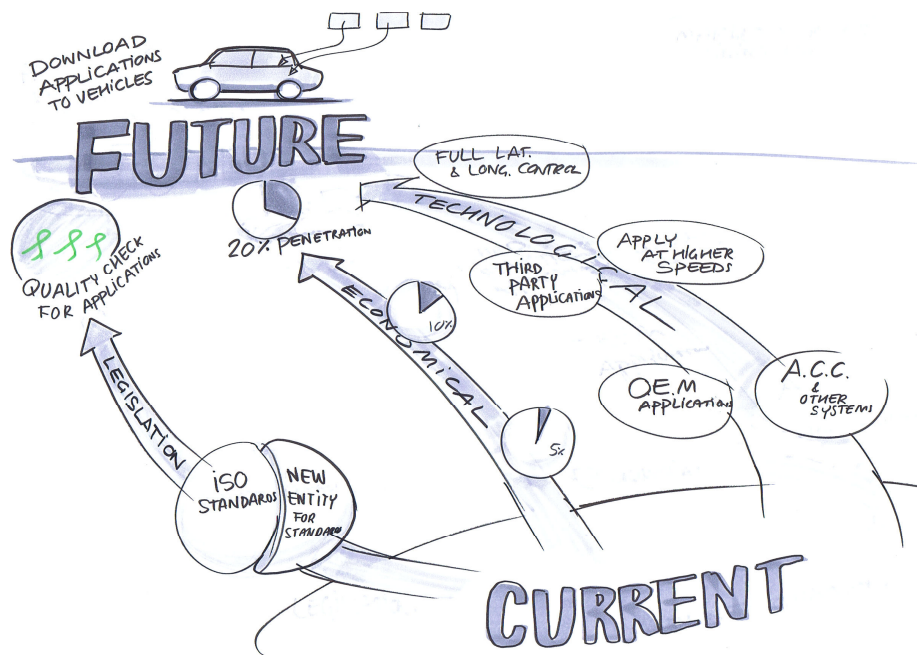
Training of people that use the systems, starting at driving schools, where active support, explanation of how to use the system, is necessary to allow for safe use of automated driving. A logical role lies with the OEMs to teach the driver on how to use the system in the correct way, the moment a vehicle is bought.

**Economical benefits**

An important question is, at which penetration level (percentage of vehicles), can the individual (mostly safety and comfort related) applications be extended to applications in which a complete traffic system or network can benefit directly from the existence of automated driving vehicles as part of the complete fleet? The role of the private sector is to find ways to come to shared business models, that go beyond the interest of, for instance, a single OEM or fleet owner. A typical example is platooning of trucks. This enables significant fuel consumption (individual benefit) and effective use of the road capacity (shared benefit). Since fuel consumption is dependent on the position in the platoon, it should be decided who drives in which position/how to share benefits?

**Technological developments**

Longitudinal support of the driver while driving already exists. It is known as A.C.C. (Adaptive Cruise Control). Active steering (when leaving the lane unintentionally) is an example of lateral support. This is another example of automated driving. A likely path is that longitudinal and lateral support (and actuation) will be increasingly integrated in the future, working at both high speeds or very low speeds (e.g. during a traffic jam). The role of the private sector is to find ways to make the automated driving systems both (highly) reliable and affordable at the same time. The benefit for the end user should be the cost of the system. The fact that customers want value for money, is not different for an active private sector scenario versus an active government scenario. However, at an early stage, subsidies from an active government to reduce the cost of an automated driving vehicle, with specific functionality that support the societal (shared) benefits (as happens with electric vehicles currently, e.g. in the Netherlands) could accelerate the process of getting a significant penetration rate in a relatively short time-scale.



**Figure 8: Deployment driven by the private sector**

In comparison to the active government scenario, the private sector scenario focuses on development of vehicles with automated driving systems. These must perform under all conditions and in all environments. It is not likely that the private sector, including all major vehicle OEMs would develop automated driving systems that, in the end, are heavily dependent on road infrastructure.

### 1.4.3 Conclusion

The direct benefit of the private sector totally depends on the business model, but it is clear that the end user needs to have a direct, concrete benefit, to allow for a fast uptake of the technology and to come to significant deployment. Besides the end user, all other members of the value chain must gain a certain benefit in the end. The different (key)players in the private sector need to combine their forces to overcome the non-technological hurdles.

## 1.5 Disruptive developments

Imagine that developments will not evolve in a step by step process, but instead disruptive developments in combination with new business models occur as happened with the introduction of e.g. the smart phones and downloadable Apps and services.

Such a disruptive development could be an artificially intelligent car. This car would be able to drive in fully autonomous mode in mixed traffic situations but could also be driven (manually) by a driver. The technical equipment of the vehicle could allow new features and interaction, e.g. the driver could call the vehicle and the vehicle drives on its own from the parking lot to the requested address. Or the vehicle could transport freight or passengers to a predefined destination without the need for a driver. This artificially intelligent car requires working on a platform, on which all kinds of services and applications could be implemented. The artificially intelligent car could be a vehicle that is not privately owned. Is

this all science fiction and can the majority of the people get rid of the idea that we have to own a car?

This study is not about autonomous vehicles (see definition in section 1.1) and does not assume disruptive developments technologically seen, from a legislative point of view or business wise. However, it is important to be aware that some of the developments may and will go much faster than expected. These developments are not expected from the automotive sector only, on the contrary, it is more logical that new key players will take the lead.

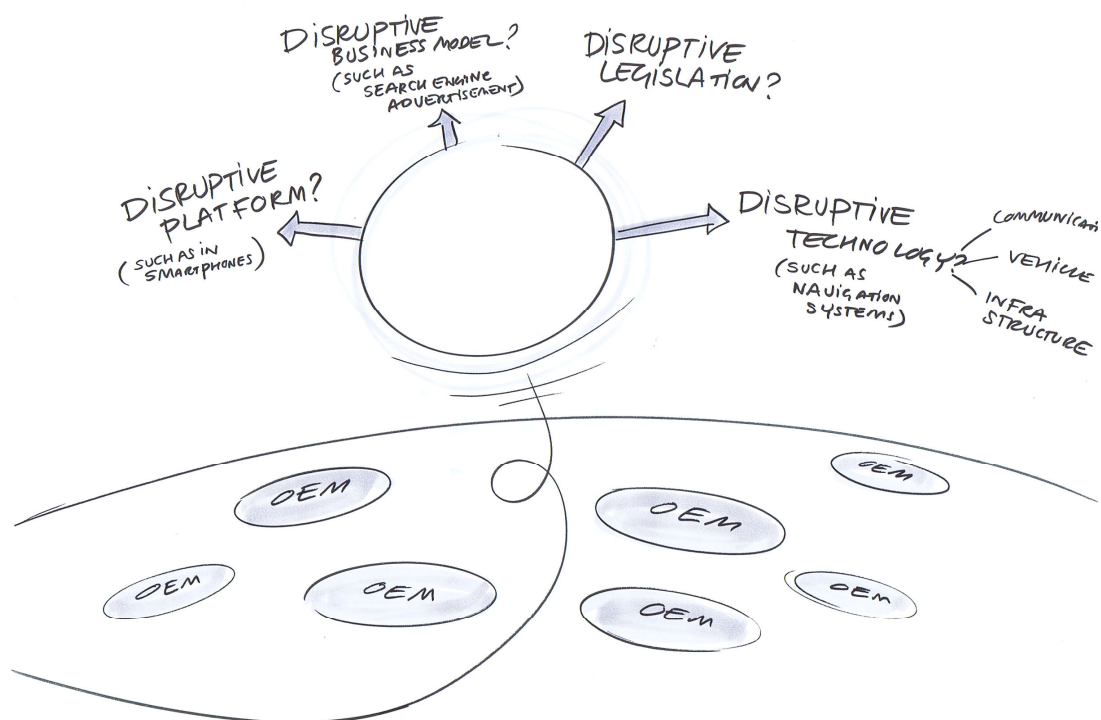


Figure 9: Disruptive models, potentially creating new possibilities and markets

## 2 State-of-the-Art

When considering the future routes for broad deployment of automated driving, it is important to know and understand the current starting point. This section addresses the activities shown in recent and running relevant projects, products on the market and the latest technological developments. A brief overview of technological hiccups that must be overcome to speed up the deployment process is included, as well as the state-of-the-art on infrastructure systems.

### 2.1 List of relevant projects

In the field of (semi)automated driving, a lot of recent work is being done worldwide. The list below shows the most relevant projects, not older than before the year 2000. These projects include national projects, Europe-wide projects and also projects on other continents.

- **HAVEit**, Highly Automated Vehicles for Intelligent Transport - aims at a higher level of automation to be used on existing public roads in mixed traffic [1].



- **Interactive**, this project aims to take the next step towards the goal of accident-free traffic and develops advanced driver assistance systems for safer and more efficient driving [2].



- **CityMobil**, a major research, development and demonstration project (2006-2011) that addresses the integration of automated transport systems in the urban environment [3]. CityMobil is a 5-year Integrated Project in FP7 supported by DG Research. The focus of the project is integration based on real-life implementations of the automated transport system on 3 test sites. The project has looked at guided buses in the Castellon demonstration, and Cybernetic Transport Systems in the demonstration of Personal Rapid Transit (PRT) at Heathrow airport, and of Group Rapid Transit (GRT) at the new Rome exhibition centre.



- **SAFESPOT**, creates dynamic cooperative networks where the vehicles and the road infrastructure communicate to share information gathered on-board and at the roadside to enhance the driver's perception of the vehicle surroundings with the purpose to create a safety margin in time or space [4].



- **COOPERS**, Cooperative Systems for Intelligent Road Safety, the goal of this project is to enhance road safety by direct and up-to-date traffic information communication between infrastructure and motorized vehicles on a motorway section [5].

The main objective of the project was to demonstrate I2V cooperative systems for



improving safety. During the project, 12 services were defined for motorway applications based on wireless and in-vehicle information including hazard warning, intelligent speed adaptation, road charging and dynamic route guidance.

- **PreVENT**, contributed to road safety by developing and demonstrating preventive safety applications and technologies, also one of the largest Integrated Projects in FP6 on road transport issues [6].



- **CVIS**, Cooperative Infrastructure Vehicle-Infrastructure Systems (2006-2010), aims to create/enable open architecture and open application framework for communication between vehicles and infrastructure [7].



- **(Pre)DRIVE C2X**, prepares a large-scale field trial for vehicular communication technology [8].
- **NETMOBIL**, (2003-2005), funded by EC; forerunner to CityMobil, was an EU FP6 DG Research sponsored cluster project supporting R&D and demonstration in innovative urban transportation systems, including projects: **CYBERCARS** and **CYBERMOVE** on automated road vehicles development and demonstration; **EDICT** on personal rapid transit; and **STARDUST** on Advanced Driver Assistance and Automated Guidance systems.

The objectives of NETMOBIL were to exploit the collective expertise and learning from the projects by disseminating the results to a wide audience including government, industry, commerce, interest groups and experts from other areas, and engaging them in the debate to determine the way ahead with respect to exploitation and deployment and, hence, to sustainable transportation systems for the future,



**CyberMove**, the aim is to create a new transportation option for city authorities to move towards sustainability and increase the attractiveness of city centres [9].

**CyberCars**, the main objective was to accelerate the development and the diffusion of a cybercar transport system by improving the performances and lowering costs [10]

- **DARPA Grand Challenge**, a competition to produce a vehicle that could autonomously navigate and reach a target in the desert of south western USA [11]. The third competition of the DARPA Grand Challenge (- prize competition for driverless vehicles, funded by the Defense Advanced Research Projects Agency, US.) was held in November 2007. Initially 53 teams qualified, but after a series of qualifying rounds, only eleven teams entered the final race. Of these, six teams completed navigating through the non-populated urban environment, and the Carnegie Mellon University team won.
- **Intersafe-2**, (2008-2011) aims to develop and demonstrate a cooperative Intersection Safety System that is able to significantly reduce injury and fatal accidents at intersections [12].
- **SARTRE**, Safe Road Trains for the Environment (2009-2012) aims to develop strategies and technologies to allow vehicle platoons to operate on normal public highways (where the following vehicles (cars and trucks) operate in dual-mode (fully autonomous within the platoon) with significant environmental, safety and comfort benefits. The project runs until 2012 [13].
- **Chauffeur**, within this project, new electronic systems for coupling trucks at close following distances are developed [14].



- **S.I.P.Si.Vi**, development of a perception system able to record the driver performance during driving tests under the influence of drugs, alcohol, medicines [15].
- **Google driverless car**, with a test fleet of autonomous vehicles that by October 2010 have driven 140,000 miles (230,000 km) without any incidents [16]
- **GCDC**, (Grand Cooperative Driving Challenge) aims at accelerating the development and implementation of cooperative driving technologies, by means of a competition between international teams [17].
- **SPITS**, (Strategic Platform for Intelligent Traffic Systems) aim is to create an open Intelligent Traffic Systems platform that can improve mobility and safety [18].
- **EuroFOT**, a suite of Field Operational Tests with the aim of assessing the main Advanced Driver Assistance Systems (ADAS) that have recently appeared on the European market [19].
- **Aktiv**, (Adaptive and Cooperative Technologies for the Intelligent Traffic) a large German project on active systems, in which many industrial parties are heavily involved. In total, there are 29 partners. The project has as major objective application oriented research work for active safety. The project consists of three pillars: Aktiv Traffic Management, Aktiv Active Safety and Aktiv Cooperative Cars [20].
- **INVENT**, intelligent traffic and user-friendly technology, develops and investigates solutions that will make traffic safer and more efficient [21].
- **ASV-3**, 3rd phase Advanced Safety Vehicle project, focuses on technologies that improve safety by coordinating a vehicle's movement with those around it [22].
- **Smartway**, development of a road system that allows the exchange of various types of information among cars, drivers, pedestrians, and other users [23].
- **KONVOI**, German project that aims at realizing and analysing the use of electronically regulated truck convoys on the road [24].
- **NICHES+**, 2008-2011. FP7 DG RES Support Action project due to end in April 2011, more broadly based and aimed at identifying promising niche applications in transport and promoting them to a wider audience. One of 4 work areas is concerned with 'automated and space efficient' transport systems, and within this P/GRT systems have been identified as worth promoting. The project has produced Guidelines for implementers of G and PRT systems and also for using electric vehicles in car share clubs [25].
- **Foot-LITE**, (2007-2011) funded by EPSRC/DFT - aims to deliver innovative driver/vehicle interface systems and services to encourage sustained changes to driving styles and behaviour which are safer, reduce congestion, enhance sustainability, help reduce traffic pollution emissions, and reduce other social and environmental impacts. Fundamental research is being used to support the strong industry base in the project [26].
- **NEARCTIS**, (2008-2011) funded by EC - NEARCTIS draws together expertise within Europe and establishes a working network for the research and development needs of cooperative traffic management systems (i.e. those involving communications between vehicles and the infrastructure) [27].
- **STARDUST**, (2001-2004) funded by EC - The objective of this project is to assess the extent to which ADAS (Advanced Driver Assistance Systems) and AVG (Automated Vehicle Guidance) systems can contribute to a sustainable urban development. During the project, user needs, potential impacts, and liability issues were focused using



methods such as SP surveys, simulation, and Instrumented Vehicle test. Potential impact of running Stop&Go on urban roads was investigated, [28].

- **Isi-PADAS**, is a European project of FP 7 working to provide innovative methodologies to support risk based design and approval of Partially Autonomous Driver Assistance System (PADAS) focusing on elimination and mitigation of driver errors by an Integrated Driver-Vehicle-Environment modelling approach [29].

Other relevant organisations/labs/challenges/networks:

- **Eltis**, (European Local Transport Information Services) focus lies on automated driving in city traffic [30].
- **Stanford's and VW Electronics Research Lab's Robot Car AUDI TTS "Shelly"**. Autonomous car able to drive at speeds resembling race speeds. No obstacle detection sensors, only GPS based for positioning [31].
- **VisLab Intercontinental Autonomous Challenge (VIAC)** is the challenge organized by VisLab and Overland Network for autonomous vehicles. It ran from July 20, 2010 to October 28, 2010, involving four driverless vehicles driving with minimum human intervention on a 20,000 km trip from Milan (Italy) to Shanghai (China). The ARGO vehicle is the predecessor of the BRAiVE vehicle, both from the University of Parma's VisLab. Argo was developed in 1996 and demonstrated to the world in 1998; BRAiVE was developed in 2008 and firstly demonstrated in 2009 at the IEEE IV conference in Xi'an, China [32].
- **The VW Golf GTI 53+1** is a modified Volkswagen Golf GTI capable of autonomous driving. The Golf GTI 53+1 features an implemented system that can be integrated into any car. This system is based around the MicroAutoBox from dSpace [58], as it was intended to test VW hardware without a human driver (for consistent test results) [33].
- **The Audi TTS Pikes Peak** is a modified Audi TTS, working entirely on GPS, and thus without additional sensors. The car was designed by Burkhard Huhnke of Volkswagen Research [34].
- **Leoni** is a test vehicle of the University of Braunschweig that showed autonomous driving in the urban environment in autumn 2010 based on the work of the CarOLO team for the DARPA challenges [48].

## 2.2 Latest technological developments

The latest technological developments regarding automated driving vehicles are making intensive use of Advanced Driver Assistance Systems (ADAS). This is already in the market and has allowed transforming commercial vehicles into dual-mode vehicles that are able to drive automated at close range (platooning) or that are able to intervene at intersections or in hazardous situations (emergency braking, collision mitigation systems).

These systems are based on e.g.:

- sensor systems to 'sense' the surrounding environment and the performance of the vehicle in it;
- smart fusion of several sensors to enable a more comprehensive sense of the surroundings and to provide duplication so a failure of one sensor still enables a result;
- object/obstacle detection and recognition

A few examples of the latest technological developments which make use of the above mentioned aspects are:

- Obstacle avoidance (risk estimation):
  - i. Collision avoidance by braking;

## ii. Collision avoidance by braking and steering;

- Merge assist;
- Platooning;
- First attempts for realization and use of fully autonomous vehicles have been done, in various projects including, DARPA, Google, Vislab, Race car Audi TTS, CityMobil, etc., but the reliability of the systems of fully autonomous vehicles is not generally considered high enough to let them operate outside a segregated environment (such as the segregated track used by the Heathrow PRT system) circuit or without human supervision.

Also, recent progress has been made in driving assistance by means of augmented reality. An example of such technology is given in Figure 10 where advanced navigation systems are combined with head-up displays projected on the windscreen to indicate the correct path of the vehicle when approaching an intersection.



Figure 10: GPS navigation based on augmented reality and head-up display (source: cardesign-news.com)

Other recent technology developments that will enable automated driving in the future address the accurate positioning of vehicles by means of lane detection and GPS navigation (see Figure 11).

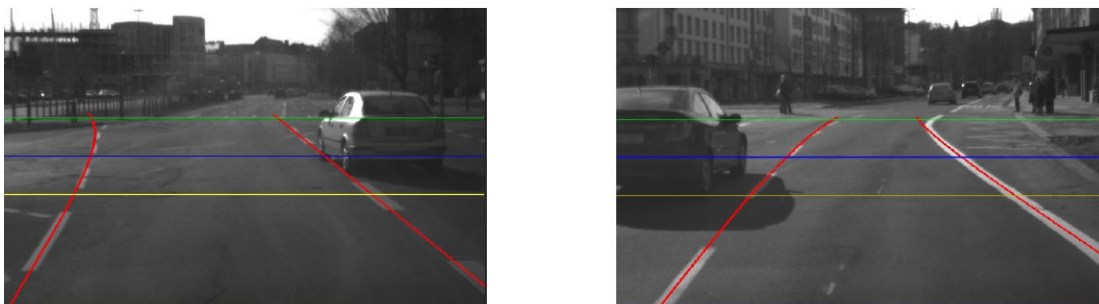


Figure 11: Advanced lane detection for lane positioning and GPS navigation (source: R. Schubert – Chemnitz University of Technology)

## 2.3 Products already on the market

Automated driving systems are already on the market, as well as warning based systems that do have mostly the same sensor function, but still require the driver for the actuation. Applications like ACC and safety braking, are typical examples of automated driving. Lane Departure Warning (LDW) and Lane Change Assistant (LCA) are typical warning based applications. Both types of applications use the following technologies that are needed to build automated driving technology:

- (High) accuracy positioning systems: GPS, DGPS, RTK;
- Long and short range radars;
- Laser scanners;
- Communication electronics;
- Artificial vision systems;
- Software and control algorithms.

Many of these sub-products are already on the market in several Active Driving Assistance Systems (ADAS):

- In the category **towards CACC** (including platooning):
  - Cruise Control and speed advice;
  - Adaptive cruise control adjusts the speed of the vehicle automatically, according to a pre-set condition (such as 1.5 seconds or 3 seconds headway) between you and the car ahead;
  - Start & stop Cruise Control is a system which automatically starts driving and stops in case of a traffic jam (for low velocities);
  - Active braking; under certain (mainly low speed urban) situations the car will brake at full force when an object or vulnerable road user is detected, preventing it from a collision.
- In the category **Warning systems**:
  - Lane Keeping Systems, these systems are mainly based on vision sensors which give a warning to the driver as soon as the vehicle tends to depart a lane;
  - Blind-spot warning, several current models use sensors to detect approaching vehicles. Most blind-spot warnings do not use an audible chime, which can distract the driver, but instead display a light near the side mirror, where the driver is supposed to be looking. Video cameras are mainly used to detect movement in the blind spot, but also ultrasonic sensors or radar can be used;
  - Driving advisor, a system that notifies drivers when they inadvertently stray too close to the edge of the lane [35];
  - Speed limit detection, video based sensor systems are used to scan road signs to find the current speed and these alert the driver if he is going too fast;
  - Collision Detection, several vehicle models become equipped with a collision detection and prevention system. For example, some vehicles which are already on the market will not only brake slightly if the car senses another car ahead, but will apply brakes in full force if an impact is imminent.
- In the category **Assisting systems**:

- Active Brake Assist is already on the market, this system includes a warning, active braking, and emergency braking if required [36];
- Lane Keeping Assistance Systems centre the vehicle in its lane in case of inadvertent lane departures, see [37] and [49];
- Parking aid system, an Active Park Assist feature uses a combination of robotics and driver assistance. An example of a parking aid system is described in [38];
- In the category **Informative systems** such as:
  - Strategic and dynamic route guidance;
- In the category **Autonomous** vehicle systems, from:
  - Freight transport in controlled environments, e.g. factory automation systems;
  - Passengers, i.e. public transport, in controlled environments (e.g. Heathrow PRT).

Some of these applications (e.g. road intersection safety applications) have already started merging the vehicle capabilities with infrastructure communication, making a step forward towards highly automated driving. At the moment, steering the vehicle on the road as well as acting in their mechanical functions in an autonomous way, providing safe results, is possible, but there is still a need for further effort to be invested in the development of detection electronics and algorithms that will allow the vehicle to detect and handle every obstacle on the road as well as a human driver would do ideally.

## 2.4 Hiccups in current technology

The hiccups in current technology needed to facilitate highly automated driving are:

- Common standards and protocols for vehicle and sensor performance and V2I or V2V communication are lacking, these should be clarified and solved at an early stage;
- The required sensors and electronic systems are expensive to develop and supply;
- The required infrastructure systems are not developed and will require legislation;
- ADAS features are slow to market when introduced as “differentiating” features and options by the vehicle manufacturers;
- Motion Planning is required to complement sensor, navigation and actuation technology developments;
- Reliability and safety in safety critical systems – although these are being addressed in the current implementations of PRT and GRT systems which (provided they do not run faster than 40kph) can be self-certified to meet railway systems specifications;
- Relevant machinery directives can also be used in some cases;
- False alarms with forward collision warning/avoidance, lane keeping systems, etc.;
- There is not much knowledge on thresholds, e.g. for what penetration level communicating systems must achieve in order to realise a true benefit for both the driver (individual benefit) and e.g. the overall safety and throughput (shared/collective benefit);
- The HMI (Human Machine Interface) differs from brand to brand, sometimes there are even large differences between the models of one brand. This potentially leads to large confusion especially for less experienced drivers, and to low acceptance levels. More work is needed on integration of the functionality of different ADAS to one common interaction design so that the driver can handle the vehicle in an easy

way and does not have to activate and deactivate several separate functionalities with different availability;

- Reliability of wireless communication (data collisions, packet loss);
- Object classification;
- International standardization;
- Cost-performance ratio of components;
- Complexity of on-board software;
- Acceptance by the public;
- In future: security.

Normally, current technology provides single applications, operating separately to allow a few automated driving actuations. However, the scenarios described in Section 1.2 require more technological challenges, such as reliable obstacle detection. Another potential barrier to the deployment of several applications (such as CACC) is that V2V and V2I communication systems are not reliable enough yet. Furthermore, there is the individual's data privacy and security to be guaranteed. Also, sophisticated sensor systems which are very reliable are currently very expensive, so they need to be replaced by cheaper sensors to reduce costs (challenging the reliability of these sensors). Filling these gaps and finding an integrated interaction concept would allow significant steps forward.

## 2.5 Readiness of current technology towards broad European deployment

From a technical perspective, current technology is ready for autonomous driving on separate segregated lanes in a controlled environment, see PRTs and GRTs. However, challenges exist for usage of fully automated vehicles or highly automated vehicles with a driver on board in mixed traffic.

The main challenge is not of a technological nature, but lies in other fields. One of these fields is the **relation between costs and reliability**. Many sub-systems are reliable, but at very high cost. The challenge is to use cheaper sub-systems in a smart way such that the same reliability can be achieved, see Section **Error! Reference source not found.** Also, as long as automated driving systems are not covered in internationally accepted standards, large scale deployment will remain difficult, see Section **Error! Reference source not found.** For highly automated driving systems there is the issue of responsibility. As long as a driver is in control of the vehicle the situation is covered by the present laws, but when an automated driving system takes over (part of the) control, it is not clear where the responsibility lies in case of an accident, see also Section 2.

Another challenge is in lowering the costs of the required highly accurate sensors. This could be done by using several low-cost sensors which are less accurate and combining the information from these sensors with smart algorithms to enable a more accurate estimate. The maturity of an evolving technology can be measured by a technology readiness level (TRL), starting from a level of 1 when the basic principals of a technology are reported to level 9 when the technology is on the market. This measure is used by some U.S. government agencies and many of the world's major companies. Table 2 shows the TRL for the automated driving applications as given in the scenarios in Section 1.2.

**Table 2: Technology readiness levels (TRL) for automated driving applications**

Application	Level	Description
1.a Safety pull over	3	Proof-of-concept validation

1.b. Automated lane keeping	9	Already on the market
1.c. Automated steering assist in case of road blocks	3	Proof-of-concept validation
1.d. Platooning by means of CACC	7	E.g. Sartre project [13]
1.e. Forward collision warning	9	Blind spot monitoring, collision warning systems are already on the market, e.g. [23].
1.f. Lane merge assist	7	In certain areas it is tested, e.g. [39].
1.g. Driver warning in case of drowsiness	9	Already on the market
2.a. Emergency braking for VRU	9	Already on the market
2.b. Automated parking and parking spot reservations	3	Automated parking is already on the market, but parking spot reservation is in the phase of proof-of-concept validation
2.c. Contextual speed limit	7	There is no system on the market yet which sets the speed of a vehicle based on communication of the infrastructure, but it is proven to be technically possible
3.a.CACC	7	E.g. Sartre project [13]
3.b. Lane Keeping	9	Already on the market
3.c. Road pricing	9	On the market; e.g. for many wanted parking places needs to be paid nowadays
3.d. Fuel use optimisation	9	On the market; e.g. a navigation system which calculates a route which saves fuel.

## 2.6 State-of-the-art on infrastructure systems

There are already developed and tested Road Side Units (RSU) that will be the most direct link between vehicles and infrastructure systems in a near future. They use the CALM (Communication Access for Land Mobiles) family of standards for continuous communication (ISO TC204 WG16). CALM supports various access technologies (e.g., cellular, satellite, microwave, mobile wireless broadband, infra-red, dedicated short range communication), which provide in a flexible way the most appropriate access technology for message delivery between vehicles and infrastructure.

Existing applications of V2I (Vehicle to Infrastructure) are based on GPS, Mobile Phone Signals and ANPR. Systems developed are mainly for tolling and enforcement applications.

PRT and GRT systems provide fully autonomous driving, but these are public transport systems and the vehicles effectively run on dedicated lanes (rather like trains, but not on railway lines). Note that the transits at airports and most modern metro systems built these days are fully automated. P/GRT systems use the same obstacle detection and sensor systems as used in ADAS for cars, and in addition require a vehicle location system and communication with a control centre.



**Figure 12: CVIS/Safespot infrastructure part**



When driving on roads, work in e.g. CityMobil and HAVEit has shown that highly automated driving is possible today, and with no need for active participation by roadside infrastructure except for a distinct and continuous means of delineating lanes. All that is necessary is Automated Cruise Control with a 'Stop & Go' capability for detecting and following the car in front i.e. platooning, and automated lane keeping for staying in lane (hence the requirement for continuous and distinct white line markings, although other means such as buried cables or magnets have been tried and have been shown to work as well). However specific infrastructure can increase the safety of the interplay between automation and the driver. For example, infrastructure could warn about situations that are not handled by the automated vehicle (e.g. road works, bad weather) to hand over the control to the driver in time.

A great deal of early US and European research has been undertaken on Automated Highway Systems (AHS) with cars running in dedicated lanes. However, dedicated lanes are not viable on cost grounds and automated vehicles will have to be mixed with manually driven vehicles, at least in the early days. *CityMobil has proposed specially designated eLanes that are certified for automated driving where automated and manually driven vehicles can co-exist (called open eLane compared to dedicated eLanes where only automated or autonomous vehicles are allowed)*. This solution seems more economically viable than dedicated for automated vehicles only.

In COOPERS, several road operator partners have demonstrated I2V communication systems on motorways for improving safety (e.g. hazard warning with in-vehicle information). Not only can such technology convey information/guidance from traffic control/operation centres, but also vehicle status data (e.g. location, speed, journey time, etc.) can be collected through floating vehicles for traffic monitoring and incident detection.

## 2.7 (Almost) Available infrastructure systems

The infrastructure systems available are mostly within the highways, for tolling purposes and information to drivers or more generally on every road type as speed detection systems (radars).

Systems developed for transits at airports and metros are available and proven. Newer systems developed for the GRTs in Rivium and Rome etc. and for the PRTs in Heathrow and Masdar are available but are very much in their infancy.

Systems currently available and widely used for traffic monitoring, control and management include:

- Video Monitoring Systems
- Video/cameras for traffic monitoring and journey time estimation
- Speed cameras
- Traffic detection (e.g. ILD, laser/radar/microwave)
- National/regional traffic control/information centre (e.g. UK NTCC)
- Urban Traffic Control systems, for controlling the traffic lights common in most major European cities
- Video/cameras for number plate reading (e.g. London congestion charging)
- I2V communication for toll collection
- Inference methods
- Cooperative information systems (e.g. floating car data)

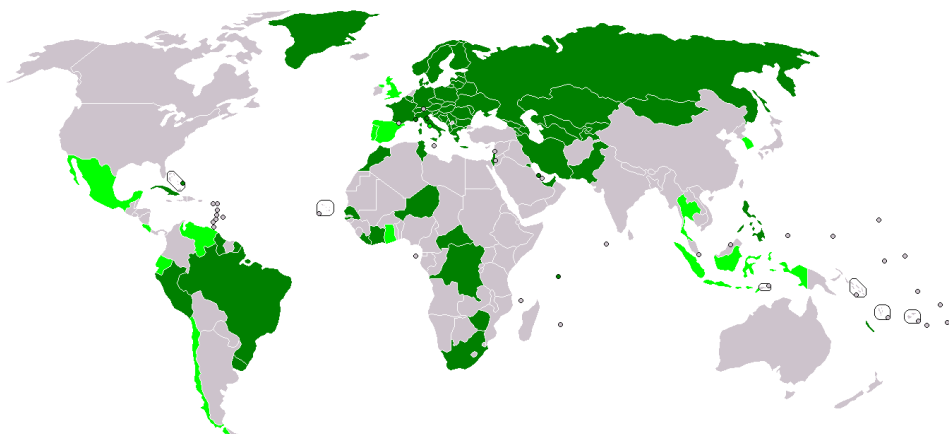
### 3 Aspect 2: Vienna Convention

The answers of this section are based on input from the SMART 64 expert panel. As no juridical expert is a member of the panel, the German BAST (Bundesanstalt für Straßenwesen) was contacted by members of the expert panel. The expert panel has been provided with relevant references regarding the topic. BAST leads the German working group on automated vehicles dealing with the Vienna Convention and German laws and regulations that might be a barrier for introducing automated vehicles in Germany. Due to strict non-disclosure agreements for this working group, information on the intermediate results of the group cannot be given at this stage. The final BAST report documenting the results is planned to be available in autumn 2011.

#### The Vienna Convention

There are several Vienna Conventions on different topics. The Vienna Convention that touches the introduction of automated vehicles is the **Vienna Convention on Road Traffic** [40].

The Vienna Convention on Road Traffic is an international treaty designed to facilitate international road traffic and to increase road safety by standardizing the uniform traffic rules among the contracting parties. This convention was agreed upon at the United Nations Economic and Social Council's Conference on Road Traffic (October 7, 1968 - November 8, 1968). It came into force on May 21 1977. Not all EU countries have ratified the treaty, see Figure 13 (e.g. Ireland, Spain and UK did not). It should be noted that in 1968, animals were still used for traction of vehicles and the concept of autonomous driving was considered to be science fiction. This is important when interpreting the text of the treaty: in a strict interpretation to the letter of the text, or interpretation of what is meant (at that time).



**Figure 13: Countries that ratified (dark green) or signed (light green) the Vienna Convention on Road Traffic [81].**

Articles that touch the introduction of automation in vehicles are:

#### Article 8: Drivers

- **ARTICLE 8.1:** "Every moving vehicle or combination of vehicles shall have a driver."
- **ARTICLE 8.5:** "Every driver shall at all times be able to control his vehicle or to guide his animals."

### Article 13: Speed and distance between vehicles

- **ARTICLE 13.1:** “Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him. He shall, when adjusting the speed of his vehicle, pay constant regard to the circumstances, in particular the lie of the land, the state of the road, the condition and load of his vehicle, the weather conditions and the density of traffic, so as to be able to stop his vehicle within his range of forward vision and short of any foreseeable obstruction. He shall slow down and if necessary stop whenever circumstances so require, and particularly when visibility is not good.”
- **ARTICLE 13.5:** “The driver of a vehicle moving behind another vehicle shall keep at a sufficient distance from that other vehicle to avoid collision if the vehicle in front should suddenly slow down or stop.”

### 3.1 Potential influence of the Vienna Convention on Road Traffic on the successful deployment of automated driving systems

The common opinion of the expert panel is that the **Vienna Convention will have only a limited effect on the successful deployment of automated driving systems** due to several reasons:

- OEMs already deal with the situation that some of the Advanced Driver Assistance Systems touch the Vienna Convention today. For example, they provide an on/off switch for ADAS or allow an overriding of the functions by the driver. They develop their ADAS in line with the RESPONSE Code of Practice (2009) [41] following the principle that the driver is in control and remains responsible. In addition, the OEMs have a careful marketing strategy and they do not exaggerate and do not claim that an ADAS is working in all driving situations or that there is a solution to “all” safety problems.
- Automation is not black and white, automated or not automated, but much more complex, involving many design dimensions. A helpful model of automation is to consider different levels of assistance and automation that can e.g. be organized on a 1d-scale [42]. Several levels could be within the Vienna Convention, while extreme levels are outside of today’s version of the Vienna Convention. For example, one partitioning could be to have levels of automation Manual, Assisted, Semi-Automated, Highly Automated, and Fully Automated driving, see Figure 14.



**Figure 14: Possible levels of assistance and automation in a highly automated vehicle**

In highly automated driving, the automation has the technical capabilities to drive almost autonomously, but the driver is still in the loop and able to take over control when it is necessary. Fully automated driving like PRT, where the driver is not re-

quired to monitor the automation and does not have the ability to take over control, seems not to be covered by the Vienna Convention.

Criteria for deciding if the automation is still in line with the Vienna Convention could be:

- the involvement of the driver in the driving task (vehicle control),
  - the involvement of the driver in monitoring the automation and the traffic environment,
  - the ability to take over control or to override the automation
- The Vienna Convention already contains openings, or is variable, or can be changed. It contains a certain variability regarding the autonomy in the means of transportation, e.g. “to control the vehicle **or guide the animals**”. It is obvious that some of the current technological developments were not foreseen by the authors of the Vienna Convention. Issues like platooning are not addressed. The Vienna Convention already contains in Annex 5 (chapter 4, exemptions) an opening to be investigated with appropriate legal expertise: “For domestic purposes, Contracting Parties may grant exemptions from the provisions of this Annex in respect of:
- (c) Vehicles used for experiments whose purpose is to keep up with technical progress and improve road safety;
  - (d) Vehicles of a special form or type, or which are used for particular purposes under special conditions”.
- In addition, the Vienna Convention can be changed. The last change was made in 2006. A new paragraph (paragraph 6) was added to Article 8 stating that the driver should minimize any activity other than driving.

### 3.2 Other conventions/legislation which need to be addressed

Besides the Vienna Convention there are a number of other topics in transport that are regulated in other treaties:

**National Traffic laws:** The Vienna Convention provides a framework for national road traffic regulations. In case of incidents there is no common European framework for the determination of the issue of guilt. Court decisions are made taking into account national aspects. The Court of Justice of the EU oversees the correct interpretation of national laws, and the correct application of EU laws in the EU Member States

**Liability issues:** Liability seems to be one of the most complex topics when bringing automated vehicles onto the market. As all existing legal and insurance protocols are based on the driver and/or the vehicle owner’s legal responsibility, a discussion on liability issues is necessary because some forms of automation might not be in line with the driver’s responsibility (e.g. in the case no overriding by the driver is possible).

There is a complex relationship between the different players for Cooperative Systems [Safespot deliverable 6.4.2, 43]. Liability issues deal with tort law (strict and fault liability) and contractual liability.

**UNECE Transport Agreements/and Conventions:** Apart from the Vienna Convention there are other agreements and conventions of the United Nations Economic Commission for Europe (UNECE) dealing with e.g. driver education/license, vehicle regulations or road markings. A quick scan on the scope does not indicate that there is a large impact to automated driving. There are relations identified such as driver education, road markings.

**Contractual law:** Contractual arrangements are likely to also address types of damage of a more commercial nature such as recall costs, business interruption and losses of sales. These types of damage may occur independent of indirect liability (through the mechanism of subrogation and right of resource) for the consequences of accidents related to the technical concept of the automated highway.

**Data protection and privacy issues:** As soon as data from the vehicle is used for V2X-communication or is stored in the vehicle itself, data protection and privacy issues become relevant. Directives and documents that need to be checked include:

- Directive 95/46/EC on the protection of individuals with regard to the processing of personal data and on the free movement of such data;
- Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport;
- WP 29 Working document on data protection and privacy implications in the eCall initiative and the European Data Protection Supervisor (EDPS) opinion on ITS Action Plan and Directive.

**Regulation on ITS:** The ITS directive (Directive 2010/40/EU) and the ITS Action Plan establish a common framework for acceleration and coordination of ITS deployment on roads including interfaces to other transport modes. The directive sets common priorities and addresses specifications and standards in the following areas:

1. Optimal Use of Road, Traffic and Travel Data;
2. Continuity of Traffic and Freight Management;
3. Road Safety and Security;
4. Linking Vehicle and Transport Infrastructure.

Regarding P/GRTs the following documents are relevant:

- Machinery directives for automated (e.g. factory) systems ◇ standard IEC61508;
- Self-certification of G/PRT systems as per railway regulations ◇ CENELEC EN50126;
- Railway applications – the specification and demonstration of Reliability, Availability, Maintainability and Safety.

### 3.3 Is there a gap in the current existing legislation?

Gap is interpreted here as bottleneck. The bottleneck is that at the current stage of development the risk related costs and benefits of viable deployment paths are unknown, combined with the fact that the deployment paths themselves are wide open because the possible deployment scenarios are not assessed and debated in a political environment. There is currently no consensus amongst stakeholders on which of the deployment scenarios proposed will eventually prevail. The positions (roles and responsibilities) of the players in the delivery of the service/product are therefore unclear. FOTs and large scale pilots will be

needed to provide the information and insight required for further deployment of the concept. These projects should also provide the information that is needed to understand the risks and the cost and benefits in order to be able to decide about the next steps in the deployment path.

Changes in EU legislation might change the role of players and increase the risk for them. Any change in EU legislation will change the position of the players, and uncertainty in which direction this change (gap) would go adds to the risk. This prohibits players from having an outspoken opinion on the issue. If an update of existing legislation is considered, this should be European legislation, not national legislation. It would be better to go for a world-wide harmonized legislation, when it is decided to take that path.

It is not clear what should be done if a vehicle has two interfering systems. Interference could be in systems technically affecting each other (e.g. an OEM system and a 1<sup>st</sup> Tier or 2<sup>nd</sup> Tier system), but a major concern is also in the potential for presenting unclear information to the driver, which might end up to be contradictory. How to handle this type of situation is appointed as a *future research need*.

Other uncertainties are in the misuse and abuse of systems. So far, this has not gained too much attention, but with the growing number of ADAS sold, this is becoming an issue to tackle. Training can strongly reduce the risk of misuse. Tackling this issue is also appointed as a *future research need*.

### **3.4 No need for dedicated European regulations for automated driving?**

There was no clear agreement within the expert group regarding this issue. Arguments supporting dedicated European regulations are that there is confusion about what automated driving is and that this could be clarified by regulations. In addition, it seems to be better to have European wide regulations rather than several different regulations on a national level. Arguments against European regulations are that the systems may be well designed and cope with the current legislation and regulations so that no change in regulations is necessary.

Adapting the legal framework in light of a complex concept such as automated driving is a complex and time consuming issue, and therefore not likely to happen unless there is a clear consensus on a deployment scenario. Adaptation of the legal framework in advance changes the position of the players in the playing field. Relations between players can also be arranged by means of contracts. Insurance companies could play an important role in solving the liability issues if there is a clear business case.

At the moment, there does not appear to be any true justification to adapt or design dedicated European regulations for automated driving until there is an adopted implementation scenario. In preparation for such a scenario the ITS directive and ITS action plan could be adapted to include a process and the *necessary* steps and measures needed to supporting a decision making process leading to implementation of the concept of automated driving.

### **3.5 Possible legal interpretations of “control” allowing automated driving**

Within the juridical expert community there seems to be a discussion of what the term “control” that is used in Article 8 of the Vienna Convention means. There are currently two

definitions resulting from different understandings of the term “to control” with no clear consensus [44]:

1. Control in a sense of influencing e.g. the driver controls the vehicle movements, the driver can override the automation and/or the driver can switch the automation off.
2. Control in a sense of **monitoring** e.g. the driver monitors the actions of the automation.

Both interpretations allow the use of some form of automation in a vehicle as it can be seen in today’s cars where e.g. ACC or emergency brake assistance systems etc. are available. The first interpretation allows automation that can be overridden by the driver or that reacts in emergency situations only when the driver cannot cope with the situation anymore. Forms of automation that cannot be overridden seem to be not in line with the first interpretation [45, p. 818].

The second interpretation is more flexible and would allow also forms of automation that cannot be overridden and are within the Vienna Convention as long as the driver monitors the automation [44].

### **3.6 Lessons to be learned from State-of-the-Art technologies towards a legal framework for automated driving**

State-of-the-Art technologies looked upon here, are Adaptive Cruise Control (ACC) and Electronic Stability Control (ESC). ACC and ESC are within the Vienna Convention due to several reasons:

- ACC only controls the longitudinal axis and the driver is still in control of the lateral axis;
- The driver can take back control and override the ACC at any time (e.g. by braking or accelerating);
- The ACC can be switched off by the driver;
- ESC works on a very basic level and it supports the drivers’ intention;
- The ESC can in many cases be switched off by the driver.

In the literature, some other assistance and automation functions were appraised by juridical experts. For example, [46] postulates that automatic emergency braking systems are in line with the Vienna Convention as long as they react only when a crash is unavoidable (collision mitigation). Otherwise a conflict between the driver’s intention (here, steering) and the reaction of the automation (here, braking) cannot be excluded.

Albrecht [47] concludes that an Intelligent Speed Adaptation (ISA) which cannot be overridden by the driver is not in line with the Vienna Convention because it is not consistent with Article 8 and Article 13 of the Vienna Convention.

### **3.7 Potential lessons from aviation legislation**

The existing regulations in aviation provide an example of how the design and use of automation like the Flight Guidance System can be standardized across countries, if it would be chosen to go for new regulations. Relevant regulations are those of the Federal Aviation Administration (FAA) and Joint Aviation Authorities (JAA) (now: European Aviation Safety Agency (EASA)) that regulate the use and design of automation in aviation.

For example in the Certification Specifications for Large Aeroplanes CS 25. In CS 25.1329 “Flight Guidance Systems” several regulations for the Flight Guidance Systems are stated for example in paragraphs (a), (i) or (l):

- (a) Quick disengagement controls for the autopilot and auto thrust functions must be provided for each pilot. The autopilot quick disengagement controls must be located on both control wheels (or equivalent). The auto thrust quick disengagement controls must be located on the thrust control levers. Quick disengagement controls must be readily accessible to each pilot while operating the control wheel (or equivalent) and thrust control levers.
- (i) The flight guidance system functions, controls, indications, and alerts must be designed to minimise flight crew errors and confusion concerning the behaviour and operation of the flight guidance system. Means must be provided to indicate the current mode of operation, including any armed modes, transitions, and reversions. Selector switch position is not an acceptable means of indication. The controls and indications must be grouped and presented in a logical and consistent manner. The indications must be visible to each pilot under all expected lighting conditions.
- (l) The autopilot must not create an unsafe condition when the flight crew applies an override force to the flight controls.



## 4 Aspect 3: Liability

There have been and continue to be a number of projects funded through the EU that are providing information and researching liability aspects associated with automated (and autonomous) driving systems. The most relevant projects are listed in Table 3. A number of EU directives have also been issued, see Table 4.

**Table 3: Projects working on liability issues related to automated driving**

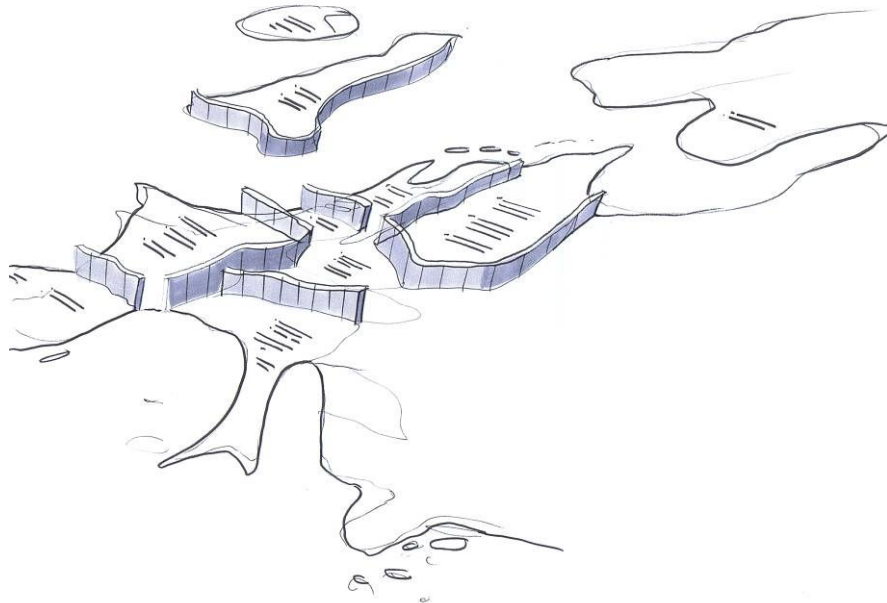
Project	Field of work
RESPONSE-2 [50]	Provided an insurance focus throughout directed mainly towards whether motor insurers would reduce premiums for vehicles fitted with ADAS
RESPONSE-3 [41]	A horizontal sub-project of PReVENT, continued to research into liability issues and created a Code of Practice for the Design and Evaluation of ADAS
ADVISORS [51]	Included a statement to the effect that insurers can, through their policies, influence the behaviour and decisions of drivers/car owners and, at least in theory, strongly influence the development of ADAS
AWAKE [52]	Ran a survey of liability issues, insurance and legal aspects and established the liability of the driver, the vehicle owner and the manufacturer in the context of use of AWAKE from the perspective of traffic law and product liability
STARDUST [53]	Assessed the extent to which ADAS and AVG (Automated Vehicle Guidance) systems could contribute to sustainable urban development. Liability issues were also researched, identifying a potential need for liability insurance to be made available

**Table 4: Relevant EU directives**

EU directive	Focus
85/374/EEC, OJ 1985, L. 210/29	This European Council Directive (85/374/EEC, OJ 1985, L. 210/29) on liability for defective products was introduced in 1985 to harmonise product liability law in Europe and to provide consumer protection
Community Regulation COM (2005)650 final	On 15 December 2005 the European Commission adopted a proposal for a Regulation to convert the Rome Convention of 1980 into a Community Regulation on the law applicable to contractual obligation
Regulation (EC) No 864/2007 of the European parliament and of the council	11 July 2007; on the law applicable to non-contractual obligations (Rome II). The European Union's initiative to bring about harmonised rules on law that is applicable to civil liability (the Rome II Regulation) stems from the need to regularise issues concerning civil liability for damage caused to others, particularly in the event of an accident and applies to road accidents, defective products and environmental pollution. As the European Community expands in size, increasing the number of Member States, disputes of this kind will become more frequent

Currently many aspects are still determined by the national laws of the Member States. As a consequence, the legal solutions are likely to vary widely from one Member State to another and parties could be tempted to refer the dispute to the court which will apply the law most favourable to them.

For incidents, there are no common rules throughout Europe



**Figure 15: European barriers**

#### **4.1 Status of civil liability in European countries**

By definition, civil liability is considered the potential responsibility for payment of damages or other court-enforcement in a lawsuit. There may be a variety of liability relationships between the different players. These relationships may be based on tort law or contract law and the existence and details of such a relationship differ between national legal regimes.

There may be links between front-line compensation payment by an insurer of a vehicle/owner/driver and use of subrogated rights by that insurer to obtain recovery from the liability insurers of manufacturers, suppliers etc. of faulty components or services.

The domain of legal liability is characterized by openly formulated liability standards, such as the standards that may be set for public roads, the safety a person is entitled to expect from a product, or standards of care to be applied by drivers. The advantage of such vagueness is that it does not restrict the ability of judges to deal with matters on a case-by-case basis, taking all relevant circumstances into account and enabling them to deal with societal developments, including the application of new technologies.

Contractual liability may be transferred because of insurance. Insurance offers people and companies the opportunity to transfer financial risks to insurers, thereby alleviating the burden of liability inherent in certain activities which could include bringing ADAS or co-

operative vehicle systems to market or as a legal prerequisite for driving a motor car. The availability of insurance could be regarded as a crucial facilitator in the deployment of these systems and, equally, the absence of its availability a barrier to success.

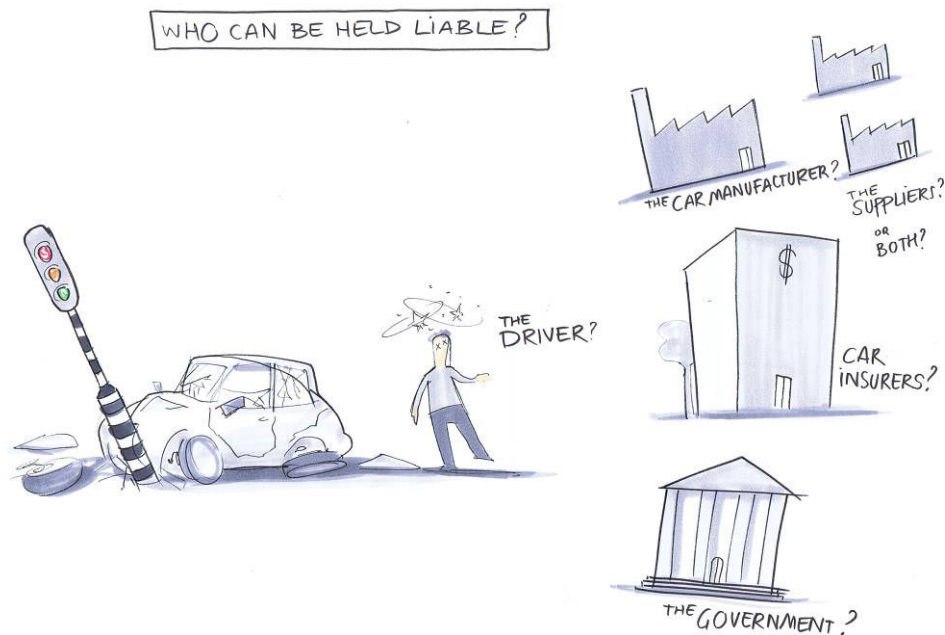
A useful case study for understanding the issues associated with automated driving can be found in SAFESPOT [4] which can be viewed as a parallel to automated driving functions (for more details, see Appendix I. Related to aspect 3). SAFESPOT provided an in-depth analysis of the legal aspects of the service named 'Speed Warning', in two configurations V2I and V2V. It is performed against two fundamentally different law schemes, namely Dutch and English law.

This analysis concluded that the concept of co-operative systems raises questions and might complicate legal disputes. This is for several reasons:

- There are more parties involved, all with their own responsibilities for the proper functioning of elements of a cooperative system.
- Growing technical interdependencies between vehicles, and between vehicles and the infrastructure, may also lead to system failure, including scenarios that may be characterised as an unlucky combination of events ("a freak accident") or as a failure for which the exact cause simply cannot be traced back (because of the technical complexity).
- Risks that cannot be influenced by the people who suffer the consequences tend to be judged less acceptable by society and, likewise, from a legal point of view.
- The in-depth analysis of SAFESPOT concluded that (potential) participants such as system producers and road managers may well be exposed to liability risks. Even if the driver of the probe vehicle could not successfully claim a defense (towards other road users), based on a failure of a system, system providers and road managers may still remain (partially) responsible through the mechanism of subrogation and right of recourse.

Current law states that the driver must be in control of his vehicle at all times. In general, EU drivers are prohibited to exhibit dangerous behaviour while driving. The police have prosecuted drivers in the UK for drinking and/or eating; i.e. only having one hand on the steering wheel. The use of a mobile phone while driving is prohibited in many European countries, only use of phones equipped for hands free operation are permitted.

Liability still rests firmly with the driver for the safe operation of vehicles. However OEMs, including to a lesser extent the tier 1 suppliers, have to comply with EU Member State legislation for the safe deployment of technology in the automotive market. For new technologies such as ACC new ISO standards have been created to enable suppliers and OEMs to develop their systems and bring them to market within a framework of accepted performance objectives and requirements that still allow for some feature and performance differentiation. As is concluded in the RESPONSE project from the ergonomically viewpoint the aspect of "controllability" of the driver needs to be assessed carefully, especially in the increasingly complex environment of intelligent cars.



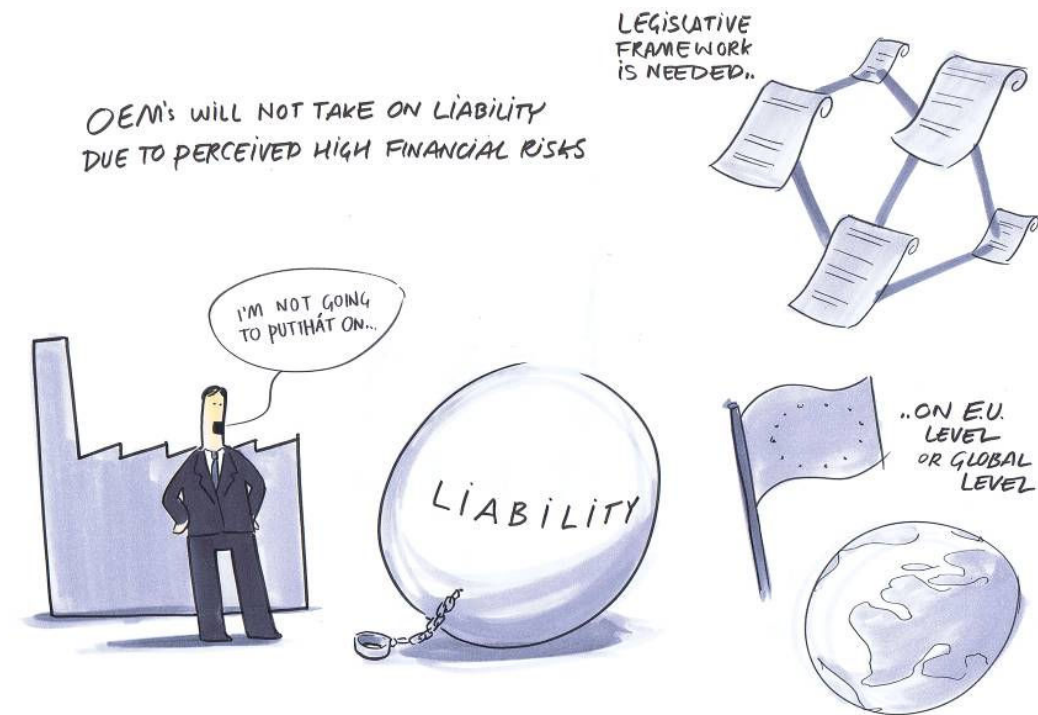
**Figure 16: In case of an accident, it is not too obvious who can be held liable when an automated driving system was used**

## 4.2 Potential effect of civil liability on deployment of automated driving

Assessing liability aspects of automated driving is a complex issue that will require an in-depth analysis determining the liability issues based on:

- The definition of the service. What does it actually do, what are the limitations and how was it “sold” or presented to the user/driver/owner.
- The technological configuration (architecture) of the system. How is data transferred between the components, what technologies are used.
- The implementation context. Will introduction be (solely) market driven or will there be regulatory interventions?
- The players involved in the delivery of the service and their organisational relationship.
- The role of insurance.
- The actual “error” scenario.

New legislation may be required for automated driving. It is highly unlikely that any OEM or supplier will risk introducing an automatic driving vehicle (where responsibility for safe driving is removed from the driver) without there being a framework of new legislation which clearly sets out where their responsibility and liability begins and ends. In some ways it could be seen as similar to warranty liability, the OEM warrants certain quality and performance levels, backed by reciprocal agreements within the supply chain. Civil (and possibly criminal) liability in the case of accidents involving automated driving vehicles is a major issue that can truly delay the introduction of these technologies.



**Figure 17: OEM view towards liability when automated driving is deployed. For non-contractual obligations, a primary framework exists. To protect the end uses, guidance should be given towards contractual obligations**

#### ***Deployment of Vehicle-to-Vehicle communication in the US***

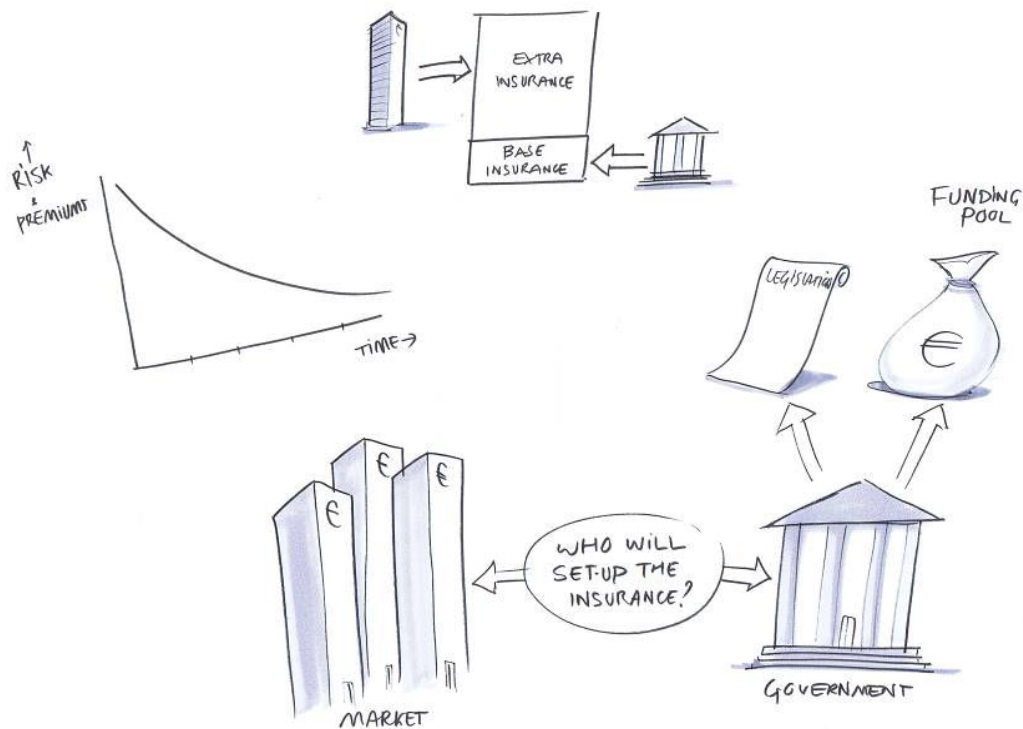
The US government initiated a process to introduce wireless communication in vehicles by means of regulation. Their implementation strategy is primarily directed to improve road safety. The National Highway Transportation Safety Administration (NHTSA) determined in 2010 that V2V communications had the potential to significantly reduce traffic accidents and declared an intent to begin the process to initiate a regulatory decision in 2013 on whether to require inclusion of V2V technologies in new vehicles.

### **4.3 Future policy of insurance companies**

The principle of insurance is to attract a pool (fund) to cover the risks. The premium, i.e. cost of insuring, is usually based on an assessment of the risks using statistics over a long period. Lowering of premiums reduces the float and with the current state of the technology the risks increase. Insurance companies will not change their policies easily. Opportunities emerge if there are new markets to serve with a new pool, e.g. a “without prejudice restoration fund” or another sort of pool [Safespot, 6.4.1 Legal Analysis]. Since there are no statistical records of the effects of automated driving systems, the entrepreneurship of insurers should compensate for the issue of unknown risks. Cooperation with the automotive sector and EU and national governments in (research) projects would help to obtain a better view on the requirements of insurers and along which lines formal cooperation could be established.

The following factors are regarded as hindering an optimal role to be played by the insurance industry in promoting new safety systems through their insurance policies:

- Premium-setting is based on statistical principles, resulting in a time-lag problem;
- Competition/sensitive relationships with clients;
- Investment costs (e.g. aftermarket installations);
- Administrative costs;
- Market regulation.



**Figure 18: Force field for insurance companies**

It has been speculated that once ADAS systems become standard, cars equipped with them could potentially attract lower insurance premiums, but in reality the driver remains the highest risk element even with ADAS systems deployed. Once new markets and/or market forces are developed for insurance companies, their policies might change.

#### 4.4 Potential effect of insurance companies' policies on other players?

There are two types of insurances to consider: Motor Insurance, as is required for car owners, and Insurances covering risks of the players in the chain of production and operation of highly automated driving.

In the final report of the ADVISORS project, it was stated that insurance companies, before taking the decision to support or promote a certain type of ADAS, would most likely want to:

- Have some guarantees as far as liability was concerned. For example, if the ADAS malfunctioned and this malfunction was the primary cause of a car accident for which the insured driver could be held liable according to legislation, the insurance

company would want to be able to refer the injured party to the ADAS manufacturer;

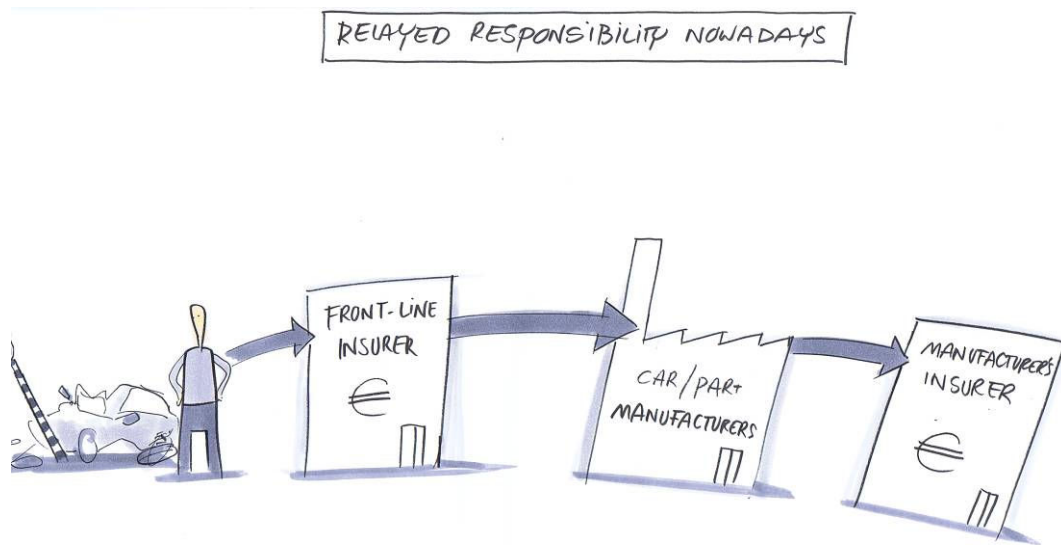
- Have data on high user acceptance of the specific ADAS (i.e. to ensure that there would be high user take-up);
- Have scientific and statistical evidence of the potential safety benefits, as motor vehicle insurance premium setting are based on statistical systems;
- Integrate the new policy easily into their administrative system.

In the final analysis, insurance companies base their business on the assessment of risk, they could potentially offer policies to OEMs to mitigate their risk in introducing such systems, but because the technology is new and unproven such policies would likely to be prohibitively expensive.

Insurance products for fleet owners appear to offer the best potential because of a better cost/benefit ratio and a more business-like relationship with the client. For further reference the AWAKE project [52] analysed the role of insurers in the field of safety systems.

#### **4.5 Is there a need to adapt systems to remove liability from (part) manufacturer?**

Since the concept of automated driving is not yet set and rather flexible in the minds of the policy makers and industrial experts, it is clear that removing liability from manufacturers beforehand is not to be considered. As argued above, the overall distribution of the risks should be analysed first for each of the possible implementation scenarios, based on the roles of the players involved, the exchanges of value such as information, hardware and software, licences etc. The contractual matrix and the analysis of cost and benefits of the designed concept helps to determine the options for the relations between the players involved. Giving advantages to manufacturers beforehand would be a political decision and would influence the business model and therefore an economically viable solution. This should only be seen in the light of a (European) solution for deployment of automated driving.



**Figure 19: Current liability interactions**

## 4.6 Conclusion

In conclusion, assessing the liability aspects of automated driving is a complex issue. The only “general” rule that applies is that there are no generic answers possible. For a solid conclusion, an in-depth analysis of the concept for automated driving is required. From there, by means of “responsibility mapping” related to the players involved, different implementation scenarios of the automated driving concept are identified and can be analysed. Further, there may be differences because of the differing national legal schemes and differences in the national implementations of the relevant EU directives. Further recommendations and questions raised within this study include:

- Government could step in to support the take-off of automated system via a legislation framework (provide risk assessment), funds (e.g. insurance pool for claims), by providing incentives (congestion zones, free parking, etc.) and by supporting standards.
  - Conformance to standards can be a way to “prove” that sufficient safety standards have been met, and can be used as defense against potential claims. A theoretical “stress-test” with lawyers can be done, and has been done before e.g. the Safespot analysis.
  - No precedence lawsuits of liability with automated systems have happened to date. The Toyota malfunctions of their brake-by-wire system in 2010 did not end in a lawsuit. A system like parking assist is technically not redundant. What would happen if the driver claimed he/she could not override the brakes?
  - For (premium) insurance a critical mass is required, so initially all stakeholders including governments should potentially play a role.
- The business case of the governments/road operators (i.e. a Cost-Benefit Analysis) could be based on less accidents happening, less lanes are required due to higher throughput, etc. These savings could be used to support an initial insurance fund. However, the overall business case of ADAS systems is not clear yet. These systems are claimed to be safer, but this has not been proven yet with statistics.



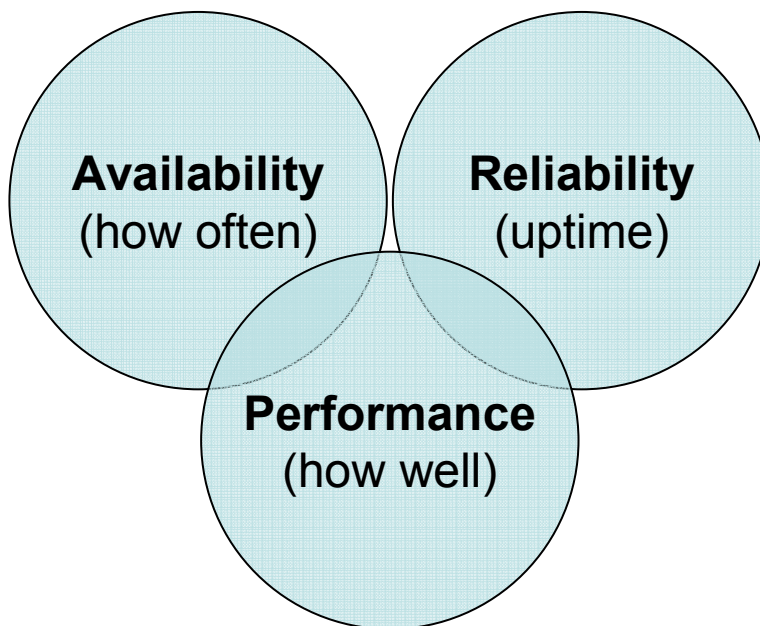
- Could OEMs eventually become liable for not implementing safety systems, e.g. like ABS that is known to improve safety?
- Lessons learned from the aviation and rail sector could be examined, however this experience may not be so relevant due to some important differences. The main difference being that these environments are much more constrained, trained (pilots) vs. untrained people, latency aspects.
- Concern was also expressed regarding the differences in the quality of ADAS systems, e.g. greater sensor redundancy on higher class vehicles, higher sensor performance on more expensive vehicles (BMW vs. Suzuki). There is clearly a role here for standards and a potential Euro NCAP rating.

## 5 Aspect 4: Reliability

This section covers reliability aspects of automated driving. The section starts by defining reliability and goes on to cover the requirements for reliability as discussed by the expert group. After that, new safety systems are considered. Next, redundancy aspects are dealt with. Finally, deployment strategies with regard to reliability issues are provided.

### 5.1 Definition of reliability in automated driving

In the realm of engineering, reliability can be defined as the ability of a system or component to perform its required functions under stated conditions for a specified period of time and is often reported as a probability. Reliability should not be confused with performance and availability. Performance refers to the quality of operation in the operating conditions. Performance of a system can degrade with wear, dirt and so on, while the system is still operating. Availability refers to the conditions under which a system should be able to operate, e.g. traffic, weather etc. Reliability could be rephrased as the probability that the system keeps on operating in conditions when the system should be available, this could also be called “uptime”, see Figure 20.

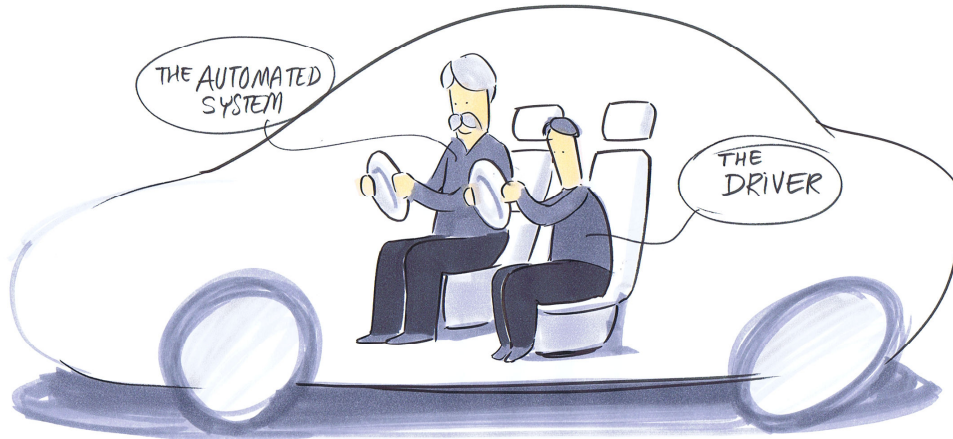


**Figure 20: Availability, reliability and performance**

In general, reliability can be defined as “the ability of a person or system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances.” [83]. In the context of this study, this can be loosely translated as the ability of an autonomous vehicle to operate at least as well as an “experienced” driver, see Figure 21. It relates to a great extent to the expectation of users about what an experienced driver exactly is. The meaning of an experienced driver may differ between and within individuals and is therefore not well defined.

By definition, “experience” does not necessarily equal “safe” or “efficient” driving, but the expectation in this definition is that an experienced driver is one who would in most circumstances be safe and efficient.

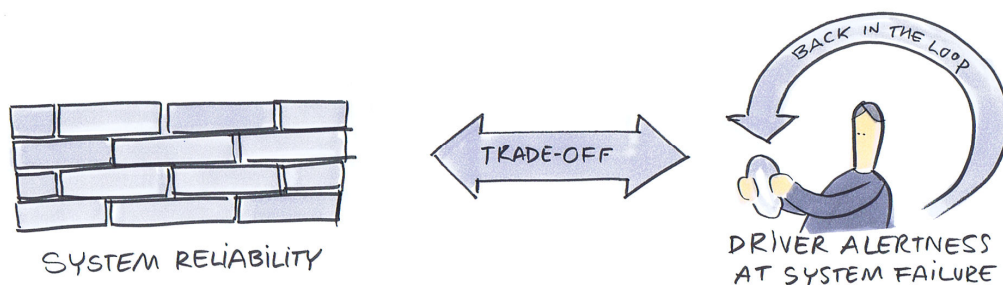
*AUTOMATED SYSTEMS SHOULD OPERATE AT LEAST AS WELL AS EXPERIENCED DRIVERS*



**Figure 21: Automated driving versus an experienced driver**

## 5.2 Required reliability

In general, the required reliability differs according to application. ISO 26262 describes Automotive Safety Integrity Levels (ASIL) for a range of applications. Part of the application is the ability of a driver to recover in a situation of system failure. That is, when a system fails, but the driver is able to recover control quickly enough (“back in the control loop”) to avoid an accident. This highlights the trade-off between system reliability and driver recovery, see Figure 22. Automated systems that include lateral control are considered most critical, e.g. merge assistant. Longitudinal control systems are also critical, e.g. (C)ACC, but some useful experience has already been gained with these systems.



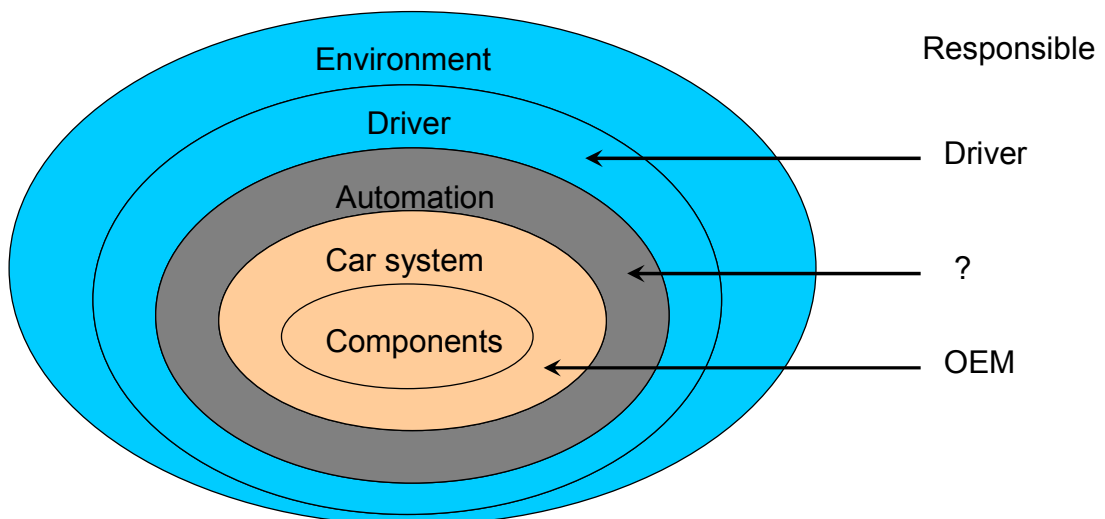
**Figure 22: Trade-off between system reliability and driver recovery**

Safety is an important aspect regarding reliability. So far, safety standards have not only been driven by acceptance of users (public forces) but also by the industry (OEMs), who are strongly motivated to prevent recalls and liability cases. Traditionally, reliability of systems can be expressed as ppm (part per million) failures or as “statistically functioning well” in a

certain percentage of well-defined test cases. Extensive validation tests have been setup to define the operating conditions of mechanical, electrical and software components where the behaviour is deterministic. Note that the introduction of V2V and V2I communication challenges these traditional tests, due to the potentially large number of additional circumstances under which to test the correct functioning of these systems.

Automated systems also challenge these tests, but much more with respect to responsibility. When a failure occurs, an OEM could in principle be held responsible when a breakdown happens within the well-defined traditional specifications. The driver is legally responsible for operating the car in its environment. The introduction of automated systems makes this distinction between liability of OEM and driver a grey area. In Figure 23, the different layers are shown of a car that operates in an environment.

The aspect of an ill-defined responsibility (human driver vs. OEM) is closely related to the ability of a driver to recover control of the vehicle. New ways of specifying how to test these types of systems need to be defined. As long as this remains unclear, OEMs will remain hesitant to implement automated systems. Certification of automated systems could help industry by providing clarity and thus stimulating developments, or by underwriting responsibility.



**Figure 23: Layers in the car system and responsibilities**

### 5.3 Introduction of new safety systems

Automated systems inherently introduce safety risks, due to the fact that no system is completely reliable and new systems are less reliable than old established ones. New safety systems are expected in the following areas:

- Fail safe mechanisms for critical applications, e.g. via redundancy;
- Vehicle health checks, this includes redundancy to detect failures;
- HMI systems to manage changes in control (human driver vs. automated system) and alert the driver of failures. How to get the driver back into the control loop is one of the main issues;

- On infrastructure dedicated to automated systems, gateway safety systems are required to put vehicles through 'health checks' and merge them with existing traffic on the automated lane.

Additional safety systems can be deployed that are traditionally not used, examples are:

- V2V and V2I communication;
- Failsafe measures via sensors (as opposed to the traditional mechanical failsafe measures), e.g. by continuously and independently detecting deviating vehicle behaviour;
- Specific infrastructure that provides additional safety checks, e.g. at gantries or via markings.

## 5.4 Redundancy

When system failure occurs, recovery can be made by having sufficient redundancy in the system for an automatic recovery/transition or by the driver regaining control. In the more simple environments, such as on motorways with long headways, drivers will be able to take over control, if properly primed. As headways reduce, or in more complex situations, it may not be possible to reintroduce the driver into the control loop in time to avoid an accident. In the latter, safety critical situation, redundancy is essential.

Assessing the boundary between when redundancy is needed will depend on several factors:

- i) The time available for a driver to safely recover from an unexpected system failure.
- ii) The driver's readiness to take control. This will depend on the availability of technology/techniques to maintain driver awareness and the driver characteristics. Some drivers may be less able to respond correctly to the unexpected, e.g. automatic system availability may be linked to specific drivers. However, there are considerable variations within drivers.
- iii) The risk associated with a failure. In an urban condition, failure may result in considerable risk of death to vulnerable road users. In other situations, the risk may be of damage only. (This risk should not be underestimated, as damage only accidents can result in very considerable delays in already congested road networks.)

On the basis of the above, it becomes very clear that redundancy is needed for many applications. Such redundancy may be achieved by having separate parallel systems, redundancy of key components and/or the use of sensor fusion to manage with reduced data, probably to provide additional time for the driver to take control. A key issue will be how to manage when a system is given conflicting information.

Comparisons with other automatic systems such as rail or air offer little value, because such systems are used by highly trained operators. Also because a failure rate of a rail automation component of 1 in 1 million would be quite acceptable because of other monitoring systems. For a road vehicle, such a level could be quite unacceptable simply because of the

gross number of such events which would occur across Europe each day. Whilst such vehicle automation might reduce the number of accidents overall, the press and public focus on a new type of accident could be overwhelming.

## 5.5 Strategies towards satisfying reliability

It is important to realize that failures will occur, no matter how well a system is designed. For the major risks a contingency plan can be specified for an integral risk assessment. This risk assessment contains at least the following aspects:

- Cause of system failure;
- Probability of failure;
- Severity of the impact;
- Mitigation/contingence. E.g. technology and/or driver redundancy.

The following strategies need to be taken into account:

- Use several (partly redundant) sensor systems and a robust sensor fusion algorithm to ensure a correct and sufficient world view (such that controlling the vehicle in the environment are improved);
- Use several (redundant) means to control the behaviour of the car (to ensure that the improved opportunities for control can be exploited);
- Create a fail silent system such that the driver has a reliable backup system, e.g. by requiring specific actions to be done by the driver, the awareness can be increased and a faster reaction of a driver can be expected in case of a failure of the system;
- Adopt a conservative automatic driving style;
- Seek appropriate standards and certification in the automotive industry.

For the EC especially the following aspects could be stimulated:

- R&D of technology, e.g. failsafe technologies, sensor fusion, redundancy;
- Legislation: clarify and adjust where necessary;
- Driver aspects: how to keep the human in the loop, how to take back control;
- Stimulate certification/homologation to drive and validate the reliability. Certification and standards relieve the liability issues that make OEMs hesitant to deploy automated systems;
- The combination of several applications might introduce additional risks that are not tested on the individual applications.

## 6 Aspect 5: Control units

Automated driving requires great effort in analyzing and understanding the environment and actuating controls according to the driving needs. Software and computing systems will clearly play an important role in this task. The vehicle's control unit receives input from sensors and the navigation systems, and sends orders to the actuators. Especially for safety related applications, the computing, decisions and actions (triggering) are time critical.

### 6.1 Demands on the onboard computing platform/control unit

Due to the amount of environmental information that has to be processed for automated driving within critical time restrictions, real time computing is required. Onboard computing platforms need to be equipped with Real Time Operating Systems (RTOS) capable of processing the amount of data and signals. Digital signal processing (use of modern DSPs) might be helpful as well as parallel processing, with redundant hardware devices.

The required real time computing should be within cycle times under 1ms, with at least fault-tolerant techniques. Also a failsafe technique with redundancy and fault management is necessary in order to meet the requirements of the platform, which must comply with requirements for necessary and sufficient:

- Reliability;
- Accuracy;
- Security;
- Credibility.

Systems for automated driving will need to have computing capacities and network technologies to exchange large amounts of data between the control units. These systems must be powerful, but also cost efficient in order to be accepted by the automotive market and the end user. Further demands on the required platforms include robustness of the hardware with respect to temperature as well as vibration and agitation, and quality standards for the software and the development process to assure high reliability and low fault rates.

One important point is the security level needed. Micro Controller Units offering SIL3 and SIL4 certification seem to meet the high security demands for automated driving applications, but they also should be as cheap as possible to be affordable by automotive manufacturers and users. A possible contradiction arises, which might be solved if such systems are mass produced.

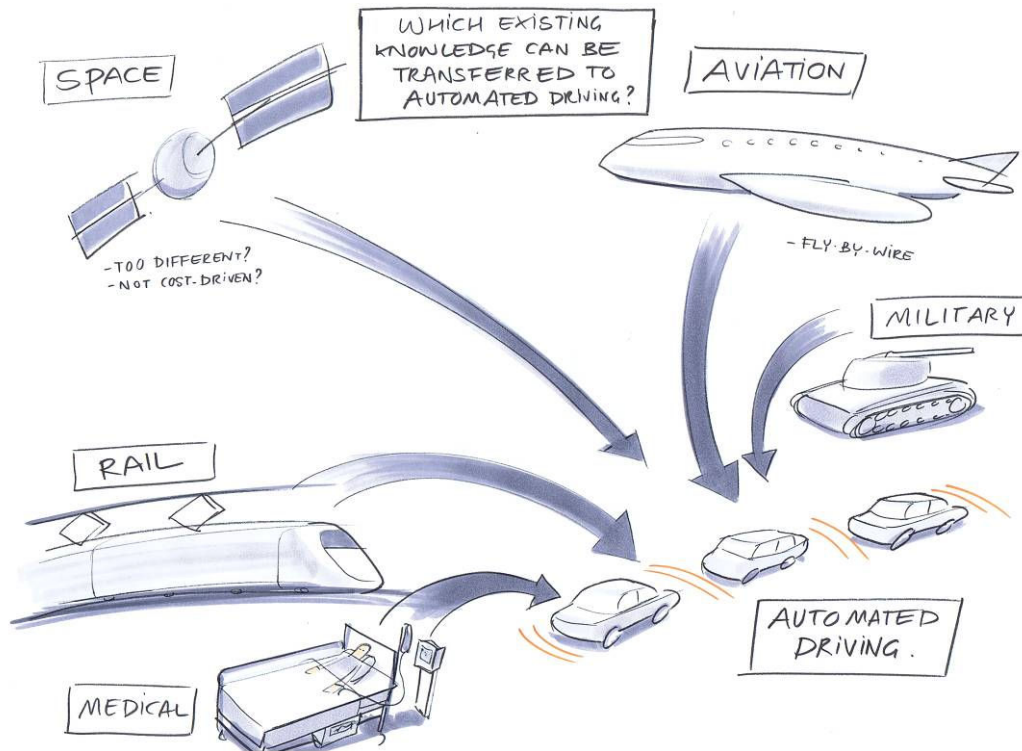
### 6.2 How far off is current technology from these requirements?

Current technology is, from the hardware point of view, sufficient to comply with the necessary requirements for automated and autonomous driving. There is already a variety of high performance platforms that allow running software and processing signals in real time. The current challenges for automated driving lie in the complex software algorithms, which have to be reliable enough for the right decisions to be made in critical situations that usually occur on the road. The other main challenge is in the cost price, which is still too high for mass application.

One critical point is that current network technologies on vehicles (i.e. the CAN bus) fail to match the increasing requirements for regarding network capacity. However the advantages of the CAN bus are cost-efficiency and the reliability of a well-known technology. For the future, and in particular for automated vehicle systems, the use of FlexRay communication is recommended. It is now available, and the first commercial off-the-shelf products are just coming to market.

A good approach for developing software and control units with respect to the requirements of automated driving will be the need to use standardized development platforms like AUTOSAR [54].

For current automotive technologies that at the moment do not meet the requirements for automated driving, knowledge transfer from other sectors already experienced in critical automated operations (i.e. aeronautics, space, military, medical, railway) might be helpful.



**Figure 24: Knowledge transfer from other sectors might help in finding new opportunities for automated driving**

It is therefore desirable to look for opportunities to transfer knowledge from other sectors and learn from standards and methodologies developed by them. Table 5 shows some of the main examples of possible knowledge transfer with the space and aviation industry.



**Table 5: Transfer of knowledge possibly leading to broad deployment of automated driving**

Automotive industry	Transfer of knowledge	Space and aviation industry
Real industrial production (thousands of units per day)	→	Artisan level (hand-craft): each unit hand made, and unique (thousands of days per unit)
Europe has a leading role	→	Europe is not at the cutting edge
Good reuse practice	→	Hardly any reuse
Scarcely fault tolerance	←	Widely spread fault tolerance: No single point of failure is allowed
Safety/dependability relies mainly on mechanic fall back mechanisms and on the driver	←	All safety/dependability measures are based on autonomous reactions of the avionics (no mechanic/operator fall back mechanisms)
Traditionally based on mechanics	←	Electronic and software based from its origin
One important optimization factor is the cost	→	Cost was not important. Now changing, but lack of experience
Power, mass and volume were not important. Now changing but lack of experience	←	Design optimized for lowest resources: power, mass, volume
Interoperability between different suppliers and between main contractor (e.g. AUTOSAR)	→	No interoperability between suppliers.
Complexity management	↔	Complexity management
Active steps to reduce the complexity (e.g. reduce number of ECUs: AUTOSAR)	→	No active steps to reduce the complexity
Standardized communication, e.g. CAN	→	No global accepted standard. Each device has its own protocol. Now one standard is emerging: SpaceWire, but it is too complex to be accepted widely
Complexity is already out of control	→	Complexity is becoming out of control
Experience on safety critical hard real-time systems	→	Time violations are not considered to be mission critical
Experience on handling sensors failures and errors due to environment conditions	→	Systematic sensors errors/failures are not a central theme of fault tolerance
Transient computation and storage errors are not a central theme for fault tolerance	←	Experience on handling transient computations and storage (CPU + MEMORY) errors, due to radiation effects.
Experience using diversity to avoid systematic errors (especially for sensors)	→	Diversity is not a central theme for dependability
Large experience on quality management (but different than space)	↔	Large experience on quality management (but different than automotive)
Large experience on system tests (but different than space)	↔	Large experience on system tests (but different than automotive)

Some examples for high reliable hardware platforms are the Qorivva family of dual-core, dual-issue 32-bit controllers, specifically designed to address the requirements of IEC61508 (SIL3) and ISO26262 (ASIL-D) standards for safety-critical automotive applications [55], and the micro controller units manufactured by Renesas, that can be used in systems seeking SIL3 certification [56].

Current State-of-the-Art indicates that technology for automated driving exists, but has still to be transferred to products. It is still too expensive for the user. Encouragement in development and mass production is highly desirable for the deployment of highly automated automotive systems and automated driving.

### 6.3 Current standards and reliable software

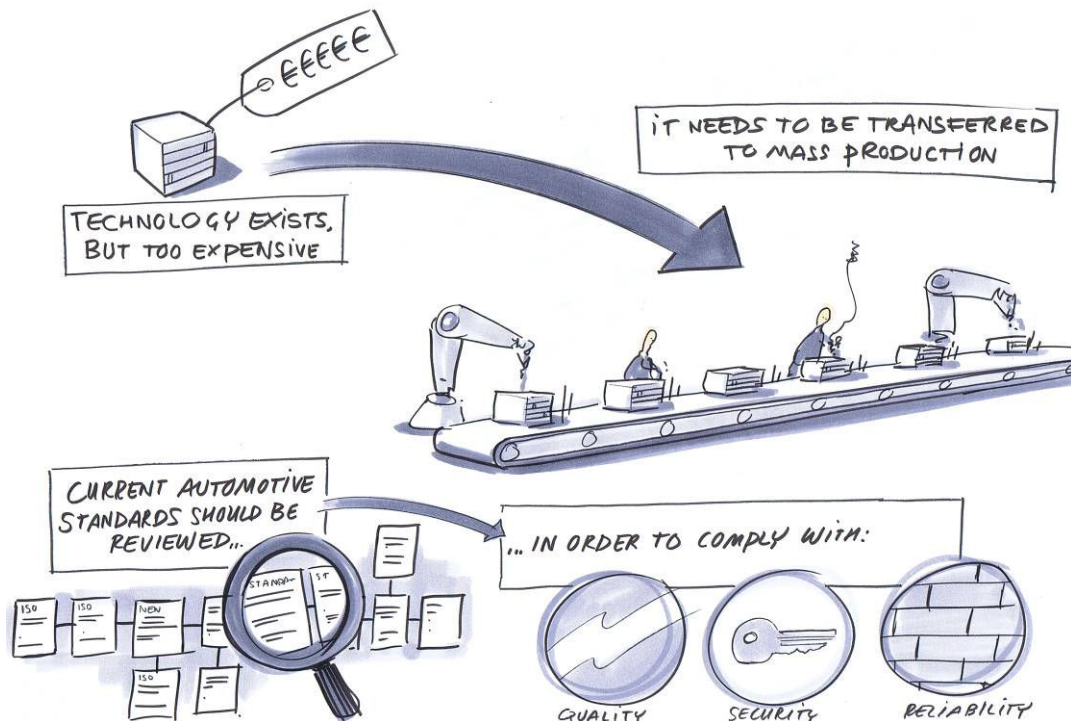
Current automotive standards suffice for reliable software for today's applications (ESP, ACC, etc) but even then problems may appear. It is a common practice that OEMs make software corrections by reprogramming control units of the vehicle, either when it visits the workshop or by service calls. Such reprogramming usually intends to correct software problems encountered when the vehicle is already on the market. Sometimes the detected errors are more or less critical, but normally the great amount of software bugs are errors that just cause slight disturbances to the driver, reducing the user's comfort or just preventing the vehicle from starting. If an error occurs in a safety system (i.e. ESP), the driver can in normal circumstances still take control of the brakes and direction to stop the vehicle in a safe manner. With the increasing complexity of automated driving, such software bugs might become more critical and can produce uncontrollable hazardous situations, which make them unacceptable. For automated driving high reliability standards have to be adopted (i.e. SIL3, SIL4).

Embedded software standards in the automotive industry, such as AUTOSAR, OSEK, FlexRay, CAN and LIN are widely deployed and supported although some might argue that recent recalls by Toyota have undermined the integrity of automotive software engineering.

ISO 26262 and MISRA are the two software standards applying to verification and validation of vehicle based software [57].

ISO 26262 is a Functional Safety standard currently under development, entitled "Road vehicles - Functional safety". The standard is an adaptation of the Functional Safety standard IEC 61508 for Automotive Electric/Electronic Systems. Part 6 of this standard addresses the recommendations for software testing and verification as part of the standard for software development.

Although the current software standards are very demanding, they seem to not be enough for the very nearly 100% reliability of software required for automated driving.



**Figure 25: Mass production of systems and review of standards is required for deployment of automated driving**

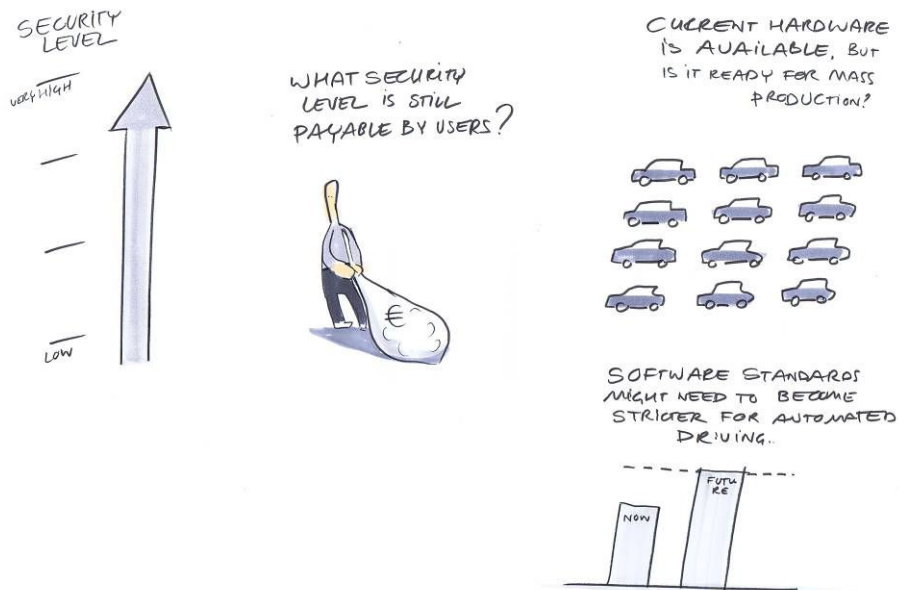
Of course, a certain amount of standardisation is necessary and fruitful for reliability. But during the last years, more and more upcoming standards are stifling creativity and limiting the responsibility from the developer, who is more and more forced into following quality and development rules and tools. There will be less creativity in creating software but a higher importance on generating automatic software building processes (including requirement engineering, harmonization and automatic test procedures as well as the parallel design processes).

This implies a lack of flexibility in software testing procedures, so although high development standards are required, some flexibility should remain within the process.

All this indicates that current automotive standards should be reviewed in order to comply with automated driving requirements in terms of quality, security and reliability, bearing in mind some flexibility and creativity for the actual development activities.

## 6.4 Improvements on software standards

For automated and autonomous driving, the allowed software error rate reduces drastically; because there are several functions that can imply a hazard in case of malfunction. Standard demands on software verification and validation for reliability must therefore increase and must comply with those already existing in e.g. aircrafts or trains.



**Figure 26: High security levels in standards can imply huge costs for the end user**

Although standards under which automotive computer systems and software are developed should be sufficient for automated driving systems, higher security integrity level standards (SIL3-SIL4) might be adopted to comply with the requirements of zero-accidents related to system failures. A review and verification of current standards will indicate if they suffice or if it might be necessary to adopt new ones.

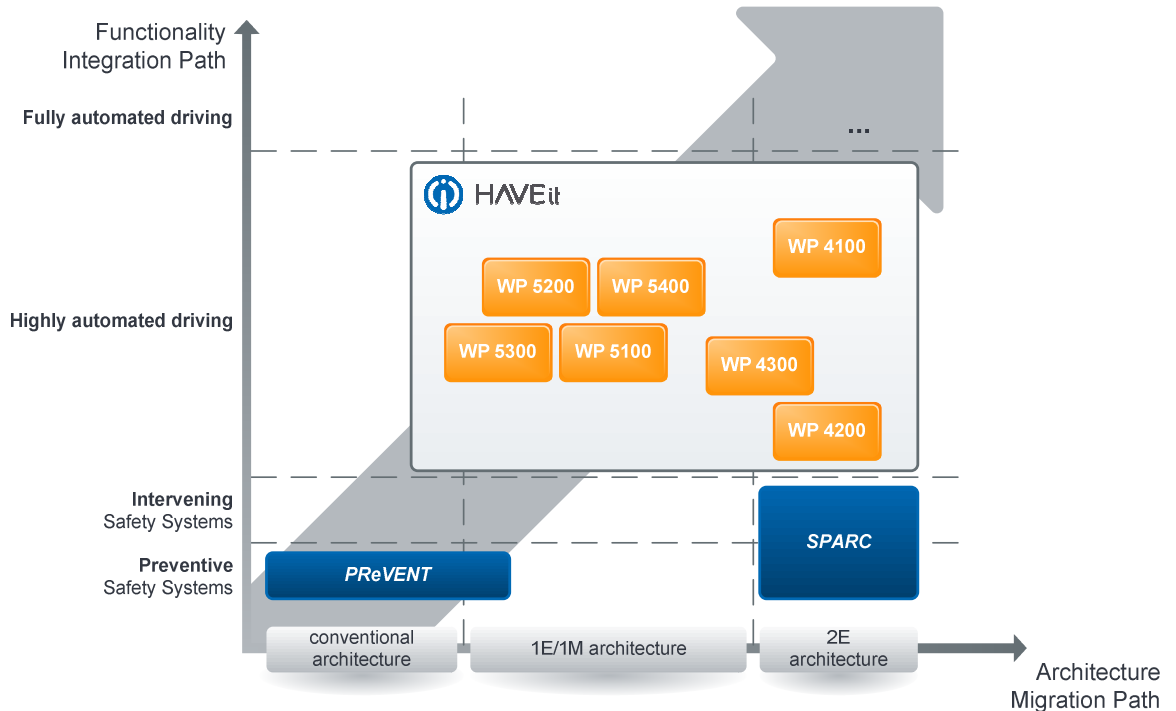
## 7 Aspect 6: X-by-wire

One major requirement to enable a vehicle to drive automatically is the reliable execution of the driving commands generated by the automation system. Whether it's the driver or the computer system that commands the power train, in both cases the control demand to the vehicles actuators (such as the steering system, the engine and the brakes) have to be executed in real time and failsafe. Also, an adequate HMI feedback to the driver about the current operation has to be assured. This feedback is needed to ensure that the driver can still control the car safely even during an intervention by the electronic co-pilot.

Depending on the required automation level, different architectures have to be taken into account for X-by-wire actuation. They are distinguished in their level of reliability, by their degree of maturity and in availability and costs. Within the EC funded project HAVEit there are several work packages dedicated to the issue of X-by-wire architecture and its applications. Two main principles of X-by-wire actuation have been identified and are represented here (the following clause is taken directly out of HAVEit deliverable D21.1 (<http://www.haveit-eu.org>)).

*Within the vehicle architectures of HAVEit (see Figure 27) we distinguish 1E/1M architectures (means one electronic system and one mechanical system) and 2E architectures (two electronic systems; no mechanical system). The first one constitutes the current solution of the automotive industry as an answer for the question how to provide computer based vehicle control. 1E/1M architectures provide the benefit that the E-system is only an add-on to the particular socially accepted M-system which usually enables the driver to control the vehicle even in cases where the E-system is lost. Nevertheless, especially for advanced driver assistant systems (ADAS) which allow the driver to get out of the loop at a certain level, the malfunction of the E-system needs to be safely detected to prevent the vehicle from getting out of control on one side and to request the driver via the particular HMI to take over control on the other side. For the HAVEit demonstrator vehicles this particular need is satisfied by the fail-passive CSC ECU.*

*With growing complexity of the automation level, fail-passive behaviour might not be enough. This is the case for specific vehicle systems which compulsory need to remain computer controllable, even after a first fault (e.g. to satisfy the requested safety) or vehicles being autonomously controlled (fully automated), allowing the driver to get fully out of the loop (e.g. reading a book ...). Here, the time gap between the occurrence of a first failure in conjunction with the sudden loss of the automation system and the reactivation of the driver is such long, that the vehicle might get out of control in the meanwhile. A solution for this problem would surely be the continuing performance of the automation in case of a first failure until the driver takes control. This is only possible, if each required component is available at least twice (including the E-system).*



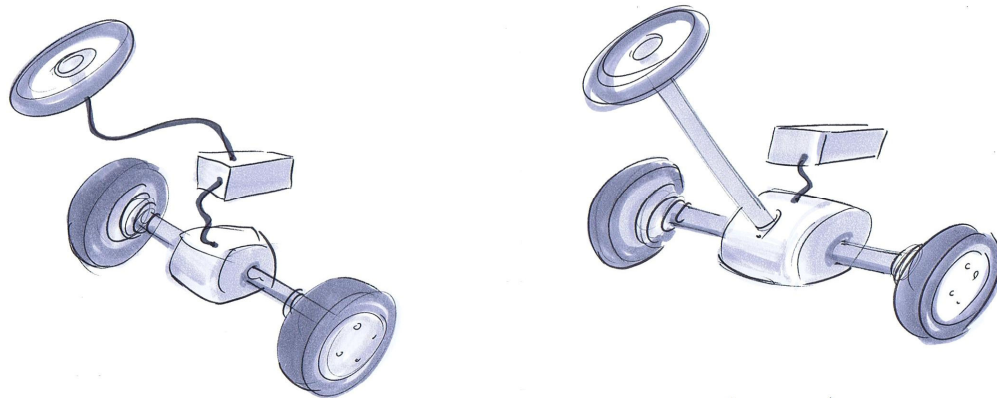
**Figure 27: EC project HAVEit (D21.1) – architecture migration path in dependence of the automation level**

With the background of these architecture considerations, in this report we distinguish between two different levels of automated driving power train technology:

1. Automated driving by controlling the actuators in terms of 1E/1M architecture. A lot of automated driving applications based on this standard technology is achievable even today just by using the actuators from series production (e.g. electromechanical power steering). This is called driving by software control.
2. Automated driving by a pure X-by-wire actuation in the manner of a 2E architecture. This includes not only redundancy in sensing and actuation but also redundant ECUs and data bus systems. The main advantages are higher degrees on automation and more flexibility in cost/weight considerations and in design of the interior. In this report we call this technology X-by-wire.

A comparison as to whether a 1E/1M system is sufficient or if a 2E system should be applied depends on the application and on the degrees of freedom for designing new innovative vehicles. In this report both systems will be considered.

Obviously, a lot of automated driving applications can be carried out even using the technology available today. That encourages one to think about further steps towards higher degrees of driving assistance even without a large amount of research. On the other hand, there are many interesting and promising applications that demand for pure 2E X-by-wire; like reducing weight space and, of course, to have the opportunities of a complete decoupled steering column with the corresponding degrees of freedom.

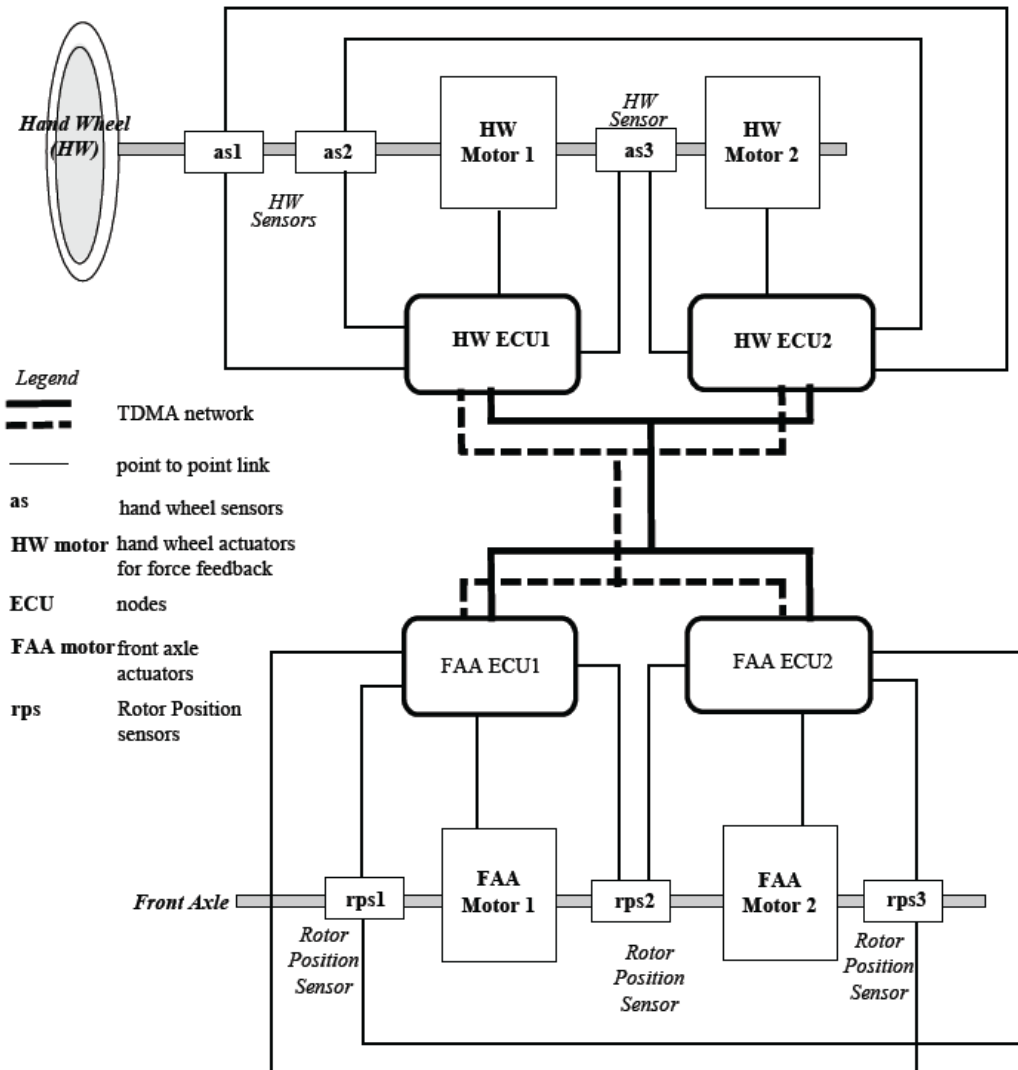


**Figure 28: Schematics for X-by-wire (left side, no mechanical steering column) and software control (right side, using the power steering actuator with the mechanical steering column in parallel)**

## **7.1 Realisation of close-to-real feedback to the driver, with X-by-wire technology**

To achieve an established and safe mixed traffic situation, for manual driving and partly automated driving, it is important that the driver obtains close-to-real feedback from the vehicle dynamics and from the road surface. Since the mechanical link disappears with X-by-wire technology, this feedback has to be generated and transmitted to the steering wheel and braking pedal. The most demanding challenge is the steer-by-wire system because of its high demands for high resolution sensing of forces and torsion of the steering column and for the real time operation of the complete steering control circuit. The basic procedure of a steer-by-wire control circuit is represented in Figure 29.

A control unit has to obtain the driver's intention by measuring the steering wheel angle and/or torque and sending this value on the electronic buses to other involved control units or electromechanical devices. The driver's command has to be detected by sensors with high precision that are integrated in the steering wheel (in particular, the torque sensor). This set-point will then be executed by the steering actuator. Additionally, the steering wheel nodes shall receive the measured torque value of the steered wheels, from the steering actuator unit. The driver is then given a feedback torque on the steering wheel based on the steering wheel angle and the steered wheel torque. The feedback torque shall be generated by the steering wheel actuators, these contain the necessary electrical motors and related haptic patterns to achieve the required feedback. In case of braking, a reaction force should also be transmitted to the pedal, in order to transmit the information that the brakes are working.



**Figure 29: X-by-wire architecture from Brite-EuRam 111 Program, X-by-wire**

In order to realize such an integrated steer-by-wire system the following components are essential for providing a close to real feedback in X-by-wire systems:

- A steering wheel actuator with the ability to apply realistic feedbacks to the driver's hands, including road surface properties and also haptic signals generated by ADAS
- Actuators that can extend the normal pedal functionality (gas and brake pedal) with additional information by haptic forces or feedback patterns to the driver's feet
- A steering column as an integrated electromechanical solution including the feedback actuator, the required sensors for angle and force detection and the steering actuator.
- Vehicle road sensors (e.g. integrated in the tires) in order to identify the current road surface properties or curbs
- A torque sensor for the steering wheel that is precise enough to detect the driver's commands even at higher speeds (only with a small deflection of the wheels)
- ECUs with sufficient redundancy and calculation power to ensure the reliable operation of the control loops
- A field bus system that transmits the required signals in real time and with redundancy



These vehicle systems are absolutely necessary for pure X-by-wire systems without any mechanical fallback option. If the driver assistance will be limited (e.g. for legal reasons) the supporting systems nowadays, e.g. like power assisted steering, already have a sufficient close-to-real feedback.

## 7.2 Potential specs of X-by-wire systems

In general, for a critical X-by-Wire system, it must be ensured that:

- A system failure does not lead to a state in which human life, economics or the environment are endangered;
- A single failure of one component must not lead to a failure of the whole X-by-Wire system.

These directives lead to several requirements which have to be addressed when specifications are defined for X-by-wire systems. They are

- It has to be defined which level of failure tolerance in the system has to be applied to the X-by-wire component. In dependence on the achieved degree of automation, there are different levels applicable e.g. like fail-silent or fail-operational. The Safety Integrity Levels defined in IEC 61508 are applicable here. Following these definitions, hardware safety integrity and systematic safety integrity have to be met to achieve a given SIL. For X-by-wire systems SIL-3 or SIL-4 are adequate.
- For every single component of X-by-wire systems it has to be proven (by a certification and/or a homologation procedure) that the safety standards are met. This can also include the definition of the automated driving application that commands the X-by-wire system.
- In addition to the component certification there should also be some regulations and certification procedures available for the development processes of components and software development
- The system shall memorize intermittent failures and it shall signal a critical failure to the driver, for example through the HMI. Moreover, it is required that the system is at least able to tolerate one major critical fault without loss of the functionality for a long enough time to reach a safe parking area
- Every single component that forms a part in the X-by-wire actuation chain has to prove its safety integrity level on its own or as a part of an integrated product

## 7.3 Are there any further developments needed in these systems?

When regarding software controlled driving interventions as is sufficient for at least some automated driving applications (e.g. emergency brake, lane keep assist, stop-and-go assistant etc...) there is no technological barrier to be reported. In this case, the further development for software controlled driving intervention should contain:

- A development of basic European wide standards and rules that assures a reliable operation of the computer controlled interventions
- Development of components (sensors, actuators, ECUs etc.) that matches the requirements coming from these standards.

However, there is much more effort needed when aiming for real X-by-wire actuation with a complete disintegrated steering column. Hand wheel force feedback systems do not transport a realistic haptic feedback at the moment. Although actual developments in this field are able to transmit some road information and feedback from the vehicle dynamics, the effect is still far away from the feedback given to the driver by a mechanical link. Further research in this haptic force feedback systems needs to be invested, especially in algorithms that compute the order that will be given to the hand wheel motor, in particular, according to:

- the speed of the vehicle,
- the front axle position,
- the front tie rod force.

In fact, this is only necessary in dual mode driving vehicles. For the case of fully autonomous driving vehicles, the force feedback to the hand wheel is not relevant.

There should also be further research and development efforts in the elaboration of the orders given to the front axle, in the form of filtering algorithms and complex control laws under stringent sampling periods of a few milliseconds. In order to ensure a smooth driving dynamic, it is critical to ensure that the end-to-end response time between a new command from the driver or the autonomous driving computer and the effect on the front axle is bounded.

Consider force feedback and realistic driving emulators: new force feedback actuators would allow transmitting more information from the power train to the driver's hands. It is recommended to continue development of activities in this field. Furthermore, it is necessary to develop failsafe components (sensors, actuators, ECUs) that are beyond prototypes. Components for mass production are needed.

A lot of further developments are needed. The following listing represents potential fields of research concerning the points taken out of Section 7.2.

- An HMI (not only the visual one but also haptic and acoustic HMI) has to ensure that in any mode of driving with automation, the driver is still in the loop with the driving task and has got the ability to take over control of the vehicle in a certain time.
- Electronic control units (ECUs): There are some promising developments ongoing today (e.g. the AUTOSAR initiative) that develop ECUs with a certain level of fault tolerance. A higher degree of fault tolerance is needed with a higher emphasis on automation.
- Reliable and redundant sensors and sensor systems are needed. Also their in/output interface has to be redundant (double cabling or redundant bus system interface).
- Cable harnesses, plug systems and a vehicle cable topology has to be integrated into X-by-wire vehicles. They have to ensure redundancy and robust plug interfaces.
- A failsafe power management system based on 42 V is required to ensure that energy is available at any time during X-by-wire operation. 42 V components have to be a mass product, the currently available 12 V power supplies are only applicable for low weight vehicles.
- For X-by-wire systems a real time, deterministic and redundant bus system is needed. There are already some current developments aiming for such bus systems

like FlexRay or TTP. They have to be available as mass produced products from the supplier market.

- Development of processes that guarantee a constant level of safety integrity level concerning the whole development chain have to be developed and brought to market

#### **7.4 Potential safety improvements by further developing this area**

There are different aspects concerning the improvement of traffic safety by the use of X-by-wire technology

- The higher degree of automation level that can be reached with X-by-wire technology helps to compensate human failure.
- X-by-wire technology allows the redesign of the inside of the vehicle, especially with respect to a better crash protection of the passengers.
- X-by-wire helps to deploy systems such as dedicated lanes, specific guidance systems or cooperative longitudinal control (CACC) that increases the individual safety of the passenger
- Computer controlled driving technology can improve individual safety by performing active control assistance.
- X-by-wire technology gives new degrees of freedom in designing the vehicles inside which can lead to more safety.
- X-by-wire (and also software controlled driving) can improve traffic efficiency by using applications that help to increase traffic capacity.

One of the main obstacles for general acceptance of X-by-wire systems is the difficulty to prove that all the necessary safety measures are followed. The dysfunction of steer-by-wire, brake-by-wire or throttle-by-wire systems would jeopardize the safety of the occupants, so it is critical to ensure that the highest safety standards for these systems are met.

#### **7.5 Role of X-by-wire systems in the deployment of automated driving**

If X-by-wire components and systems are available on the market they will serve to automatically stimulate the further development of automated driving applications. Actually, there could be parties that might not think about automated driving today but who are potential suppliers of automated functionality in the future. Compared with the existence of power controlled steering that lead to the invention of park assistance, or to a lane keeping assistance, although the system itself was originally made to reduce the effort needed to turn the steering wheel or to reduce weight (electric power assist). So every single X-by-wire component can deliver its own contribution to the deployment of automated driving just by being available on the market.

X-by-wire systems can simplify the deployment of automated driving by replacing the (hydro-) mechanical mechanisms in the vehicle by direct electronic control of the steering, braking, suspension and power train actuators, distributed in the form of fault-tolerant mechatronics systems, dependent on the current driving conditions and environmental influences.

For the first introduction into the market, behaviour similar to existing mechanical solutions is required to meet acceptance by the users.

## **7.6 Decreasing the high costs of these systems, without giving in to safety and reliability**

One main obstacle is that there is no noticeable demand of the customers for X-by-wire systems. The customer might not realize the technical advantages and only sees a higher price tag. The deployment of these systems in mass production would decrease the high production costs, so it is important that carmakers invest in this domain. The advantages of this technology can be very attractive for both carmakers and customers, if the necessary safety and reliability requirements are met.

There are different measures that can decrease costs for these systems. They are:

- Use the 1M/1E technology for ADAS with a higher degree of automation than available today. The advantage is that the actuators are already available in the market, they are licensed and are already built in a lot of cars. They only have to be approved for a wider range of intervention which is mainly a question of liability and other legal issues;
- Another way is the stimulation of mass production of X-by-wire components. These components are sensors, actuators, data processing units software development tools;
- Also the oncoming E-mobility research activities will stimulate X-by-wire due to the required vehicle architectures.

The costs can be decreased by using the existing technology (computer controlled driving) for X-by-wire applications.

Stimulating mass production of selected X-by-wire components like actuators and redundant real time data processing devices is required.

## **7.7 Current state-of-the-art in X-by-wire**

No single car manufacturer has introduced really fault tolerant safety related X-by-wire systems without mechanical backup, e.g. for braking or steering. This is mainly caused by the big expenditure in advance and cost constraints of the automotive industry, as well as the safety and legal issues related to possible hazards.

Nevertheless, solutions are available in transportation, e.g. military vehicles, aerospace, ships, trains, as well as in safety critical industrial applications like nuclear power plants.

The solutions mentioned do not meet the vehicle requirements. Aerospace solutions for example are functionally adequate (i.e. architecture of the AIRBUS A320 fly-by-wire system), but economically far too expensive for the automotive market because of the different world-wide production volumes.

Distinguishing between pure X-by-wire and driving by software control the following states-of-the art are reported:

**Driving by software control (1E/1M):**

- Nowadays, vehicle architectures enable automated driving up to a certain level of automation. Today this level means ACC, lane keep assist and some combined longitudinal and lateral control applications such as stop-and-go assistant;
- For this kind of automation the safety integrity levels of the in-vehicle systems are sufficient. If they are still sufficient when a higher degree of automation is applied, or e.g. hands-off-the-wheel-driving will be allowed, will need to be clarified under the perspective of legal issues;
- There are many systems like sensors, actuators and data processing units in serial production that enable this level of automated driving;
- There are initiatives like AUTOSAR that develop tools and processes (also software and hardware) for safe execution of power train demands. They are designed for 1E/1M architectures;
- Some actuators (e.g. a throttle pedal with built-in force feedback) are available on the market;
- The main question that is still unsolved is which degree of automated driving applications will be allowed and is useful with this architecture. For example, today there is a limit for the deflection force at the tires that can be applied during a steering intervention. How far can this limit be enhanced with a 12V battery supply?

**Pure X-by-wire (2E):**

- No 2E architecture systems are currently near serial production. There are only some prototypes available that could be part of X-by-wire systems. These prototypes are:
  - Steering wheel actuators that apply haptic feedback to the driver's hands;
  - Redundant bus system components like FlexRay couplers and gateways;
  - ECUs that are already operation at SIL-3, that might be extendable to higher SI-Levels;
  - There are some software development environments on the market (e.g. SCADE) that are certified;
  - A homologation procedure for how to allow a brake-by-wire system to drive on public roads is currently developed within EU-HAVEit;
- There is a big gap between these single prototype components and the opportunity to produce them in mass production;
- Industries like avionic suppliers could deliver some impact on automotive X-by-wire but this is not a comparable industry in terms of costs, innovation cycles and the requirements of the pilots/drivers.

To summarize the state-of-the-art, the distinction between these two technologies – 1E/1M and 2E - is evident:

- The current 1E/1M technology (software control of throttle, brake, steering) can also be used for a certain level of automated driving applications even without pure X-by-wire technology;
- The current X-by-wire prototype components such as steering actuators and redundant data processing devices are not ready or even prepared for mass production.

## 7.8 Research gaps on X-by-Wire

The following components or systems are essential for X-by-wire systems and are mostly not available on the market today. Some of them are available in prototype status so further research might bring them closer to application.

- The current V2X-applications that are already available on the market do not perform active control assistance. There is a potential to use the forthcoming connected cars information for active vehicle control (e.g. automated speed control, emergency brake by V2X information etc.);
- New power supply systems (42 Volts) with much higher operating efficiency are essential to meet the demand for increased electrical power requirements. Currently there is no global standard architecture defined for the 42V system. 42V technology has to be mature before X-by-wire products can be mass produced;
- Serial production of X-by-wire components like actuators and redundant data processing devices should be stimulated. Some prototypes of failsafe components are available but there are only a few activities visible to bring them to mass production;
- Cost/weight of the components should be reduced through the use of new materials, value engineering, and potentially through making more parts common, e.g. corner modules;
- The emerging fully electric vehicles can in principle provide the higher voltages needed for autonomous driving vehicles, by adapting the voltage from the power train batteries to serve the steering systems;
- A “killer application” of X-by-wire hasn’t been found yet. A study dedicated to combine modern vehicle information technology with the opportunities of X-by-wire could stimulate new applications and products;
- There are a lot of X-by-wire-applications which may be achievable even with the existing 1E/1M-technique that are not found on the market today (e.g. an ACC that is combined with V2X-technology so that the velocity of the vehicle is controlled by the phase of the traffic light ahead). Compare Section 10. One solution is a research opportunity here, to search for adequate applications using today’s technology.

## **8 Aspect 7: Sensor systems**

Sensor systems are obviously essential for automated driving. The sensor systems are the eyes of the vehicle. The main purpose of the sensor systems is monitoring the state of its surroundings and the state of its own vehicle.

### **8.1 Required sensor systems in the automated vehicle and on the road side to observe the driving state and the state of the environment**

Within this section different sensor systems are defined for automated driving application. First, different types of sensors are stated for the vehicle and road side. Second, the desired accuracy of the sensor systems are defined for various automated driving applications. And finally, the integration of different sensors is defined this section.

The two main goals of most sensors used for in-vehicle and infrastructure systems are first to determine driving state, i.e. position and movement of the vehicle, and second, to sense the environment, i.e. surrounding vehicles and/or obstacle. Two additional goals of sensor systems can be object classification (e.g. vulnerable road users, road sign recognition) and communication to other road users. The sensors that can be used for in-vehicle measurements are subdivided in these four categories, see

Table 6. These categories are also shown in Figure 30.

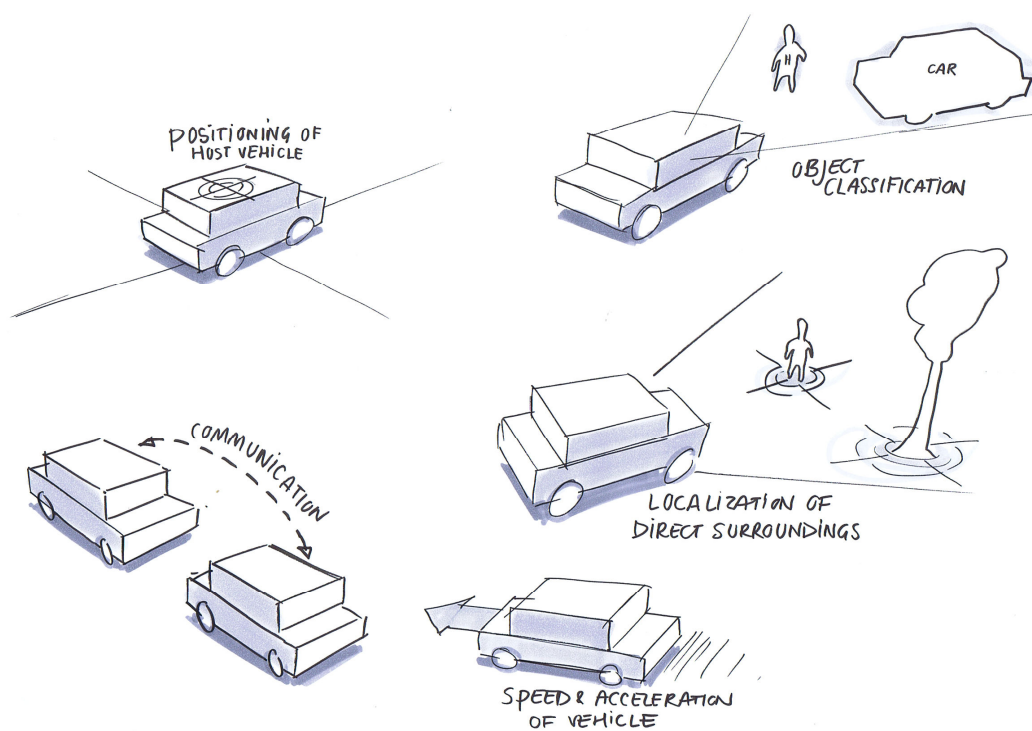


Figure 30: Categories for sensor systems of automated driving applications. Here, position and speed & acceleration are defined as one category



**Table 6: In-vehicle sensors**

	Driving state own vehicle	Environment state	Communication	Object classification
Microwave radar (24 GHz and 77 GHz)		x		
Lidar		x		
Camera (mono, stereo, 3D)		x		X
Global Navigation Satellite Systems (GNSS)	x			
Positioning with land based mobile phone technology	x			
UMTS			x	
802.11p			x	
Digital map	x			
Ultra-sonic based systems		x		
Infra red				X
Accelerometers	x			
Gyro sensors	x			
Wheel speed sensors	x			

The sensor systems that are used at the infrastructure are also divided in the four categories mentioned above.

**Table 7: Infrastructure sensors**

	Driving state own vehicle	Environment state	Communication	Object classification
Cameras	X	x		x
Beacons	X			
Lane markings	X	x		
UMTS			x	
802.11p			x	
Induction loops	X	x		
Radar	X	x		
Lidar	X	x		

The accuracy that is required for the sensor systems of automated driving vehicles is directly related to the automated driving application. Unfortunately, there is no generic answer to this question as yet. Therefore, in Table 8 the accuracy for each sensor is defined in relation to a specific automated driving applications.

**Table 8: Sensor for various automated driving applications.**

Application	Type of sensor (in-car)	Accuracy needed	Minimal sensor set needed	Contribution from roadside
Automated lane keeping	Camera, beacon detection, DGPS, steering wheel sensor, inertial sensors, digital map	Positioning* < 0.1 m, 0.5 o/s for gyroscopes	Camera, steering wheel sensor, inertial sensors	Lane markings, beacons

Platooning	Radar, lidar, vision, GNSS, mobile phone triangulation, vehicle-to-vehicle comm. (V2V), vehicle-to-infrastructure comm. (V2I), inertial sensor	Positioning* < 0.1 m, velocity < 1 m/s, acceleration < 0.1 m/s <sup>2</sup>	Radar or camera (mono) and inertial sensors. Platooning with short time headways includes V2V communication	Detect other traffic (not necessary)
Safety pull over	Driver monitoring (camera, IR), GNSS, map data, lidar, radar, camera (lane detection), inertial sensors, V2V, V2I	Reaction < 1 s, positioning* < 0.1 m, velocity < 1 m/s, acceleration < 0.1 m/s <sup>2</sup>	Driver monitoring (camera), radar or lidar or camera (at least 180° field of view), camera (lane detection), inertial sensors	Detect irregularities of vehicles
Lane merging assistance	Radar, lidar, camera, GNSS, map data, V2V/V2I-802.11p, inertial sensors, camera (lane detection)	Positioning* < 0.1 m, velocity < 1 m/s, acceleration < 0.1 m/s <sup>2</sup>	Radar or lidar or camera, inertial sensors, camera (lane detection), wireless comm. 802.11p	Detect vehicles at the main track and/or ramp-up
Road pricing	GNSS, inertial sensors, UMTS, V2I-802.11p, transponders (in combination with beacons)	Positioning < 10 m	GNSS, UMTS	Cameras, UMTS or 802.11p, beacons
Parking	Radar, lidar, camera, ultra-sonic, inertia sensors, UMTS to traffic management center	Positioning < 0.05 m	Ultra-sonic	Lane marking, parking spot availability
Collision avoidance for VRUs	Radar, lidar, camera, IR, inertial sensors, UMTS, 802.11p	Object classification, positioning < 1 m	Vision, inertial sensors	-

It is considered to be fundamental for automated driving applications to integrate several sensors. Often, sensor systems are complementary to each other. For example, integration of:

- Short range radar and long range radar/lidar. This increases accuracy for sensing over a larger range in front of the vehicle;
- Numerous radar systems around the vehicle. A complete 360° field of view can be created to monitor the environment around the vehicle;
- Camera (mono) and radar. In general, radar is more accurate for longitudinal distance measurements and a camera is more accurate to determine the lateral position. Integrating these sensors results in an increased accuracy of both longitudinal and lateral position. Furthermore, the camera adds the opportunity for object classification of detected objects;
- Inertial sensors and GNSS. The update rate of low cost GNSS is often low (about 1 Hz). This limits the update frequency of position and velocity measurements. Inertial sensors can be used to increase the update rate and provide increased resolution between GNSS fixes. Inertial sensors can also be used to extrapolate position information when the GNSS signal is lost.

## 8.2 Does the current performance of sensors suffice?

In general the current performance of sensors suffices. The current performance of necessary sensors is evidently sufficient to allow various automated driving applications that are currently on the market. However, current sensors are open for improvements (see Section 8.3), and as automated driving systems will in the future demand increased complexity, they will also demand improved sensor systems.

Regarding the infrastructure, current sensors could also be further improved and coverage increased to monitor larger areas. For instance, current infrastructure is not able to measure acceleration of vehicles. Also, robustness and bandwidth should be increased for wireless communication in order to exchange information between vehicles and between vehicle and infrastructure.

Current automated driving systems are already compliant with these sensor needs. Nowadays, several automated driving applications are available on the market.

## 8.3 Need to develop new types of sensors

It is necessary to continue development for new and existing sensors. Currently, there is a lack of sensors that are able to measure the acceleration of other objects in its surroundings accurately. Regarding existing sensors, improvements are needed on:

- Accuracy;
- Reliability;
- Range;
- Costs, especially for mass production.

## 8.4 Potential role of sensor fusion in reducing costs

Sensor fusion is a key technology for automated driving applications. By combining several cheap sensors a price reduction may well be possible. In Section 8.1 cheap GNSS is combined with inertial sensors. It increases the update rate, enables high frequency measurements, and also extrapolation when the GNSS signal is lost.

## 8.5 Potential role of sensor fusion in improving performance of systems

As mentioned in Section 8.1, many sensors are complementary to each other. Improved performance (e.g. accuracy and robustness) of sensors can be reached with sensor fusion. In Section 8.1 the following sensor fusion combinations are explained in detail:

- Short range radar and long range radar/lidar;
- Numerous radar systems around the vehicle;
- Camera (mono) and radar;
- Inertial sensors and GNSS.

In order to accelerate the developments of sensor fusion it is potentially interesting to define standards that enable sensor fusion of different sensors in more generic ways.

## 8.6 Minimal sensor set needed

The minimum sensor set needed for automated driving is directly related to the automated driving application. Therefore, in Table 8 the minimum sensor set is defined for a number of automated driving applications.

In general, the minimum sensor set for automated driving applications is made of sensor systems that measure the state of the own vehicle (inertial sensors and/or GNSS) and measure its direct surroundings (e.g. radar, lidar and/or camera).

## 8.7 Future research needs in this field

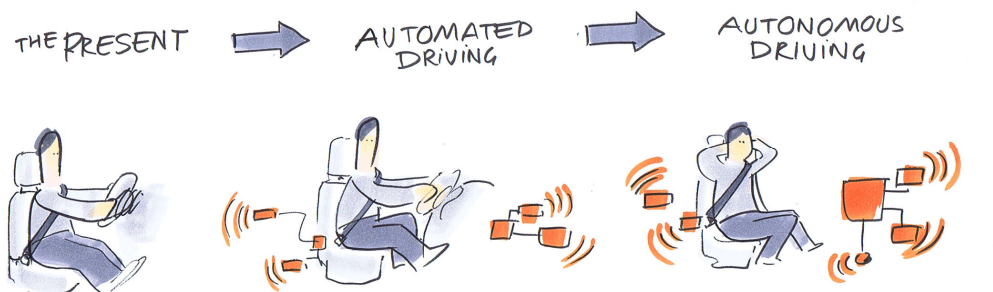
One future research need in the field of sensor systems for automated driving that shows a lot of potential is communication, both vehicle-to-vehicle and vehicle-to-infrastructure communication. Sharing data between vehicles and road operators can enrich local information for automated driving systems. Currently, road operators receive a lot of information from induction loops and cameras, and increasingly from vehicles (e.g. floating car data). Applications that actuate vehicles in return based on this additional information are very limited.

Furthermore, camera sensors are potentially interesting for low cost substitutes of radar and lidar systems. Artificial vision combined with necessary computing algorithms can improve detection with vision systems.

The role of the driver within the vehicle will change with the introduction of more highly automated driving systems, see Figure 31. Therefore, driver interface, ergonomics and driver monitoring will become more and more important.

Another future research need in the field of sensor systems is increased accuracy and robustness for GNSS systems. This is also mentioned in Section 9.

And finally, the last research need, is related to sensor fusion. As mentioned in Sections 8.4 and 8.5, sensor fusion has a high potential to increase robustness and decrease costs. This should be further exploited.



**Figure 31: The role of the driver in highly automated driving systems**

## 9 Aspect 8a: Positioning

Positioning of the automated vehicle is essential in automated driving. In this section, the needs regarding positioning systems are defined. The current positioning systems are compared to the needs of positioning systems for automated driving. The final topic of this section is related to global navigation satellite systems.

### 9.1 Needs regarding the position system

The needs of the position system are directly related to the application. Therefore, the needs, e.g. accuracy and update rate, are given for four different generic applications:

- Routing and guidance applications, including lane matching based on map information;
- Longitudinal control in urban or highway applications;
- Lateral control in urban or highway applications;
- Parking applications.

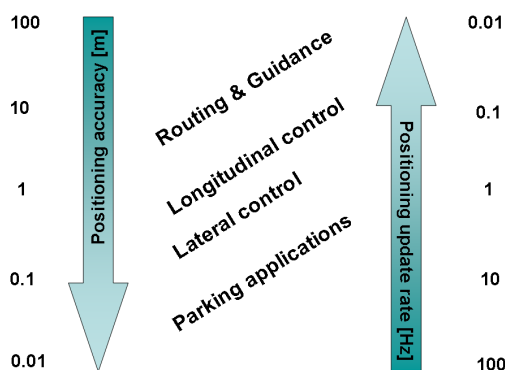
For basic routing and guidance a positioning system is needed with an accuracy in the order of the decameter level, in combination with map matching. If lane matching is included the accuracy should be increased to the meter level. The update rate regarding this application is between 0.1 and 1 Hz.

For longitudinal control (e.g. platooning, collision warning/avoidance) accuracy of between decimeter and meter level is needed. The update rate should be increased to 1-10 Hz.

The accuracy for lateral control (e.g. lane keeping) should be increased even more. Accuracy between centimeter and decimeter level is necessary for these applications. The update rate is in the same range as longitudinal control.

The positioning accuracy for parking applications is centimeter level. The update rate is at least in the order of 10 Hz or more.

These needs are summarised in Figure 32.



**Figure 32: The ranges regarding accuracy and update rate for different applications**

It is very important that these systems meet these specifications in all circumstances. Note that time delays within the positioning system are directly related to the positioning accuracy and positioning update rate. Therefore the needed time delays are not mentioned above.

## 9.2 Comparing the needs with possible technologies

The needs regarding the positioning systems can be fulfilled with, or in some cases combinations of, current sensor systems, e.g. global navigation satellite systems (GNSS), radar, lidar, ultrasonic, vision. For the latter of this section we will focus on GNSS. First, the question is addressed whether GNSS could deliver the proper resolution for automated driving applications. Second, the potential is discussed to combine GNSS with other sensors to improve positioning accuracy. Then, possible solutions are proposed when GNSS signal is lost. The future research needs in the field of GNSS concludes this section.

### Role of Global Navigation Satellite Systems (GNSS). Would they deliver the proper accuracy?

There are various GNSS systems available. Here, GNSS is limited to GPS (global positioning system) [59], EGNOS (European Geostation Navigation Overlay Service) [60,61], Galileo [62] and RTK-GPS (real-time kinematic) [63]. Since the accuracy of GPS, EGNOS, Galileo and RTK-GPS are typically about 10 meter, 1.5 meter, 1.5 meter and 1 meter, respectively, GNSS systems can only play a role in routing and guidance, and longitudinal control applications.

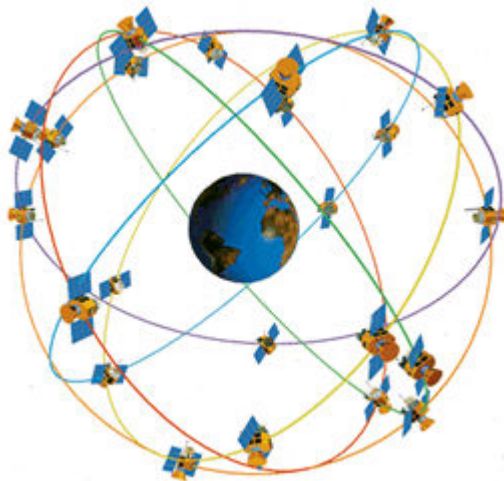


Figure 33: Global navigation satellite system (source: aero.org)

In particular, GNSS require line of sight communications, so signals become lost when vehicles are shielded for example by trees, in tunnels, or in street canyons. Consequently, GNSS cannot be relied on to function properly *at all times*. When the communication signal with the satellites is lost, the accuracy will decrease rapidly. In-car sensors should then be used to maintain positioning robustness.

### Potential of combining GNSS with sensors towards improvement of the accuracy

The accuracy of GNSS can be improved with other reference signals, such as

- Mobile phone cell triangulation;
- Local reference signals (e.g. infrastructure, beacons);
- Map information;
- Inertial sensors.

Especially, the inertial sensor set is very appropriate to interpolate GNSS signals to increase update rate. For instance, the OXTS inertial+ [64] increases positioning updates to 100Hz. Note that absolute positioning accuracy is still dependent on receiving the GNSS signal. The other reference signals are potentially interesting to increase the absolute positioning accuracy. Increasing GNSS positioning accuracy based on map information is often used by navigation devices. Beaconing is also used for differential GPS (DGPS). It corrects GPS signals from a known position using a fixed network [65]. EGNOS uses DGPS to improve its positioning.

### What to do when the GNSS signal is lost during driving?

When the GNSS signal is lost during driving, which can be due to different reasons as shown in Figure 34 (trees, high building, bridges, tunnels), extrapolation based on inertial sensors is suitable.



Figure 34: Reasons why GNSS signals are lost during driving [64]

These type of systems are currently already on the market. Again, [64] acts as an example. Besides interpolation of GNSS signals it extrapolates GNSS signals as well. When a GNSS signal is lost during driving it will have a drift of only five meters after two minutes.

If the GNSS signal remains lost, and a suitable alternative positioning system is not available, a degradation procedure should be implemented to lower the automation level of the vehicle.

### Future research needs in this field

Future research can be focused on different topics. First of all, future research can be focused on increased accuracy. Note, this would only be a necessity if GNSS is also used for lateral control and/or parking applications. A second future research topic could be to increase reliability. GNSS signals are currently easily lost while driving in tree covered areas or urban surroundings with high buildings, bridges and tunnels. Next, for automated driving it would be very beneficial that all traffic participants (not only vehicles) send out their positions at all times. This would increase safety when other road users are not within line of sight. And finally, the costs of high performance GNSS systems need to be reduced. This would increase the availability of these systems around Europe.

## 10 Aspect 8b: Applications

Numerous automated driving systems are already available on the market. These automated driving systems are identified in Section 10.1 together with future systems as defined in various (inter)national projects. Some additional focus is given on traffic state for route planning in Section 10.2, and automated parking applications are presented in Section 10.3.

### 10.1 Current and possible future applications based on automated driving

Many current vehicles are already equipped with some level of automated driving systems. For instance:

- (Adaptive) Cruise Control [66];
- Adaptive Cruise Control including stop & go, e.g. [67,72];
- Collision mitigation by means of automated braking, e.g. [67,68,69];
- Collision avoidance by means of automated braking (preventing an accident), e.g. [67,68,70];
- Lane keeping by means of automated steering, e.g. [69,71];
- Dynamic route information based on current traffic situation on the road [73];
- Assistance or automated driving in difficult manoeuvres (parking), e.g. [69,76];
- Electronic stability programs, e.g. [68,72].

Future applications will focus on a higher state of automated driving, in order to improve

- Safety;
- Comfort;
- Traffic flow;
- Emissions.

In recent European and national projects, a large number of automated driving applications have been and are being developed. Many of these applications will become available for the public in the next decade. The future applications defined in this section are applications from the projects summarised in Section 2.1:

- Traffic jam assistant that combines both full longitudinal and lateral control at low speeds;
- Platooning both in highway and urban scenarios;
- Intelligent speed adaptation based on information received from other vehicles and/or infrastructure;
- Highly automated driving in specific situations that are potentially hazardous for drivers (e.g. road works);
- Lane change assistant;
- Lane merge assistant;
- Curve speed control based on other vehicles and/or map information;
- Automated driving for specific e-lane scenarios;
- Active green driving, based on dynamic map information
  - advisory speed;
  - power train optimization;



- traffic management;
- Automated public transport applications
  - Automated taxis;
  - City car share schemes;
  - Guided buses;
  - Group and Personal Rapid Transit (G/PRT) systems;
  - Advanced City Cars (with dual mode, i.e. manual and automated driving capabilities);
- And finally: fully automated driving in everyday situations.

In Figure 35, the current and possible future applications of automated driving systems are summarized.

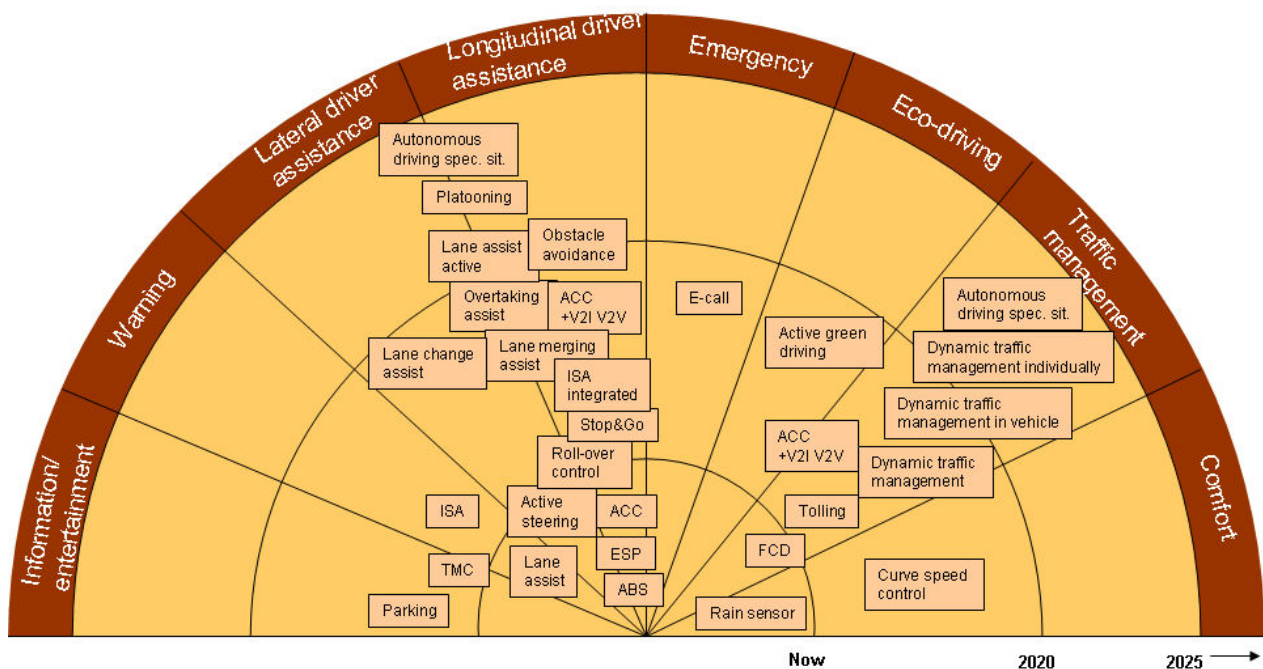


Figure 35: The current and possible future applications based on automated driving.

## 10.2 Readiness of current traffic control and communication technologies to take into account the state of traffic when planning a trip

Nowadays, it is possible to determine the current state of traffic on the roads in most cities and on most highways. Loops in the road can detect vehicles, which results in differing traffic signs and signals at intersections. The traffic speed and flow information collected by the loops can also be used to monitor congestion, and together with a growing number of cameras, and communication with emergency personnel and road inspectors are typical tools to determine the traffic situations for the national road authorities. This information is sent back to a traffic control centre. From the traffic control centre two forms of actuation are possible:

- Radio broadcast;
- Dynamic road signs.

Dynamic road signs are for instance Dynamic Route Information Panel (DRIP), Graphic Route Information Panel (GRIP), Parking Route Information System (PRIS), dosing systems for the acceleration lane, and traffic lights [74], see also Figure 36.



**Figure 36: Current infrastructure communication technologies; dynamic road signs (1), GRIP (2), PRIS (3), DRIP (4), dosing system acceleration lane (5), traffic signs (6)**

Unfortunately, it takes about 5 to 30 minutes in order to communicate this information to the vehicles on the road. Floating car data, based on mobile phone tracking technology, is currently used by single manufacturers [73]. In this specific case, communication to the drivers is done by means of 3G (cellular network).

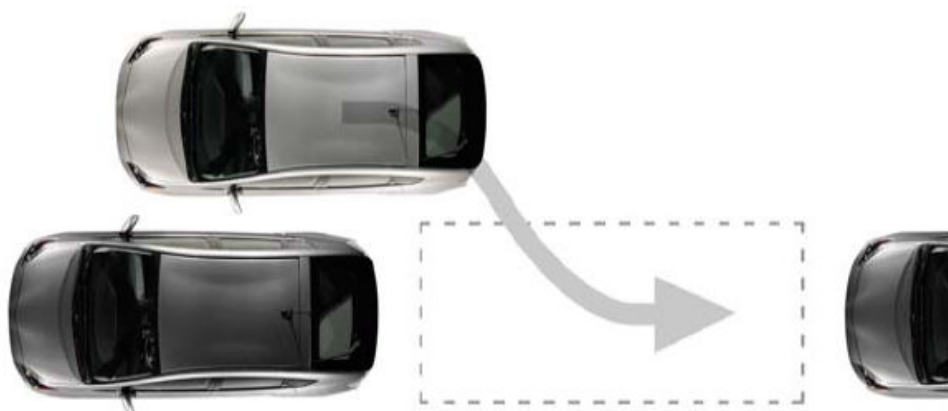
Although some basic steps are made to determine and communicate the current road situation to drivers in their vehicles, it is necessary to improve both aspects for automated driving applications. Although current communication technologies, e.g. 802.11p and 3G, are available, implementation of these technologies is very limited. Focus should be on implementation of these communication technologies. Another improvement that has a great potential is integration of in-car and infrastructure, both on the sensor data and actuation levels. Freilot is a European project that evaluates the added value of connecting infrastructure with in-car systems [75]. This project aims at increasing energy efficiency of urban freight by using deployment of intelligent services.

### 10.3 Integration of automated parking in navigation systems

Automated parking should always use highly accurate in-car sensors, since centimeter level accuracy is necessary for this application, see Section 9. Although all common navigation systems lack the centimeter accuracy needed for automatic parking, there are some addi-

tional benefits for integration of automated parking in navigation systems. In urban surroundings it is often a big challenge to find an appropriate parking spot. An added feature for navigation systems could be real time access for parking reservations and parking availability. The navigation system could guide the driver to the appropriate (reserved) parking spot. It will save time for drivers seeking a parking place and reduce traffic from drivers circulating while looking for spaces. Next to the two parking applications, additional information regarding further transportation options can be very helpful.

Currently, parking manoeuvres are already available in advisory and semi-automated advanced driver assistant systems, see Section 10.1. On the short term, these parking manoeuvre systems will develop to be fully automated systems.



**Figure 37: Automated parking application [69]**

The current strategies on the combination of automated driving and parking spot booking are limited. There are some car share clubs (e.g. Greenwheels in the Netherlands), but this is not directly related to automated driving. Obviously electric vehicles have more restrictions to parking spots, since there is the additional need of charging points.

### **Future strategies on the combination of automated driving and parking spot booking in congested urban areas**

One future strategy on a combination of automated driving and parking spot booking is that the vehicle control is taken from the driver to take the vehicle to a suitable parking spot and automatically park the vehicle.

Another strategy could be focused on increase of traffic density in urban areas. One can think of “active” roads with controllable lane marking that can be changed during the day with respect to the current parking situation and/or traffic situation. This active roads can interact with automated driving vehicles.

## 11 Aspect 9: (Potential) key players

This section focuses on key players and their role in the field of automated driving systems. The focus is on the applications as indicated in Section 1.2.

### 11.1 Current key players

To avoid the risk of overseeing one or more major key players it was decided not to make more or less random lists of parties active in this field, but rather to report the active partners involved in 6 main projects, which are identified previously in Section 2.1. This project selection is based on the following criteria:

- The project should cover parts of one or more scenarios as described in Section 1.2;
- Different types of stakeholders are involved;
- Automation is included;
- European focus.

The 6 main projects which are selected are:

- **HAVEit [1];**
- **Interactive [2];**
- **CityMobil [3];**
- **Safespot [4];**
- **Sartre [13];**
- **GCDC [17].**

The partners of these projects are shown in Table 9 (OEMs), Table 10 (Tiers) and Table 11 (R&D Institutes).

**Table 9: OEM key players**

OEM	HAVEit	Interactive	CityMobil	Safespot	SARTRE	GCDC
Volvo	X	X		X	X	X
Volkswagen	X	X				
Ford		X				
BMW		X				
CRF, Fiat		X	X	X		X
Daimler		X		X		
Renault				X		
Piaggio				X		
DAF						X
Scania						X

**Table 10: Tier key players**

Tiers	HAVEit	Interactive	CityMobil	Safespot	SARTRE	GCDC
Continental	X	X		X		
Sick	X					
Haldex	X					
EFKON	X					
Explinovo	X					
Autoliv		X				
Delphi		X				
Navteq		X		X		

TRW		X	X			
Allround Team		X				
Alcor		X				
Advanced Transport Systems			X			
CSST <sup>2</sup>			X	X		
ETRA			X			
GEA			X			
Robosoft			X			
Bosch				X		
ANAS				X		
MIZAR				X		
IBEO				X		
Kapsch				X		
Lacroix Traffic				X		
Planung Transport Verkehr				X		
Q-Free ASA				X		
Tele Atlas				X		
Peek Traffic				X		
Thomas Miller				X		
TEL <sup>3</sup>				X		
AT4				X		
Magneti Marelli				X		
TRANSVER				X		
Denso						X
Safer						X

**Table 11: R&D institute key players**

R&D institutes	HAVEit	Interactive	CityMobil	Safespot	SARTRE	GCDC
TNO		X	X	X	X	X
DLR	X	X	X	X		
EPFL <sup>4</sup>	X		X			
ICCS <sup>5</sup>	X	X		X		
ILS <sup>6</sup>	X					
WIVW <sup>7</sup>	X					
Knowllence	X					
HAW AM-WEN <sup>8</sup>	X					
Budapest University	X			X		
INRIA <sup>9</sup>	X		X			
Lab. Central d PetC - IFSSTAR	X			X		
BASt		X				
CTAG <sup>10</sup>		X				
IKA		X	X		X	

<sup>2</sup> CSST, Centro Study sui Sistemi di Trasporto<sup>3</sup> TEL, Telefonica Investigacion y Desarrollo Sociedad Anonima Unipersonal<sup>4</sup> EPFL, Ecole Polytechnique Federale de Lausanne<sup>5</sup> ICCS, Institute of Communication and Computer Systems<sup>6</sup> ILS, Universitat Stuttgart, Institut für Luftfahrtsysteme<sup>7</sup> WIVW, Wuerzburg Institute of Traffic Sciences<sup>8</sup> HAW, University of Applied Sciences Amberg-Weiden<sup>9</sup> INRIA, Institut National de Recherche et Informatique et en Automatique<sup>10</sup> CTAG, Galician Automotive Technological Center

VTT		X		X		
Lund University		X				
University JF Grenoble		X				
Chalmers		X				X
University of Passau		X				
Czech University		X				
University of Trento		X				
EICT <sup>11</sup>						
ISIS <sup>12</sup>			X			
ITS Leeds			X			
SINTEF			X			
Technicon Israel			X			
University Leuven			X			
University Southampton (TRG)			X			
Cidaut				X		
University Genova				X		
Hellas Centre for R&T (CERTH)				X		
ISMB <sup>13</sup>				X		
MIRA				X		X
SODIT				X		
University Chemnitz				X		
University Munchen				X		
Politechnica Warszawska				X		
University Madrid				X		
Tecnalia					X	
IDIADA					X	
Ricardo					X	
SP Sweden					X	
University Eindhoven						X
Fontys Hogescholen						X
University Twente						X
Waterloo University						X
Inst. Measurement and control						X
University Karlsruhe						X
Okan University						X
University Ohio						X
HAN University						X
University Delft						X
KTH Sweden						X
Victoria Institute						X
Halmstad University						X
Latvia University						X
Inst. Electronics and Computer Science						X

<sup>11</sup> EICT, European Center for Information and Communication Technologies

<sup>12</sup> ISIS, Istituto di Studi per l'Integrazione dei Sistemi

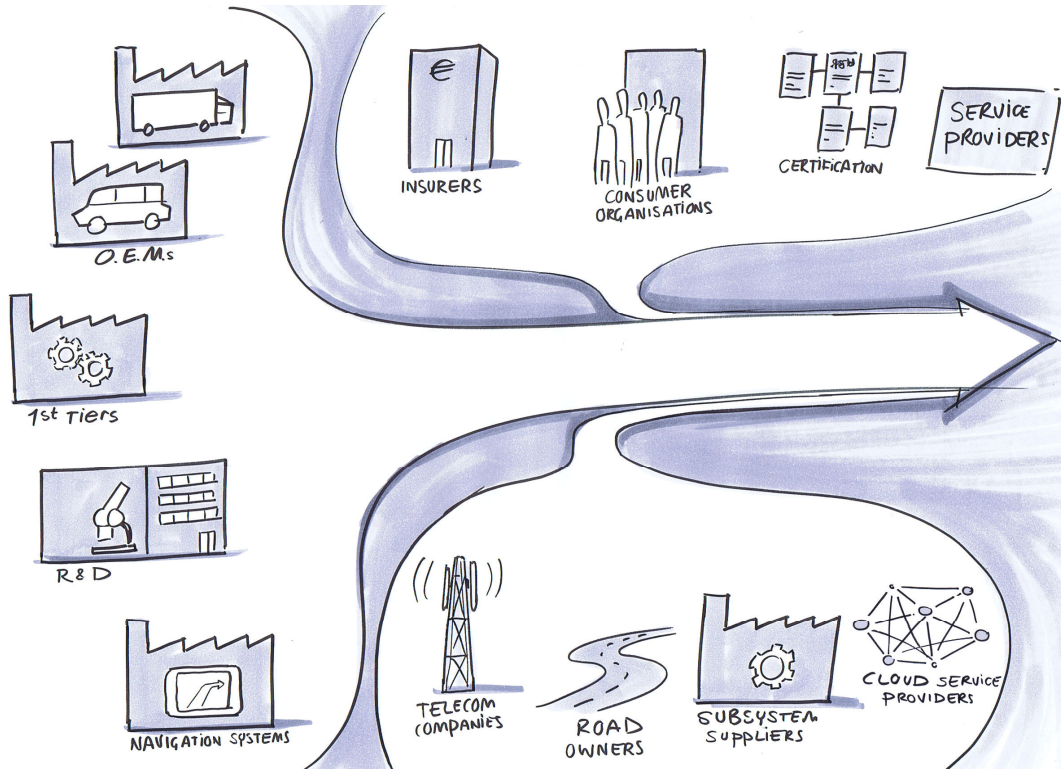
<sup>13</sup> ISMB, Istituto Superiore Mario Boella

## 11.2 New key players within the period until 2025

In the upcoming period, key players will have to choose their positions carefully. New players and new types of players will enter the field, see Figure 38. The role of, for instance, service providers, telecom companies and insurance companies will be increasing, which will in turn influence the possibilities and roles of the current players. It might even be that parties like these will enter the market with completely new products which could disrupt the current balance, offering a totally new view on the topic.

Foreseen types of key players within the period until 2025 are:

- Telecom companies;
- Service providers;
- Truck OEMs when legislation becomes available;
- Car OEMs from specific countries (Korea & China);
- Suppliers of information technology solutions;
- Suppliers of subsystems, aftermarket systems and sensors;
- Insurance companies;
- Certification/Homologation organizations (also for software);
- Road construction & maintenance companies;
- Manufacturers of high efficiency electric motors for X-by-wire systems;
- Software development companies;
- Consumer organisations.



**Figure 38: The players in the field of smart mobility will be changing significantly over the coming years**

### **11.3 Activities of current key players in this field**

Many of the above mentioned key players are working on several of the projects mentioned within Section 2.1.

### **11.4 Current products of key players**

Many products are mentioned within Section 2.3. Amongst others:

- Obstacle detection;
- Automatic cruise control with 'Stop & Go' capability;
- Lane keeping assistance;
- Automated parking;
- Location (GPS) and navigation systems;
- Autonomous route guidance;
- Information and communications systems and services coupled with route guidance;
- Intelligent speed adaptation.

### **11.5 Potential contribution of key players to the deployment of automated driving**

Automated driving represents a collection of concepts and applications that have the potential to enhance safety on the road, improve traffic flow, and contribute to reduced fuel consumption and less CO<sub>2</sub> emissions. At the foundation of (cooperative) automated driving lie several basic technologies like automotive radars, cameras and dedicated communications between cars and between cars and road infrastructure. Many of these technologies and applications are readily available or are currently under development, but their market introduction will take place gradually and for some of them may last 10 to 20 years. From another perspective, however, several automated driving technologies have already entered the market within premium cars.

There are several reasons why many companies are not particularly interested in accelerating the deployment of automated driving. First of all, there are implications in urban and highway traffic resulting from adding advanced driving assistance systems (ADAS) to new vehicles and addressing simultaneously the liability of vehicle manufacturers in undesired situations or the need for new legislation. In particular, changing the legislation is a slow process and automotive companies may decide not to undertake risks before the legal and/or liability framework has been completed.

A second reason that is often cited by various industry representatives to interfere with the deployment of automated driving, is the relation between vehicles equipped with ADAS and the required infrastructure equipment to enable communication with these vehicles. Deploying the right infrastructure requires investments, which can only be paid off if there are enough cars making use of the new roadside units. This upgraded road infrastructure needs to be provided by a scattered audience of national and local road authorities.

Last, but not least, automated driving, when including cooperative driving, requires by definition the collective participation of more than one vehicle at a time in the process of exchanging traffic information. In many situations, the information communicated wirelessly can become crucial in avoiding accidents or mitigating a traffic jam. Because of the collec-



tive participation of multiple participants in traffic, the deployment of cooperative driving technologies requires practical validation by dedicated field operational tests (FOTs) that tend to be cost prohibitive and cannot be solely performed by one vehicle manufacturer or system supplier. This results in organizational delays, the need for adequate funding, and the need for common interests in a competitive market. On the other hand, these FOTs can also be seen as an instrument to deployment, as significant numbers of vehicles then are equipped with dedicated systems.

Essentially, the key stake holders in automated driving that wish to **move from R&D to market deployment** in a reasonable short time might consider the following guidelines:

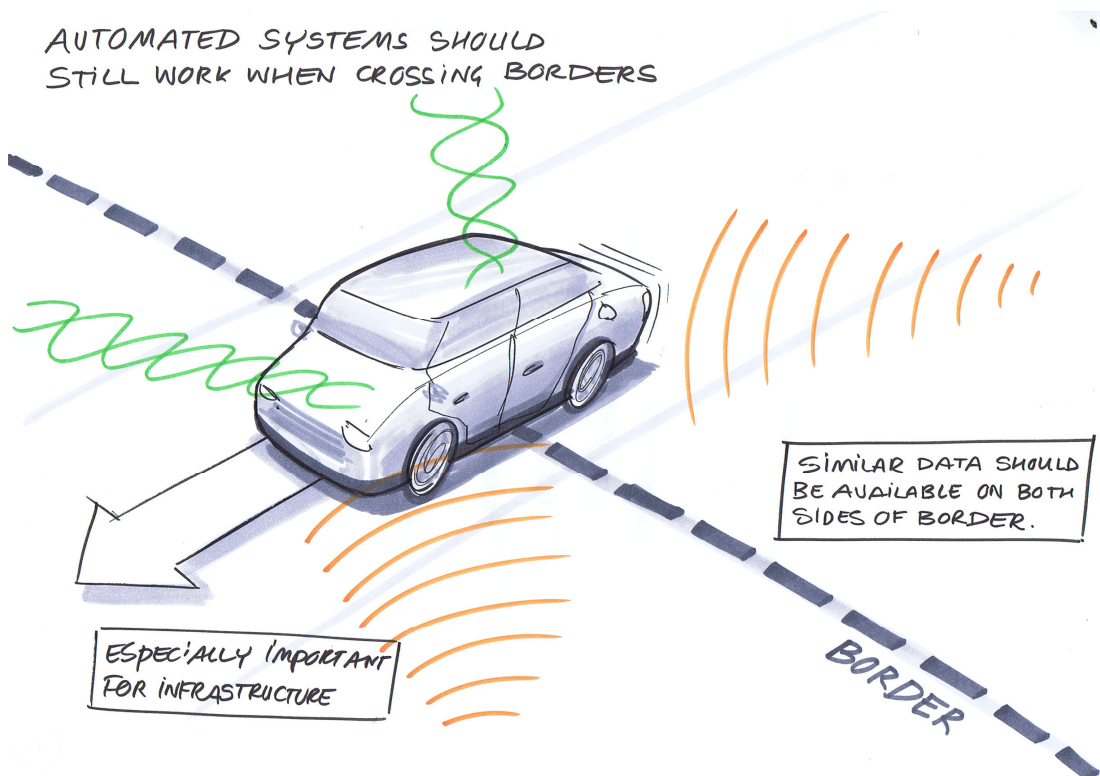
- Research solutions that temporarily bypass the need for significant investments in road infrastructure;
- Consider automotive applications that can be gradually built on top of the existing technical solutions (including communication networks) and later enhanced with dedicated technologies;
- Consider taking more business risks at various stages in the deployment chain, starting with vehicle OEMs and their suppliers and ending with governmental organizations and road administrators;
- Consider a more efficient spending of public finances by acting more toward solving real issues and implementing the necessary solutions than diversifying the R&D based on spin-offs from previous research results;
- Create novel business models, refine and implement them toward profitability rather than waiting until, for example, the appropriate road infrastructure becomes operational;
- Act more self-critically when participating in public projects by taking into account the return of investment to the public domain as to the return of investment to the participants company;
- Early research, development and production of the necessary mechanical and electronic components to allow the necessary availability at user-level price of the components needed (OEMs, Tier suppliers and ADAS suppliers);
- Early deployment of the necessary infrastructure (governments or local authorities, regulatory bodies);
- Good marketing related to autonomous driving, emphasizing the safety, security and reliability aspects, as well as the comfort and environmentally friendly aspects (consumer organizations).

## 12 Aspect 10: Cross border driving/standards

This section is concerned with the issues that must be addressed when automated vehicles cross international borders.

The essential requirement is that the system of automation used by the vehicle must continue to operate when the border is crossed i.e. the system of automation must be **inter-operable** with any other systems it depends on, on both sides of the border, see Figure 39. These other systems may be:

- In the ether;
- At the roadside;
- On other vehicles.



**Figure 39: Limits regarding cross border driving are mostly on the side of infrastructure**

If the system does not continue to operate as the border is crossed it must gracefully degrade by handing back the control of the vehicle to the driver in an appropriate way. However, this is out-of-scope here as this research concentrates on 'full implementation' of automated driving, also across borders.

**Interoperability with systems in the ether** means interoperability with systems which are inherently independent of borders, currently mainly GPS, some public satellite based telecommunications systems and other GNSS satellite systems under development for the future (GLONASS, EGNOS, Galileo); but also perhaps including the necessary electronic/digital maps carried on board vehicles which can be downloaded anywhere, anytime from the internet using the cellular network to support positioning, location and on-board navigation

sub-systems. Long range radio broadcasts that extend across borders, including some traffic messages broadcast over the Radio Data System (RDS-TMC) can also be considered in this category.

**Interoperability with systems at the roadside.** Roadside systems can be **passive** e.g. white lines and road markings or buried cables, magnets, which can be used by on-board systems to facilitate vehicle guidance; or **active** systems which may be used to support vehicle guidance as well as to communicate additional information such as floating car data and hazard or speed warning messages. The active systems may use a range of communication technologies including:

- Special 1-way I2V communication links (e.g. using radio, IR, microwave frequencies);
- Beacons / transponders (e.g. RFID);
- Radio broadcast (TMC);
- Special 2-way V2I communications: (e.g. using radio, IR, microwave frequencies);
- DSRC communication links (e.g. Wi-Fi);
- Mobile phones (e.g. GPRS, 3G).

If any of these systems are required to support the system of automation then that system must be able to recognise different systems used in different countries, and be able to interpret any relevant messages communicated.

**Interoperability with systems on other vehicles.** V2V communication may be required e.g. for hazard detection or vehicle following and merging. If V2V communication is a necessary component to support the system of automation then that system must be able to recognise different systems used in different countries, and be able to interpret any relevant messages communicated.

The last point, 'being able to interpret any relevant messages communicated' in both of the last two paragraphs above is extremely important. It means that information sent by the roadside or other vehicles should be in the same format on both sides of the border, and contain the same content.

## 12.1 Needs to make automated cross border driving possible

At the present time automated driving is possible in the sense that the automated systems acts like ADA systems; i.e. the driver remains responsible for the control of the vehicle. Definition of 'control of the vehicle' must be harmonised between countries. Going beyond ADAS, a clear definition of automated driving, which is accepted on an international level, must be agreed upon and legal regulations must be harmonised as well.

Looking at specific system components, especially connected vehicle systems (i.e. systems using data from other vehicles or the roadside) requires harmonization, or even better, standardisation (e.g. the ETSI standard). Also a minimum set of communication information must be agreed upon. Data from another country should be timely available before crossing the border to assure seamless crossing.

Another specific system component is the digital map, which must be of high precision and contain all required data in a format that is accessible. This requires a map standard not

only providing the required attributes in a certain way, but also providing map generation rules.

Road asset management harmonisation is of interest when automated systems use parts of the passive roadside systems (e.g. what is the minimal required visibility of a lane marking before the marking is replaced).

Finally, harmonisation on the homologation of automated systems and their support systems (like roadside systems) is required.

## 12.2 What standards towards the infrastructure may be needed to allow seamless automated driving across borders?

The standards required to ensure interoperability of components and systems, and hence to facilitate seamless automated driving across borders, will be determined by the harmonised European specification of automated driving and will include a **functional description** of the system of automated driving together with detailed specifications of the necessary:

- V2I and V2V services and communication links;
- Systems on-board the vehicle;
- Systems at the roadside;
- Systems in the ether e.g. GPS/GNSS, electronic maps;
- Architecture (of for instance user needs, functions, interfaces, communications links, data and flows);
- Linkages between subsystems and components and linkages with existing ITS systems and services including accidents and breakdown (e.g. eCall).

Foreseen necessary standards are to a large extent covered by the work of existing organisations including CEN, ISO and ETSI for standards, and projects such as FRAME for system architectures.

The main body concerned with relevant standards in Europe is **CEN** Technical Committee TC 278 'Road Transport and Traffic Telematics' [77]. TC 278 currently has 12 active Working Groups responsible for standards/standards development in areas as shown in Table 12.

**Table 12: Active Working Groups in TC 278**

CEN/TC 278 – Structure	
Secretariat	Chairperson
NEN	Mr L.Eggink
SC/WG	Secretary
	Mr J.A.Dijkstra
SC/WG	Title
CEN/TC 278/WG 13	Architecture and terminology
CEN/TC 278/WG 12	Automatic Vehicle Identification and Automatic Equipment Identification (AVI/AEI)
CEN/TC 278/WG 10	Man-machine interfaces (MMI)
CEN/TC 278/WG 16	Co-operative systems
CEN/TC 278/WG 15	eSafety
CEN/TC 278/WG 14	After theft systems for the recovery of stolen vehicles

CEN/TC 278/WG 3	Public transport (PT)
CEN/TC 278/WG 2	Freight and Fleet Management systems (FFMS)
CEN/TC 278/WG 1	Electronic fee collection and access control (EFC)
CEN/TC 278/WG 9	Dedicated Short Range Communication (DSRC)
CEN/TC 278/WG 8	Road traffic data (RTD)
CEN/TC 278/WG 4	Traffic and traveller information (TTI)

The WGs are responsible for 90 published (i.e. existing) standards [78] and some 51 standards under development [79]. With the possible exception of WGs 1 EFC, 2 FFMS, 3 PT and 14 'After-theft' systems, all the others can be relevant to a greater or lesser extent for automated vehicles that are in communication with the infrastructure; especially:

- WG 13 Architecture, for integration with existing systems;
- WG 10 MMI for driver guidance;
- WG 16 Co-operative systems for communication with the roadside.

Also relevant will be:

- WG 15 eSafety, for driver safety considerations;
- WG 9 DSCR for communication with the roadside and possibly other vehicles;

and possibly:

- WG 12 Automatic vehicle identification;
- WG 1 EFC for charging and access control;
- WG 8 RTD for hazard warnings and temporary network events like road works or dynamic speed limits (i.e. temporary updates of the digital map);
- WG 4 TTI for driver information and messages.

Particular consideration will need to be given to aspects of the system which are safety critical and the implications for reliability and security of data exchange.

The equivalent organisation under **ISO** is Technical Committee 204 'Intelligent Transport Systems' with 14 active Working Groups [80] as shown in Table 13.

**Table 13: ISO Technical Committee 204 – Structure**

WG 01	Architecture
WG 03	TICS Database Technology
WG 04	Automatic Vehicle and Equipment Identification
WG 05	Fee and Toll Collection
WG 07	General Fleet Management and Commercial - Freight
WG 08	Public Transport – Emergency
WG 09	Integrated Transport Information, Management, Control
WG 10	Traveller Information Systems
WG 11	Route Guidance and Navigation Systems
WG 14	Vehicle-Roadway Warning and Control Systems
WG 15	Dedicated Short Range Communications and For TICS applications
WG 16	Wide Area Communications - Protocols and Interfaces
WG 17	Nomadic and Portable Devices for ITS Services
WG 18	Co-operative Systems

It is evident from the tables above that there is a good deal of overlap between the work of the two organisations. In recognition of this overlap there is a formal mechanism agreed for CEN and ISO to work together and to share effort on the WGs that are common to both.

**ETSI** the European Telecommunications Standards Institute produces telecommunications standards for Europe which are effectively a subset of standards used by the telematics or ITS systems that are the subject of the CEN standards work described above. The international equivalent of ETSI is the **ITU** International Telecommunication Union, previously CCITT standards (from the French: "Comité consultatif international téléphonique et télégraphique")

Note that both CEN and ISO have working groups to cover systems architectures. Additionally, recognition of the requirements for including automated driving in the ITS Systems Architecture has been considered in the CityMobil project. **Appendix II** is an extract from CityMobil Deliverable D4.2.1 Systems Architectures for the e-lane scenario.

### **12.3 Conclusion and recommendations for automated cross border driving**

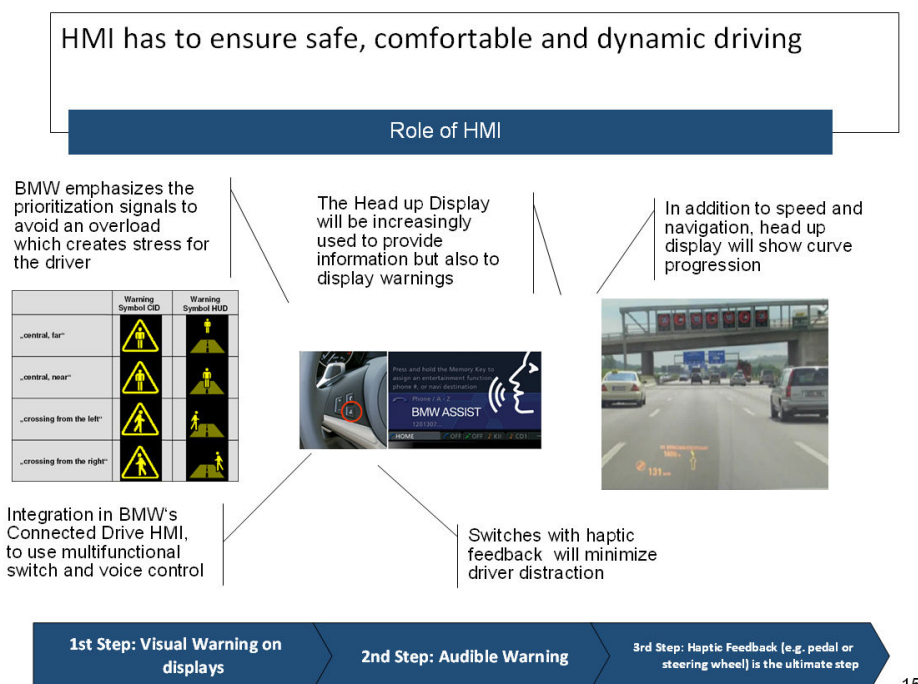
Concluding on the foregoing sections, the most important step to take first is to come to a common understanding, or better, a common definition of automated driving including the involved systems. Automatic equipment that is self-contained within a vehicle and meets individual country legislation should then be allowed to cross the border.

The next hurdles depend very much on the system architecture that should realise automatic driving. If an automatic driving system heavily depends on external sources like roadside data, harmonisation and standardisation of the communication and the communicated data is required.

Hence an initial rapid introduction is most probable using in-vehicle solutions, taken that they will act as driver assistance systems. It is necessary to give time to the different standardisation and certification bodies to define the international standards for more advanced systems and the systems outside the vehicle.

### 13 Aspect 11: Human driver interaction

While for many organisations the focus is on the technological developments regarding automated driving, SMART64 identified an increasing need to pay more attention to the human driver in interaction with the vehicle. From Human Factors research in other domains where automation is already widely used (e.g. aviation, central rooms) it is known that automation has both positive and negative effects on the human operator. With increasing automation in the vehicle domain these effects need to get far more attention on the short term to have some countermeasures if necessary.



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**Figure 40: Example of Human Machine Interface thoughts of BMW**

Currently there is little real evidence on which to base an assessment of the human driver aspects of automated driving. Experience with ADAS technologies is limited and standard driver interfaces and interaction schemes have not been developed. The issue of HMI is being addressed by individual OEMs who are developing their own solutions to the problem, some examples are shown in Figure 40 and Figure 41.

Daimler wants to reduce to a minimum the degree to which the driver is distracted by the Information Display systems

Daimler researching on Multifunctional Human-Machine-Interface that will bridge the gap between head-up displays and future virtual projection screens. It consists of a LED-matrix, which is applied beneath the windshield.



Preference is given to acoustic warning and more feedback on steering wheel and pedal can be expected in the future

Daimler believes that customers should be in a position to de-activate all the ADAS functionalities in cars



Daimler strives to choose the right components, such as indicators and displays that are easy to read and switches that you can find without having to take eyes from the road

16

Figure 41: Example of Human Machine Interface thoughts of Daimler

A positive example of a conjoint interface and interaction design process that were done together with OEMs and suppliers were set up in the EU project HAVEit [82]. In the beginning of the projects generic interaction schemes and generic display elements were defined together with all partners and were refined in an iterative process of testing and alignment. Figure 42 gives an example of the generic HAVEit display elements and Figure 43 shows the concrete design of the display for the HAVEit Joint System Demonstrator.

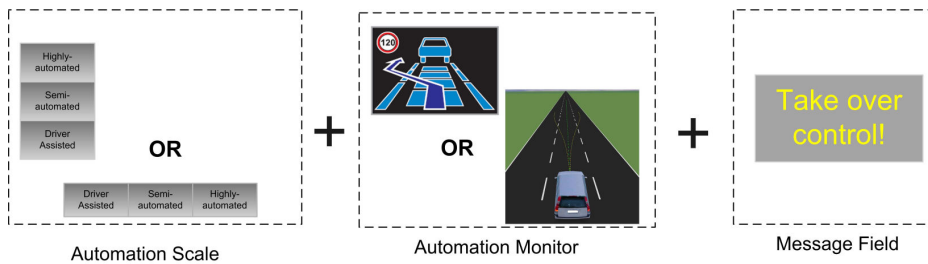
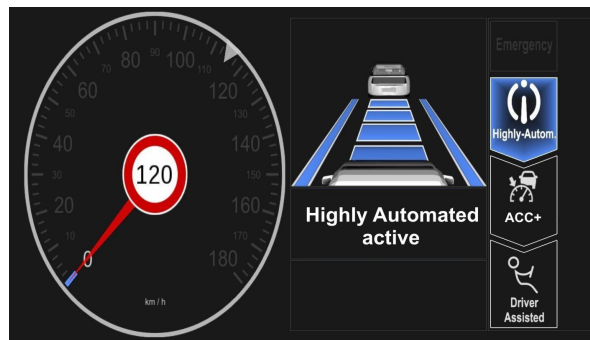


Figure 42: Generic HAVEit display elements

### 13.1 New approaches to support the driver with respect to control of the vehicle and safe and effective used of the new technologies





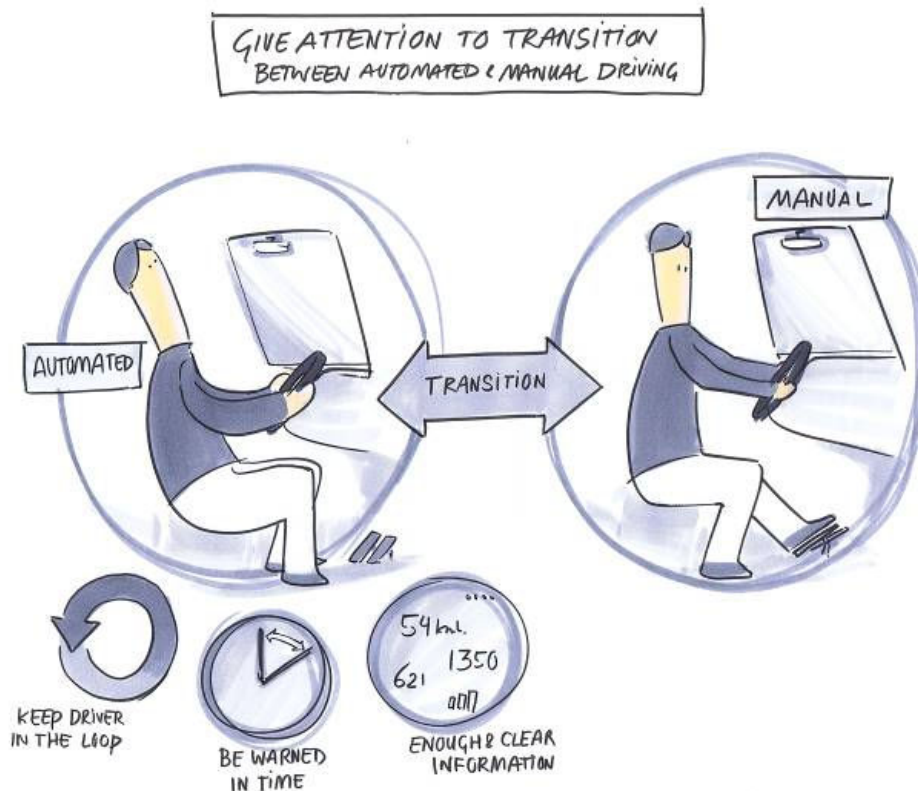
**Figure 43: Concrete display design for the HAVEit Joint System Demonstrator based on the generic display elements**

There are currently several approaches under research and development, from assistance (EU-project Interactive) and automation of specific driving tasks (ACC, LKAS), highly automated driving (HAVEit, CityMobil) up to fully automated driving (CityMobil), see Section 2.1. In most of these approaches the human driver plays an important role for the overall safety of the driver-vehicle system. Either he is requested to do the driving (assistance) or requested to monitor the automation and take over in cases of system limits or system failures (semi-automated up to highly automated driving). To support him in these different roles the following HMI approaches seems to be most important:

- a. **Predictive information** about the driving environment for example provided by V2X technology will allow new forms of assistance and automation. Here, the question which information is important and how this information can be provided for the driver (e.g. augmented reality techniques or Head-Up-Displays) are relevant. Another option of V2X technology lies in the potential to use meta data for improving the traffic flow. Here, the question if a specific routing (that might imply a longer travelling time for him but improve the overall traffic flow) is acceptable for a single driver and how this information is communicated to him seem to be important.
- b. With increasing capabilities of automation and increasing information pressure in the vehicle, the interfacing between the human and such a powerful technology becomes the key factor. Further research and development of the human machine **interface and the interaction design** strategies is essential. To raise the situation and mode awareness of the driver and to support him in monitoring the automation new interface concepts needs to be designed and explored that helps the driver to understand the actions and the limits of the automation.
 

The vehicle offers several assistance and automation functions. A focus should be on the **transitions** between the changes of different levels of automation. Here, an explicit concept for take-over requests during which the driver has to take back control from the vehicle needs to be defined and explored.

  - In addition, an overall interaction concept integrating the different functions in a vehicle should be explored to keep the operation understandable and usable for the driver. An overall interaction concept would also help to align and standardize the different concepts of operation of the OEMs. This would be important to allow a safe and easy driving of vehicles from various OEMs.

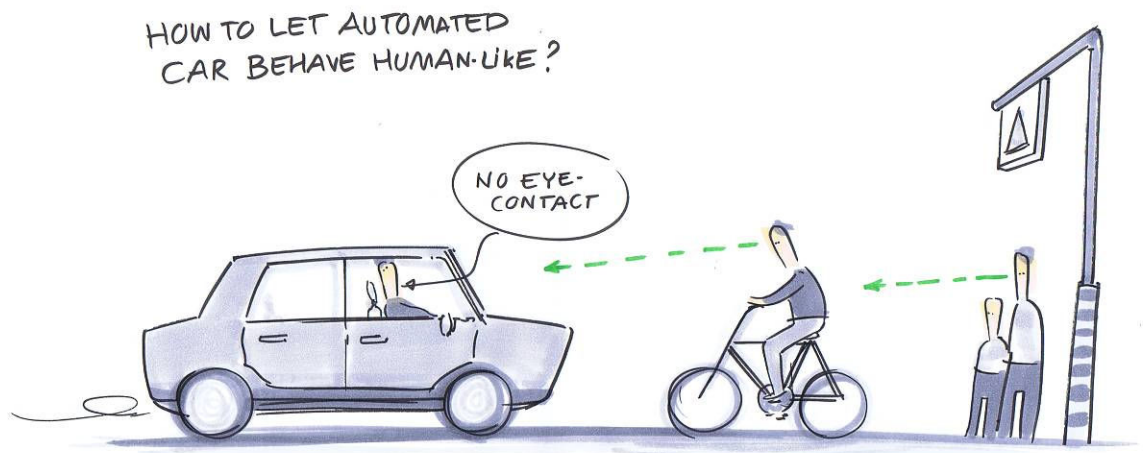


**Figure 44: Transition between driving modes: keep the driver in the loop**

For a safe and effective use of the new technology not only the driver is in response but also several stakeholders can help to improve the use of this technique. OEMs have to provide clear instructions in their manuals. Driving schools can provide detailed information and trainings on new forms of assistance and automation, and regulatory authorities have to decide if there are additional testing requirements and/or trainings in a simulator needed.

### 13.2 Important aspects regarding non-automated driving road users?

It is not reasonable to expect other road users to adapt to automated driving vehicles which must react to other road users in the same way as if driven by a person (or better). Predictability of manoeuvres is important to ensure that the manoeuvre is easy to predict. In addition, feedback should be made visible on the outside of the vehicle, in order for non-automated road users to know how the vehicle reacts (e.g. stop at a pedestrian crossing or traffic sign). This is especially important for cyclists and pedestrians as the typical eye-to-eye contact can no longer be used for feedback, see Figure 45. It is also felt that other road users could undergo training on automation, e.g. solutions based on V2X technology to train them how to interact with a platoon on the highway. From the meta-perspective, the impact of automated driving on overall traffic flow needs to be better understood, particularly with regard to the way in which automatic vehicles would integrate with older vehicles not equipped with such technology. Automated driving systems also need to be able to deal with abnormal behaviour, and not encourage it.



**Figure 45: The automated driving car should especially in urban environments show humanlike behaviour**

### 13.3 How to cope with non-automated driving road users?

If driving in a mixed environment with non-automated road users is not safe from a technical perspective dedicated lanes or dedicated spaces may be required for automated driving (see open vs. closed e-Lane in CityMobil). However, dedicated areas might not offer a good migration path towards higher automation due to limited space capacity. More likely are highly automated vehicles with more than one automation mode in which the driver can take over when the environmental situation does not allow automated driving.

For the period till 2025, focus of implementation seems to be on mixed traffic situations, both for urban and highway transport. Automated driving may require vehicles to have several modes of operation from fully automatic to driver supported and in addition automatic vehicles must be compatible with non-automated road users. Automatic vehicles must also have 360 degree sensing and control so that they avoid collisions at all speeds of operation and in all conditions. These vehicle adaptations will be expensive to introduce and may not necessarily be developed without government support.

In conclusion a number of questions remain to be answered, in e.g. future research and discussion forums:

- What effects does higher automation in the vehicle have on the driver?
- How do we improve the driver interface without over loading them with information?
- How can we achieve standardisation for automated vehicle control and interface design without legislation?
- How can we improve driver training for automated systems?
- Should we continue to allow a gradual migration of skill or introduce some form of universal training?
- How do we integrate automated vehicles with other road users?
- Will other road users also require training?

## 14 Final remarks

This executive summary at the beginning of this report has been prepared to introduce as clear as possible the subjects discussed in each section and to create the links necessary to understand the interrelations between technologies, legislation, business models, and stakeholders in automated driving. The executive summary also included a set of high-level conclusions. Each chapter of the report addressed one of the 11 aspects specified in the tender, ranging from the Vienna Convention and liability issues to system reliability, vehicle positioning, automated driving applications, and human-machine interaction. Each chapter gives answers to intriguing questions in automated driving and makes suggestions for future research. A significant number of issues in automated driving, covering a large spectrum of knowledge, have been discussed in detail. At this stage, no complete wrap-up of the report will be given, but several key understandings will be stressed once more as final remarks because they are considered essential for the deployment of automated driving.

### The driver

Automated driving should meet *the driver's needs* for safe, efficient and comfortable driving. The driver is and must stay in control: responsibility remains with the driver. When buying an automated driving vehicle, the driver should understand the usage of the system, accept it, and directly experience its benefits.

### Technology

While manufacturers target affordable prices, often realized with less complex components, the in-car sensors will need to feature sufficient accuracy to guarantee a high reliability of the advanced driving assistance systems. Standardization of components and procedures is essential during the development, manufacturing and homologation of complex automated driving vehicles. The underlying systems must remain fail-safe under all circumstances while exhibiting graceful performance degradation accompanied by warning in outstanding situations.

### Deployment

New key players, new value chains, new business models are already needed and will continue to be needed in the future in order for the many stakeholders to make a next step in the deployment of automated driving. In the end, each player in the value chain from vehicles manufacturers to end users and governments should benefit from automated driving and all stakeholders should find a place in the new business models to ensure a broad and yet smooth deployment.

## 15 Acronyms and abbreviations

This section contains a list of important Acronyms and abbreviations that are used in the previous sections of this report.

Abbreviation/Acronym	Meaning
ADAS	Advanced Driver Assistance System
PRT	Personal Rapid Transit
GRT	Group Rapid Transit
AVG	Automated Vehicle Guidance
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
I2V	Infrastructure-to-Vehicle
OEM	Original Equipment Manufacturer
Tier 1 supplier	A supplier who directly delivers to OEM companies
1 <sup>st</sup> Tier	See Tier 1 supplier
ACC	Adaptive Cruise Control
DAS	Driver Assistance System
ABS	Anti-lock Braking System
ESP	Electronic Stability Program
RTOS	Real Time Operating Systems
DSP	Digital Signal Processing
SIL	Safety Integrity Level
MCU	Micro Controller Units
CPU	Central Processing Unit
ECU	Engine Control Unit
GPS	Global Positioning System
EGNOS	European Geostation Navigation Overlay Service
RTK	Real Time Kinematic
DGPS	Differential Global Positioning System
DRIP	Dynamic Route Information Panel
GRIP	Graphic Route Information Panel
PRIS	Parking Route Information System
3G	3 <sup>rd</sup> generation GSM
RDS	Radio Data System
RFID	Radio Frequency Identification
TMC	Traffic Message Channel
DSRC	Dedicated Short Range Communication
GPRS	Data communication via GSM (General Packet Radio Services)
HMI	Human Machine Interface
V2X	Vehicle-to- other road user/infrastructure

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## 17 Appendix I. Related to aspect 3

### *Case study SAFESPOT as a parallel to automated driving functions*

SAFESPOT analysed in-depth analysis the legal aspects of the service named 'Speed Warning', in two configurations V2I and a V2V, is performed against two fundamentally different law schemes: Dutch and English law. For above mentioned issues, using tools such as responsibility mapping, a contractual matrix, use case and scenario analysis, the analysis performed to explore the liability position of the main players. This analysis lead to the following SAFESPOT specific statements and conclusions.

#### The concept of cooperative systems adds more complexity (summarised)

The concept of co-operative systems raises questions and might complicate legal disputes. This is for several reasons:

- There are more parties involved, all with their own responsibilities for the proper functioning of elements of a co-operative system.
- Growing technical interdependencies between vehicles, and between vehicles and the infrastructure, may also lead to system failure, including scenarios that may be characterised as an unlucky combination of events ("a freak accident") or as a failure for which the exact cause simply cannot be traced back (because of the technical complexity).
- Risks that cannot be influenced by the people who suffer the consequences tend to be judged less acceptable by society and, likewise, from a legal point of view.

#### The in-depth analysis of SAFESPOT concluded (summarised):

(Potential) participants such as system producers and road managers may well be exposed to liability risks. Even if the driver of the probe vehicle could not successfully claim a defense (towards other road users) based on a failure of an SAFESPOT-system, systems providers and road managers may still remain (partially) responsible through the mechanism of subrogation and right of recourse.

However, it should be emphasized that the claimant still has the burden of proving, on the balance of probabilities:

- 1) that a failure of the SAFESPOT-system (incorrect or lack of information) indeed occurred;
- 2) that the cause of this failure does not fall within his sphere of control/risk (i.e. that the failure was caused by an external factor for which the probe vehicle driver is not legally responsible), and
- 3) that this failure was causative of the claimant's damage, meaning that the incorrect or lack of information was – in a legal sense – an effective cause of the ensuing accident.

In principle users should be entitled to rely on such a system because otherwise it would not be 'fit for purpose'. This puts high requirements on the quality of the SAFESPOT-service. To guarantee a sufficient quality of level of service, organised quality control procedures or even the establishment of enabling administrative structures will often be required.

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## 18 Appendix II. Related to aspect 10

An extract from CityMobil Deliverable D4.2.1 on Systems Architectures  
The extract concerns the specific scenario relating to e-lanes.

### Scenario 2: Principal urban roads with an equipped 'e-Lane'

#### Description of the scenario

Scenario 2 raises a situation where the increasing availability of modern dual-mode vehicles equipped with special systems that enable them to operate in automatic i.e. driverless mode, leads to the introduction of so called "e-Lanes" on principal urban roads.

An e-Lane is a special lane on a road that provides all the facilities necessary to make it possible for the advanced vehicles (which are essentially the same as the ACVs described in Scenario 1 above) to operate in highly or fully automatic mode. Therefore, these vehicles would be able to automatically adapt their speeds and trajectories to the actual situation around them, and they would form platoons enhancing the traffic flow.

This scenario is internally split in two sub-scenarios, representing two different stages that e-Lanes will go through as the proportion of dual-mode vehicles increases. The first of them considers that the ratio of dual-mode cars is still low, so the e-Lane needs to be shared between "normal" and advanced vehicles. In the second one, the ratio of advanced vehicles is high enough to make possible the reservation of the e-Lane only for vehicles capable to operate automatically. The operational architecture investigated for this scenario gives support to all the control and management functions required for these e-Lanes, giving support to the expected growth on the existing roads of vehicles capable of operating without driver interaction. This architecture must give support to the whole integration process, from a situation with few dual-mode vehicles to a situation where they become the main transport means on the road.

#### Functional architecture

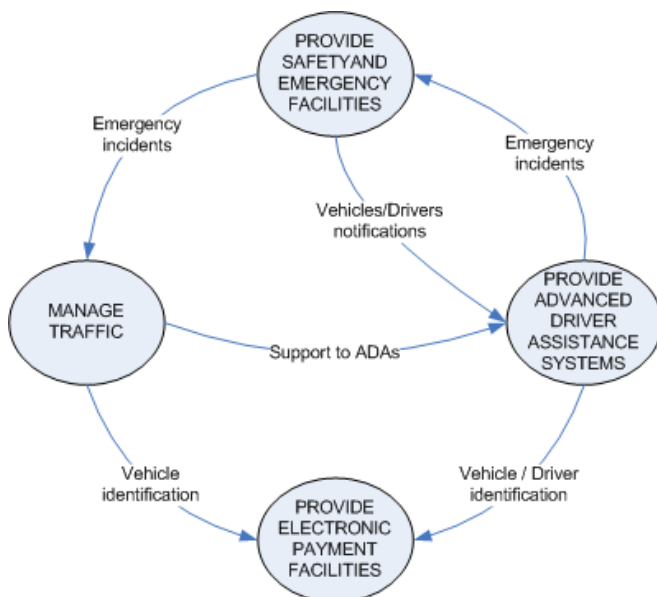


Figure 46: Functional architecture for scenario 2

During the early insertion of e-Lanes together with the existing infrastructure, the most outstanding functional area of this scenario is the "Traffic Management" area. A complete

urban traffic control becomes necessary to achieve a high integration level between normal and advanced vehicles within the e-Lane. This area must obtain statistics and real-time data on urban road usage (especially on e-Lanes, where conflicts are likely to appear during the integration phase). Classic (e.g. surveillance cameras) and modern (e.g. vehicle to infrastructure communication) sources can be also employed to obtain control information. This information is then used to dynamically adapt the signalling to the characteristics of the traffic flow, maximising the performance of the roads.

Dedicated functions and control could be also necessary to permit the access of emergency vehicles to determined points of the e-Lanes, and give them priority over normal traffic while minimising the impact of an incident over the flow of non-related vehicles.

Finally, special monitoring of the e-Lanes “health status” must be performed to prevent misbehaviours, since they include some technology in charge of assisting the automatic driving functions.

Once the penetration rate of advanced cars in the cities becomes high enough, the operation in the e-Lanes will be mostly determined by automatic driving systems. Therefore, the functional area “Advanced Driver Assistance Systems” is clearly necessary. This area is in charge of maintaining and ensuring the availability of the information required by the automatic driving systems within the e-Lanes. This information comprises lane and headway control, customized traffic control signals, real-time optimized routes, vehicle platoons organisation, intelligent speed adaptation support... Most of these exchanges are based on vehicle to vehicle and vehicle to infrastructure communication.

In addition, this area must be able to manage automatically or manually emitted emergency requests, automatically providing the “Safety and emergency Facilities” area with all the information available.

The “Electronic Payment Facilities” area must control who is using the e-Lanes, and charge the corresponding fares or tolls to the account of the driver or vehicle owner. Since no interface to the user is provided, the determination of who is using the e-Lane must be performed via automatic vehicle to infrastructure communication (in such case, a close communication with “Provide Driver Assistance Systems” area should be used) or other classical means (such as identification via cameras).

At last, the “Safety and Emergency Facilities” area is in charge of providing management and support to those emergency situations produced within the e-Lane. It would receive the notifications of incidents, and specifically inform the required emergency systems (maybe special rescue teams for the e-Lane are required) and provide them with as much information as possible. It would also need to inform the “Manage traffic control” area, which is responsible of granting priorities to the emergency services and initiating policies to readapt the traffic flow.

Functional area	Main functions
Traffic Management	Obtain real-time traffic flow information
	Adapt signalling to traffic flow
	Provide priorities to vehicles requiring them
	Monitor e-Lanes “health status”
Advanced Driver Assistance Systems	Manage customised traffic signalling
	Recommend alternative routes
	Manage automated vehicles organisation on an e-Lane i.e. platoon and speed management.

	Driving Assistance i.e. lane, headway control
	Automatically inform about incidents
Electronic Payment Facilities	Identify users of e-Lanes
	Charge fares/tolls to users of e-Lanes
Safety and Emergency Facilities	Manage incident notifications
	Provide emergency services and Traffic Control with suitable information

### Information architecture

The integration of e-Lanes together with existing infrastructure will offer a high amount of traffic control information (real-time road occupancy measurements, rate of vehicles equipped with advanced driving systems). In addition, new information means, such as floating car data - via vehicles to infrastructure communication -, will be also available. All this information together will be utilised to prevent traffic congestions and will help in the design of traffic management policies to get better and better traffic flow.

Functional area	Database	Description
Safety and emergency facilities	Common Emergency Data	Details of all the information needed to process the data that is produced when any emergency takes place
	Incident and Emergency Data	Details of all incident notifications that have been received but not yet processed
Traffic management	Urban Traffic Data	Flow and car park data within the urban environment. This information is obtained via infrastructure and vehicles, and is used to provide optimized routes to users' destinations
	Environmental Data	Environmental conditions within the controlled geographic area, useful to assist in routes design or to inform road users
	Incident Data	Current and predicted incidents, and incident management strategies
	Demand Data	Statistical data about the use of the different urban roads, useful for the traffic flow management
	Maintenance Data	Records of all maintenance actions that have been carried out, including those not yet completed
	Urban Road Static Data	Information about the configuration of the road network (intersections, road directions...)
Advanced Driver Assistance Systems	Operational Data	Data about each vehicle (both static and dynamic information), driver and current conditions. This information is generated within the vehicle, and used by the Driver Assistance Systems
	ISA Data	Speed limit information of every road in the service area. It is necessary for the Intelligent Speed Adaption system

### Management architecture

Scenario S2 'Principal Urban Roads with E-Lane' involves the following functional areas:

Functional Area	Required by S2	Stakeholders
1. Electronic payment	Y	TMS
2. Safety and emergency facilities	Y	ES
3. Manage traffic	Y	TMS
4. Manage PT operations	N	
5. Advanced driver assistance	Y	TMS
6. Traveller journey assistance	N	
7. Support for law enforcement	Y	Police
8. Manage freight and fleet	N	

In S2, special lanes are provided in which vehicles which are suitably equipped can operate in automatic mode. It is likely that vehicles will be charged for use of the facility and therefore, that an electronic payment facility will be needed. The special lanes will need to be provided by the LG if on local roads, or by a National Roads Authority if on national roads. The charge in this case is likely to be imposed by the TMS with arrangements for sharing revenues at a national level if appropriate. The main stakeholders involved therefore are:

- Local government (and/or National Roads Authority)
- TMS
- ES
- Vehicle manufacturers
- System end-user

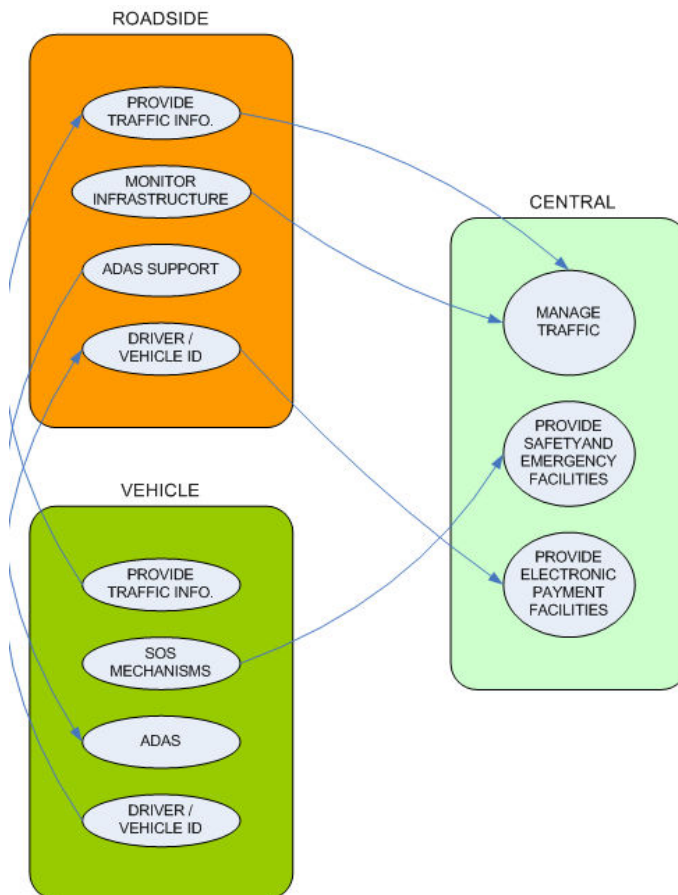
In terms of relationships, responsibilities, and hierarchies the costs are shared by end-users who have to buy an equipped vehicle and local government or national roads authority who must install the necessary infrastructure. Vehicle Manufacturers will have to develop/offer specially equipped vehicles at acceptable pricing. Special TMS facilities may be required. The success of the system generally will be determined by the penetration of the technology as a percentage of all cars on the road.

### **Physical and communications architecture**

Scenario 2 states a situation where a central management location becomes vital to receive all the information from both vehicles and infrastructure, take decisions and transform them into actions directly influencing the traffic flows (both on e-Lanes and normal lanes). The different functions can be therefore physically moved to the following locations:

- Central: a central operation centre receives most of the road information from the roadside and ACVs, and analyses it to assist the traffic management functions. All decisions about special situations, management of incidents, prioritising of emergency vehicles... will be taken here.
- Roadside: provides the infrastructure necessary to implement the e-Lane and support the ADAs and Automatic Driving functions. In addition, some systems regarding e-Lane state monitoring and traffic flow sensors are also included here.
- Vehicle: ACVs are equipped with several systems to assist the driver, such as route guidance based on real-time conditions, Intelligent Speed Assistance, Advanced Driving Assistance systems and Automated operation systems (i.e. lane and headway control), vehicle to vehicle and vehicle to infrastructure communication... The vehicle must also include safety mechanisms, such as driver monitoring and automatic incident notifications.

Due to the limited locations employed in this scenario, most communications can be performed using the arising vehicle – vehicle – infrastructure communications channels, and typical wired channels to communicate infrastructure with the operations centre.



**Figure 47: Physical and communications architecture for scenario 2**