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Facilitating automated driving

Task 1: Identification of requirements towards network operators

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Preface

The sub-activity 4.2 ‘Facilitating automated driving’ of EU ITS Platform has a scope to prepare road authorities and operators to make decisions on facilitating automated driving and automating their own core business. This is a report of task 1 ‘Identification of requirements’. This task initially focused on the requirements of higher levels of automated driving, and especially the requirements of automated driving towards the road authorities and operators concerning road markings, traffic signs, real-time and predictive traffic information, digital maps, cooperative ITS infrastructure and other aspects. The scope of the deliverable was then extended to encompass requirements of automated driving to ensure the safety and the efficiency of the transportation system.

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1. Introduction

The sub-activity 4.2 ‘Facilitating automated driving’ of EU ITS Platform has a scope to prepare road authorities and operators to make decisions on facilitating automated driving and automating their own core business. It has a task to identify requirements. Specifically, this task first focused on the requirements of higher levels of automated driving, and especially the requirements of automated driving towards the road authorities and operators concerning road markings, traffic signs, real-time and predictive traffic information, digital maps, cooperative ITS infrastructure and other aspects. The scope of the task was then extended to encompass requirements of automated driving to ensure the safety and the efficiency of the transportation system.

The purpose of this deliverable is to describe the state of the art of the automated driving (Chapter 3), and the expectations that general public, commercial vehicles and fleets and road network managements have on automated driving (Chapter 4). The deliverable describes also the identified requirements toward physical (Chapter 5) and digital (Chapter 6) infrastructure. In addition, it discusses topics related to legal and regulation framework (7), requirements on cooperative ITS (Chapter 8), and external boundaries of automated driving (including weather conditions) (Chapter 9). In the end, conclusions are made (Chapter 10).

2. Basic definitions and levels of driving automation

2.1. Basic definitions

An **automated vehicle** is a vehicle equipped with an automated driving system. That is a system which is able to at least carry out steering and acceleration/deceleration and the monitoring of the environment.

An **autonomous vehicle (or a system)** is an automated vehicle (or system) that is able to perform its tasks without being connected to the infrastructure or other vehicles.

A **connected vehicle** is a vehicle with communication capabilities able to receive and send data about its environment, the traffic situation or driving conditions to other vehicles (vehicle-to-vehicle communication, V2V), the network operator (vehicle-to-infrastructure communication V2I) or its manufacturer and service providers. An automated vehicle would not necessarily be a connected vehicle.

2.2. Levels of automated driving

Vehicles with automated driving capabilities can be classified in different automation levels with respect to situations and driving modes an automated driving system can cope with. The most used scale is published by SAE international and J3016 (SAE 2016). It contains six levels ranging from no automation (Level 0) to fully automated

driving in all modes and situations (Level 5). The following

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	*OEDR*		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**			*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.				
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

summarizes automated driving levels and corresponding capabilities and limitations. These levels will be used in this report while describing the different levels of vehicle automation.

This report focuses on Level 5 requirements, since this level is the goal for all car manufacturers and it has the strongest and widest requirements. Furthermore, several car manufacturers, e.g. Volvo and Ford, have announced their intention to entirely skip the Level 3 in their automated driving system research and already target higher levels, 4 and 5.

Table 1. Summary of Levels of Driving Automation for on-Road Vehicle Copyright © 2016 SAE International.

Abbreviations: ADS = automated driving system, DDT = dynamic driving task, OEDR = object and event detection and response, ODD = operational design domain.

Level	Name	Narrative definition	DDT		DDT fallback	ODD
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2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
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3. State of the art of automated driving systems and automated vehicles

3.1. Automated driving systems

Currently, the progress in development of automated driving systems varies from manufacturer to manufacturer. Most if not all of the major players in the automotive industry have already added basic automation capabilities to their vehicles that are already on the market:

- Cruise control or adaptive cruise control

  Cruise control is a system that automatically controls the speed of a motor vehicle. The system is a servomechanism that takes over the throttle of the car to maintain a steady speed as set by the driver.

  Adaptive cruise control is an optional cruise control system for road vehicles that automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead. It makes no use of satellite or roadside infrastructures nor of any cooperative support from other vehicles. Hence control is imposed based on sensor information from on-board sensors only.

- Lane departure warning or lane keeping assistance

  Lane departure warning system is a mechanism designed to warn the driver when the vehicle is about to leave its lane unintentionally (the turn signal is an indicator of that intention) on freeways and arterial roads.

  Lane keeping assistance is a further development of the modern lane-departure warning system. The lane-keeping assist system is able to support the driver in staying within a lane. This means it combines the features of a convenience system with those of a warning system. The system usually assists the driver through electronic assistance with the steering force.

- Emergency braking system

  Advanced emergency braking system is an autonomous road vehicle safety system which employs sensors to monitor the proximity of vehicles in front and detects situations where the relative speed and distance between the host and target vehicles suggest that a collision is imminent. In such a situation, emergency braking can be automatically applied to avoid the collision or at least to mitigate its effects.

- Parking assistance

  Parking assistance system can steer the car by itself into a parking space with little or no input from the user.

There are numerous systems on the market, at the time of writing this deliverable, for example the Autopilot system from Tesla motor and the Intelligent Drive Driving Assistance package from Mercedes-Benz. Those systems belong to Level 2, partial automation systems since the driver still needs to monitor the driving environment to be able to reclaim control of the vehicle at any time.

Tesla's Standard Autopilot features include: Autosteer to steer within a lane; Traffic-Aware Cruise Control to maintain the car's speed in relation to surrounding traffic; Auto Lane Change to assists in transitioning to an adjacent lane on the right or left side of the car when it is safe to do so when Autosteer is engaged; and Autopark to indicate a parking spot while driving at low speeds on urban streets and to manoeuvre the vehicle into the parking space.

Mercedes-Benz's Intelligent Drive features include: Distance Pilot to automatically maintain the correct distance to vehicles in front and to follow traffic ahead in its lane at speeds of up to 200 km/h; Steering Pilot to keep the vehicle on the lane (not dependent on clearly visible lane markings, up to speed 130 km/h); Speed Limit Pilot with COMAND Online to adjust the vehicle's speed in response to camera-detected speed limits or speed limits logged in the navigation system; Active Brake Assist to warn the driver of imminent crash situations, to optimally assist them during emergency braking and, if necessary, also to initiate automatic autonomous braking; Cross-Traffic Function of Active Brake Assist to detect crossing traffic and pedestrians in the danger area in front of the vehicle; Evasive Steering Assist to help to pass a pedestrian safely by adding precisely calculated steering torque to support the movement of the steering wheel; Active Lane Keeping Assist to help stop the driver from unintentionally changing lane; Active Blind Spot Assist to warn of the risk of a lateral collision and likewise correctively intervene at the last moment to prevent a collision; and PRE-SAFE® PLUS to protect against collisions with traffic following behind.

3.2. Automated vehicles

Experiments on automating vehicles have been made since at least the 1920s. The first self-sufficient and truly autonomous prototype cars appeared in the 1980s, with Carnegie Mellon University's Navlab and ALV projects in 1984 and Mercedes-Benz and Bundeswehr University Munich's Eureka Prometheus Project in 1987 (Wikipedia 2016).

Table 2 summarizes major personal car manufacturers' plans for high level automated vehicle, as of August 2016. For a given level of automation, models already on the market are specified along with the year of introduction. Expected year of commercialization are in *italic*. Many car manufacturers have automated vehicle projects in-progress but have not communicated the year for market introduction. Those are marked with 'TBA' (i.e. to be announced) in the table. It must be noted that no manufacturers have announced a date for the market debut of a fully automated vehicle, despite having announced working on such vehicles.

Table 2. Advanced driver assistance systems and higher level automated driving system introduction or expected introduction (compiled from car manufacturers press releases).

Manufacturer	Level 2	Level 3	Level 4	Level 5
Audi	2016 Audi A4 2017	*2018*	*Late 2020s*	TBA
BMW	2016 BMW 7 Series	Skipped	*2021*	TBA
Ford	*2019*	Skipped	*2021*	TBA
Honda	2016 Honda Civic-Sedan	*2020*	TBA	TBA
Kia	2016 Kia Sportage	*2020*	*2030*	TBA
Mercedes-Benz	2013 Mercedes-AMG C63	*Skipped*	TBA	TBA
Nissan	2016 Nissan Serena	*2018*	*2020*	TBA
Renault	2016 Renault Espace	*2020*	TBA	TBA
Tesla	2015 Tesla Model S	Skipped	*2018*	TBA
Volvo	2016 Volvo XC90	Skipped	*2020*	TBA

Testing of Level 4 and 5 automated vehicles on open roads is in progress in several countries. Because of the small number of vehicles and their prototype nature, these tests or test vehicles are not included in the table above. Nevertheless, as some of these experimentations have started to yield information on requirements towards infrastructures and operators, they have been taken into account in latter chapters of this report.

In 2015, the ERTRAC task force on “Connectivity and Automated Driving” published roadmaps for Level 3 automated driving. The expected time frame for conditional automated driving industrialization was 2020 to 2022, for long distance travel with automated commercial vehicle was 2022 to 2024.

Being driven by marketing imperatives, car manufacturers are more optimistic than the ERTRAC task force but the announced dates for Level 3 automation are reasonably close. On the other hand, most announcements of vehicle manufacturers concerning the roll-out of highly automated vehicles have in 2016 referred to Level 4 vehicles and thereby Level 3 has been evidently skipped by most.

4. Expectations on automated driving

Automated driving systems are developed and regarded as a way to bring improvement to the following issues:

- Road safety: by reducing most crashes which involve human errors
- Efficiency: the transportation system efficiency could be increased by reducing congestion via better utilisation rates or via increase in capacity, and by reducing energy consumption and vehicle emissions
- Comfort: users comfort while travelling could be improved by enabling them to rest or pursue other activities.
- Provide with new freedom and enhanced mobility for disabled individuals.

Other long term expectations where automated vehicles could boost the development include improvement of mobility for everyone by facilitating new mobility as a service concepts and disconnecting the ability to travel from the material possession of a car and city centre accessibility.

Expectations concerning automated vehicles in general can vary widely depending on the actor position in the driving ecosystem. Drivers of personal cars and commercial vehicles have a different set of expectations, as well as fleet managers, transport network managers and operators, and car manufacturers.

4.1. General public

General public's expectations are well known. Several studies and surveys have been carried over the past years by various researchers to better understand drivers and evaluate the market. However, there is a gap between what the general audience expects to be possible in the short term versus what is realistically available. Steven Shladover describes this so-called disconnect in an article in Scientific American (The truth about "Self Driving" cars, June 2016).

A survey about the general public acceptance of automated cars and its readiness to switch to a car equipped with an automated driving system was published in March 2016 (L'observatoire Cetelam 2016) and carried across several countries, of which in Europe: Belgium, France, Germany, Italy, Poland, Portugal, Spain and the United Kingdom. According to this survey, the public's primary expectations toward automated vehicle were improved safety and security, savings of money and savings of time with comfort as fourth priority, almost as important as the first three. The main concerns expressed about automated vehicles were related to relinquishing the full control of their vehicle, the use of collected data, and a general concern about safety.

4.2. Commercial vehicles and fleets

Commercial vehicles and specifically the automated trucks are expected to help the transportation industry to optimize fuel consumption, travel time and cost of transporting goods.

Fuel and driver are two of the most expensive cost items in goods transportation. An automated truck could be set to travel at an optimized speed for fuel consumption, something that is not possible today due to the driver presence and the need to adapt the journey to driving time and rest regulations.

In the absence of drivers, fleet usage optimization could be enhanced a lot for goods transportation vehicles, but also for rental or person transportation service. Such vehicles could be easily moved to meet expected demand and, in the case of taxis, be used for a greater fraction of the day with down time only for cleaning, refuelling and maintenance.

Automated trucks would also ease the platooning of several vehicles. In addition to the other benefits of automated truck driving, the main advantages of automated truck platooning are:

- Improved fuel efficiency and decreased CO_2 emissions
- Improved efficiency for traffic flow (throughput). Since trucks drive more closely to each other, traffic density is increased and tail-back is reduced. There's also increased stability of the traffic flow due to reduced string instability as a result of the communication between the trucks in a platoon

Since the automated driving system take control of trucks in platoons, platoon's vehicle-to-vehicle communication would be possible and very efficient, and given that an automated system has a virtually inexistent reaction time, all platoon trucks would be able to brake at once, thus improving safety.

4.3. Road network operators and managers

Road network operators and traffic managers expect traffic safety to improve with the introduction of automated vehicles e.g. because of their compliance with speed limits and safety gaps and of their quick reaction times. However, since the aim of a traffic management is also to ensure that its network allows the traffic to flow efficiently, the introduction of automated vehicles would be badly received if they cause networks efficiency to decrease due to e.g. inability to interact with other road users.

If manufacturers and network operators work together, automated vehicles could actually be an opportunity for gaining better knowledge on the network state and implementation of more sophisticated network management strategies. It is expected that connected automated vehicles will share a lot more information about their environment than non-connected and non-automated vehicles. Network managers could use more traffic data

to better adjust their network operation strategy and improve their network overall efficiency with an improved situation awareness.

Eventually, the share of automated vehicles in the general traffic will be high enough and given that an automated vehicle will have higher compliance rate to network management instructions and advices (provided the information is widely broadcasted and reach these vehicles), the network management strategies will have a greater impact and may have to be adapted or made targeted. For example, in order to avoid saturation on urban network in case of an accident on a nearby motorway, a network manager could allocate the vehicles driving on the affected road to several alternative itineraries in order to decrease the congestion on the motorway without creating too much saturation on network used for rerouting traffic. However, to achieve network optimum like this, cooperation between traffic operators and car (or navigator) manufacturers is needed on development of routing strategies.

This higher compliance from automated vehicles could also be an advantage for modelling of the traffic flow. Taking into account the human factor is an important part of current research on traffic models and one of the reason a traffic model has to be calibrated - a tedious, long and complicated process - before being put into use. Possibly, modelling automated vehicles in traffic could be easier and more reliable due to a deterministic decision process based on programming. However, as there will be variance and timely development also among the automated vehicles due to different makes, models and software versions, also their drive behaviour models need to be calibrated.

5. Requirements toward physical infrastructure

5.1. Different road types

According to sensor manufacturers and mapping service providers, each road type brings its own set of problems and performance degradation are not linked to specifically to a given road type. For instance, perception of the road environment will be more critical for urban driving than for rural driving, but on the other hand one can expect digital maps to be better and more up-to-date on urban roads than on rural roads. Since each road type brings its own set of problems, automated driving systems will cope with them differently and with various levels of efficiency and reliability.

Often, challenges for automated vehicles that one may encounter fall in those categories: complexity and velocity. The higher the complexity and/or velocity the more challenging for automated vehicles driving is. One is usually « compensated » by the other: highways have low complexity but high velocities and cities have low velocities but high complexity.

More examples:

- On motorways, the high traffic speeds at which vehicles travel the use of communication between the infrastructure and vehicles is beneficial in increasing their event horizon beyond that of their own current sensors. On the other hand, motorways are usually equipped with the highest sign and marking quality partly due to e.g. the requirements of the EU directive on road infrastructure safety management applying to TEN-T roads (EU 2008), and are also well maintained which give automated driving system a good possibility to position itself on the road.
- Rural roads have less signs and markings and lower road surface quality but vehicles travel somewhat slower than on motorways. The corresponding environment is usually less cluttered than urban roads which can have parking spots alongside streets, pedestrian crossings, bike lanes, shops and adverts signs, etc. thus making rural roads easier to read and understand for an automated driving system. However, the types of road users that can be encountered on urban road can also be encountered on rural roads - sometimes without separation (e.g. in the case of hard shoulder running). In addition, sometimes the speed limits on rural roads are high with respect to the quality of road surface and (lack of) road markings.
- Urban roads are the slowest travelled roads that an automated vehicle can encounter but their environment is highly dynamic with various user categories (pedestrians, bikes, buses, tramways, etc.), traffic lights, parking areas and much higher frequency of conflicting encounters with other vehicles.

Each road type can be managed by a different operator and continuity of automated operation from one network to another will require operators to share procedures,

maintenance practices and control standards for example. Given that road networks are usually managed under strong economic constraints, it is possible that the automotive industry will have to carry out most of the work on vehicle side to enable safe and reliable automated driving on all type of roads.

Car manufacturers can address most issues related to the physical road infrastructure as long as those issues are generic enough and are not created by peculiar road network points. For example, such peculiar points can be a very complicated intersection or a one of a kind road development (an example given in ***Figure 1***). Addressing those issues would require the automated driving industry to make a comprehensive inventory of entire networks across several countries to identify them. More often than not, road network operators know the peculiarities of their network. Their action on those points would be more impactful than, for instance, renewing road markings on all the rural roads in a given area and upgrading their signs.

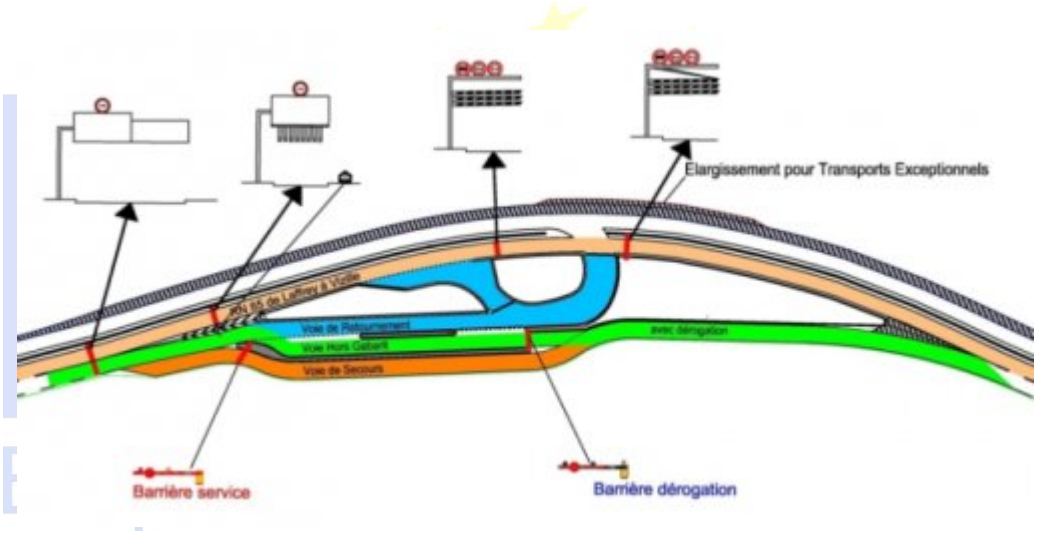

Figure 1: A road section reconstruction on the French national road network. This section was reconstructed after a coach lost braking capability in the Laffrey 12% ramp, killing 27 persons. With two barriers and four gantries, this is a unique, and complicated, implementation on the French road network.

Requirements towards network operators:

- Car manufacturers need consistency within networks and between networks,
- Automated driving system would be easier to develop if there were as few as possible local or national peculiarities to deal with. Road operators and manufacturer will need to discuss to find an optimal strategy.

5.2. Quality of existing infrastructure

On one hand, car manufacturers, parts manufacturers, suppliers and related service providers have not expressed specific needs toward the physical infrastructure. The current working hypothesis for the development of automated vehicles is that a quality of infrastructure enough for human drivers should be enough for automated driving systems (EU EIP 2016).

With regard to markings and signs, the automotive industry is satisfied by their state and quality in most, if not all, European countries (EU EIP 2016). With regard to road state, given that an automated driving system could exert a finer and swifter control of a vehicle, the surface state sufficient to guarantee safety to a human driver would be enough for its automated counter-part. Automatic systems like ESC and ABS are already well mastered by the automotive industry and adding an automated driving system to a vehicle would only add more information to ensure vehicle handling. Thus, automated driving should not cause extra requirements on road surface conditions except that the road surface should be kept clean of dirt, snow, ice or other substances covering road markings.

On the other hand, the automotive industry values consistency when it comes to physical infrastructure. The more road configurations, signs and markings are consistent across the network (cross-borders), the less situational diversity an automated system has to cope with. Indeed, a human driver is capable of interpretation and leaves lot of room for potential deviations to expectation whereas an automated system is less flexible. A consistent infrastructure also helps the automated driving system to be more resilient towards degraded conditions like heavy rain or snow. A more resilient automated driving system would be able to function, without having to give back the vehicle control to the human driver, in more driving situations.

Even without manufacturers expecting more from the physical infrastructure, ensuring the consistency of a network may force operators to upgrade their procedures. Control and maintenance are currently mainly determined by a cost/advantage strategy and differs in different parts of the road network (depending on road class, traffic volumes, etc.). This approach can lead to different driving conditions on the same network with sections just good enough for driving and brand new sections with perfect conditions. There are also situations causing problems for automated driving such as detection of an obstacle in the lane, error in digital map, existence or the absence of a hard shoulder, temporary opening of the hard shoulder to traffic, etc. In such situations, automated vehicles could need further information to operate, due to the limited range of their sensors.

Requirements towards network operators:

- Consistency of the quality of road infrastructure for continuity of automated driving,

- Possible upgrade on network operators' procedures and quality control to be able to open their network to automated driving system. Even if the current guidelines for marking, maintenance or signage may mostly be suitable for automated driving, ensuring that level of service continuously could become tricky and costly.

5.3. New or upgraded infrastructures

Automated vehicles may perform better with certain types of intersections than with other. Modelling studies indicate that particularly at high traffic volumes, roundabouts are more efficient for automated vehicles with V2V communications than intersections with traffic signals (Azimi et al., 2013).

Stricter lane keeping of automated vehicles allows narrower lane width and thereby fitting more lanes on the same carriageway improving road capacity. This will also mean that vehicles' wheels run over the same parts of the road cross-section focussing pavement wear on narrow strips along the road, resulting in the formation of wear and deformation ruts on the road. Depending on the percentage of trucks with wider axle width than for cars, the ruts may also be wider. These ruts necessitate shortening of the repaving cycle by perhaps 20%. Otherwise or in addition, changes are needed in road paving so that the narrow strips, where the vehicle wheels run, will be equipped with material tolerating wear better. This material with higher quality aggregate for better wear resistance could be 10-15% more expensive to use. Furthermore, paving equipment could face major changes to facilitate paving of "virtual rails" on the road. In any case, the costs for paving and re-paving will be affected. (Törnqvist & Kulmala 2015)

Due to safety risks of having humanly operated vehicles using the same roadway than highly automated vehicles, it may be necessary to allocate dedicated lanes or areas for highly automated vehicles during the transitory phase when moving towards road automation. This will likely reduce road capacity.

There is also a need for emergency harbours for malfunctioning automated vehicles or human drivers being unable to regain control in time. In practice, this can be accomplished by using the paved shoulders for this purpose. On the other hand, hard shoulder running has become a popular measure to increase traffic efficiency, and use of paved shoulder to accommodate use by stopped automated vehicles can be problematic in such cases.

Example of driving situation causing issues for automated driving system:

- Round-about,
- Dynamic lane assignment, and hard-shoulder opening for traffic,
- Tolls.

5.4. Classification of infrastructure capabilities

If all roads cannot be built and maintained in the quality required by the automated vehicles, a classification is required on infrastructure capabilities. A regulatory body could first open certain roads to automated driving. Such roads would have the necessary physical and digital infrastructure, suitable maintenance processes and the network operator would have included the presence of automated vehicles in its management strategies. The presence of minimum quality infrastructure capabilities should be provided together with other road attributes.

This supposes that network operators will have to carry an extensive inventory of their network, and set up a system to broadcast the roads classification and updates. Given that digital maps are a crucial component of automated driving systems. This would not be a too high requirement on network operator, except for the inventory and classification work. Since this work would be a one-time task with subsequent upgrades, this should be doable by most network operators.

6. Requirements towards digital infrastructure

In the context of automated driving and by analogy with the physical infrastructure, the digital infrastructure mainly consists of the information and systems that enable sharing, updating and broadcasting it at the scale of a country, region or road section.

The digital infrastructure is the support for automated driving system's connectivity capabilities. Vehicle-to-infrastructure communication does not necessary suppose the existence of a nation-wide digital infrastructure as they can be confined to equipped corridors.

The digital infrastructure encompasses:

- Communication networks: WLAN, ITS-G5, 3G/4G and later 5G, internet of things networks (e.g. Sigfox, LoRaWAN), ITS-G5 Road side units, Mobile edge computing, etc.
- Digital maps and systems to be updated according to the data gathered by automated vehicles
- National single point of access and systems to share, for examples, traffic prevision, road network modifications or road works
- Clouds and back office operations of vehicle manufacturers, service providers, and road operators
- Positioning capability will be provided by satellite system but fixed land stations emitting position signals would make it available in shadow areas or tunnels.

Stakeholders of the digital infrastructure to support automated driving are both private and public. Interoperability, at least on the cloud level, is essential to efficiently enable information to circulate.

A high quality digital infrastructure is an essential part for the development and reliability of automated driving systems. The amount of data that the automated driving systems are expected to share is staggering. Automated driving systems and connected vehicles send data back to the manufacturer so they can monitor and improve their software[1] which then gets updated over the wireless connection. The same mechanism will be implemented for digital maps and driving condition use cases.

Requirements towards road operators:

- Invest in the parts of the digital. This means at least to build the back office infrastructure needed to share information and updates, but also to take a

[1] As of march 2016, Tesla motor was receiving one million miles worth of data from its car (sensors and software debugging information) every 10 hours.
https://www.technologyreview.com/s/601567/tesla-tests-self-driving-functions-with-secret-updates-to-its-customers-cars/

leading role to drive third party investments in order to build the digital infrastructure under the responsibility of the network operators. Since most stakeholders are from the private sector, agreements and even contracts with the different digital infrastructure stakeholders would be very useful.

6.1. Digital mapping

Most automated driving systems currently under development heavily rely on digital maps for network navigation and vehicle positioning on roads.

6.1.1. NETWORK NAVIGATION

As for current navigation systems, digital maps are used to compute optimized routes. It can take into account circulation restrictions, for trucks traffic for example, and traffic information. This use case implies up-to-date network maps, regulation database, real time traffic information and historic traffic data. Though not specific to automated driving systems, those requirements are especially important in this context since automated driving systems may have to take action without human input from the available information.

The road hierarchy and classification is a common issue network operators have with third party navigation systems which remains unsolved today. Depending on the routing algorithm priorities, transit traffic can be navigated via feeder roads through a residential area, for example if such an itinerary is shorter or less congested. This may be a minor problem right now but as automated driving systems become more and more common, more transit traffic could be sent on roads designed to serve housing allotments. For network operator, this would generate safety and maintenance issues. Given the increased criticality of those information, streamlining the sharing and propagation of network modification, traffic restrictions and information will be essential to ensure efficiency at network operator and user levels.

The usability of specific roads and road sections also depend on the occurrence of events and incidents in the neighbouring road networks. The road operators usually deal with such events and incidents with specific traffic management plans, often diverting traffic to specific roads and rad sections by specific circulation plans. The traffic management and circulation plans should be also communicated to the navigation service providers.

Requirements towards network operators:

- Share road hierarchy and broadcast networks updates to other stakeholders.
- Share in advance or in real time the traffic management and circulation plans, and the ones to be used in the current situation.

6.1.2. VEHICLE POSITIONING

Once an automated driving system knows what route it should follow, it has to be able to locate itself on the road: where it is on the route, on which lane it is, and where it is in relation to the middle of the lane. It also has to know what to expect from the infrastructure and its environment: the number of lanes, which lane is allocated to a turning manoeuver, and so on.

Knowing what to expect from the infrastructure ahead allows the automated driving systems to make better decisions by comparing what it knows with its sensors' observations. This process is enabled by high definition digital maps. The two main actors of the digital map field, TomTom and Here, are working on solutions to bring detailed knowledge of the network to automated vehicles. Not only the road geometry and markings are mapped, but any detectable features from the environment, also called landmarks (safety and sound barrier, police and directional sign, street lights, billboards, bridges, etc.).

By looking for the landmarks listed above, an automated driving system will be able to position itself on the road within tens of centimetres. This precision would allow automated driving systems to drive safely on roads even with poor markings and in degraded weather conditions. Indeed, the greater the number of reference points, the lower the chance that all of them are undetectable under heavy rain, snow or fog.

Despite the service providers' ability to update such digital maps according to the data gathered by their mapping vehicles or by any equipped vehicles, in a crowdsourcing spirit, infrastructure maintenance will still be useful for automated driving system. Indeed, well maintained roads and well mowed environment, for example, will allow the points of reference to stay in good condition and well visible over time.

On the other hand, the road network operator could benefit from the wealth of data gathered, processed and ordered by high definition map providers to have a more up-to-date and complete vision of their network state. Answering questions like "Are markings worn out on this section?" would be possible without having to send extensive control patrols on the whole network.

Requirements towards network operators:

- Ensure that the road environment is reasonably free of obstacles that could prevent vehicles accurately positioning themselves (for instance, by mowing or plowing),
- Setup maintenance policies that contribute to the continuity and consistency of reference points.

6.2. Single access point and cloud

The extension of the electronic horizon of the vehicle requires high quality data of the conditions and situation on the road sections ahead along the route. This likely requires much higher quality than what is today provided by real-time traffic information services.

The data will be managed and provided via clouds. The model that seems to emerge is that a single access point / national cloud will offer an interface with the service providers' and manufacturers' cloud and not directly with the users. According to the results of NordicWay, the timeliness of information will not suffer too much from the additional data transfer nodes in the chain (Lindqvist & Skjetne 2016).

From a public operator standpoint, safety and security information have to be distributed as widely as possible; either using broadcasting channels or through push services with relevant service provider clouds. User access to the publicly broadcasted safety relevant information should not depend on which cloud drivers are connected to.

Single access point is generally viewed as being a state responsibility.

Requirements towards network operators:

- Ensure, together with relevant service providers, the availability of good quality real-time road, traffic, weather, incident and event status data covering the relevant road network
- Contributing to the single access point and share data through it.

6.3. Interoperability

To avoid replicating work on communications and information exchange, already existing standards should be employed when possible. If needs were to arise, they should probably be extended as a public standard before setting up a proprietary approach.

The European TN-ITS action (TN-ITS 2016) has published guidelines, tools and maintains a standard that support this objective for digital maps.

Concerning communications, several standards exist for V2X communications via ETSI ITS-G5. Standards for LTE-V2X are currently being developed. For 5G, the standards are still unclear.

As for navigation system and digital maps, cross-border interoperability is also a must-have feature since it would allow service providers to develop once and deploy in all countries and facilitate cross-border travel while preserving the same level of service.

Requirements towards network operators:

- Adhere to European or international standards or guidelines to ensure cross-border interoperability and avoid replicating work done elsewhere.

6.4. Service sustainability

A risk of the private cloud intermediary between public cloud and users approach would be that users are dependent on the willingness of the cloud owner to maintain its cloud so long as there are users connecting to it.

In case of a one-time cost business model, as soon as the provider migrates away from the current offering, for instance by marketing a new version of its service, he has no incentive to maintain the previous one. In case of a subscription based business model, as soon as the user payments no longer cover the service maintenance costs, the provider may want to cease the service maintenance.

Legislations tackling this possible issue could mandate the obligation for service provider to provide continuity of service solution, in the previous example it could under the form of a supported upgrade path. This would allow providers the opportunity to innovate without having to comply with legislation and rules on service specification.

If the service was providing security and safety information, it is not in the interest of public authorities to allow the breach of the information chain. Interoperability between automated driving system and cloud could give users the possibility to switch to a different provider (i.e. freedom of choice of service) and allow service continuity despite the original provider offering change.

The European Commission could consider mandating the provision of safety related information more clearly (i.e. use of certain standard like DATEX II) than what is currently done in the delegated act for safety-related traffic information given within the scope of the ITS directive (CEC 2013).

Those requirements are at state and European level. Network operators do not generally have the regulation power to ensure service continuity in time i.e. sustainability but what is mandated for private stakeholders should also be mandated for public stakeholders and among them for network operators. Continuity of service requirement for network operators is also a must-have for other stakeholders, and would allow them to build their digital infrastructure knowing the network operators would not move away from the current solution without providing a replacement.

Requirements towards network operators:

- Ensure sustainable service provision with long-lasting agreements and contracts with the relevant stakeholders.

7. Requirements towards legal and regulation framework

7.1. Testing and homologation

Vehicle manufacturers have a commercial interest in providing safe vehicles to their customers. The liability of the vehicle manufacturers in case of vehicle crashes should be clarified by legislation for different levels of automated driving to ensure that manufacturers have also a legal incentive to produce safe vehicles.

On Level 4 and 5, since vehicle type approval is currently only physical, something additional has to be devised to cover also the software included. Since it seems hard to test an automated vehicle in enough driving condition to ensure it will answer suitably to real world situations, processes set up in the aeronautic world could provide the basis for highly automated driving systems certification and homologation. For example, the quality control and development process for flight critical software are very strict and well documented and compliance by industry stakeholders is mandatory.

Currently, type homologation can be done once in a European country and still be valid in other countries. A similar way of doing type homologation and development processes certification at European level would avoid putting too much strain on car manufacturers.

It may happen that automated vehicles will be allowed to operate only on specific types of roads and for certain weather conditions.). In addition to road operators, it may also be the car manufacturers who define these safe operating conditions for their systems.

However, it is not possible to test all possible real world scenarios before allowing vehicles on the market. And even if testing can be done once with a mutual recognition for all other European countries (as is it now for manual vehicles), a testing framework would cost a lot to elaborate and maintain.

Requirements towards states or at European level:

- Clarify the liabilities and responsibilities of stakeholders to ensure they have incentives to design automated driving systems with road safety as a key requirement.
- Set-up European-wide type homologation and standards for automated vehicles.

7.2. Data privacy

Today, car manufacturers and service providers exploit data collected from partially automated vehicles operating on the public roads. The more the vehicles will be automated, the more the data will be valuable for manufacturers to evaluate and improve their systems. Should user be allowed to refuse the data sharing? At what cost? Currently, the car owner does not have an option but to accept data sharing if they want the service.

It is challenging to find a balance between level and effort to put into anonymization and the re-usability of data if individual vehicle data is needed. However, as network operators only need anonymized data which is aggregated by road sections anonymization typically should not be too problematic. But since the road operators are not directly connected to the vehicles, the intermediary will have individual data anyway.

Requirements towards states or at European level:

- Data privacy agencies (ombudsmen) already exist in European countries. Specific regulation may be necessary for automated driving systems.

7.3. Vehicle and systems propriety

More and more manufacturers wish to keep control of the sold vehicles and embedded systems. Nowadays when someone buys an advanced vehicle they have to agree to a contract with the manufacturers by which they allow the manufacturers to retain certain rights on the vehicle. E.g. Tesla is using these rights through their dash board and cellular connection to retrieve data on driving condition, system performance and environment monitoring for them to use in their developments.

Such dispositions may also be used to prevent security researchers, being from publicly funded organisations or not being irrelevant, to perform security analysis of vehicles. In a previous case, a European group of researchers were prevented to publish their work after a car manufacturer took the matter in front of a judge. It took several years of negotiation before publication was agreed upon by the manufacturer. (Grierson 2015)

From a network operator stand point, automated driving system safety and security can undoubtedly gain from being audited and analysed by more experts than just the manufacturers' teams. In the long run, a legal framework to allow such analysis while preserving the commercials interests of automated driving stakeholder would certainly help to build a safer automated transportation system.

Requirements towards states or at European level:

- Set up a legal framework to proactively protect consumers and network operator rights and interest before overreaching "end user agreement".
- Set up a legal framework to allow independent researchers to analyse and audit automated driving systems without have to risk facing legal action while allowing industry stakeholders to reasonably preserve their commercial interests.

8. Requirements on cooperative ITS

Requirements on cooperative ITS are not specific to automated driving system. As for any other source of information, a human driver is capable to interpret and handle with great flexibility incoming information but an automated system can only act according to its programming, rules and models. Thus, the importance of information integrity, correctness and consistency is more important for automated systems than it is for human drivers.

The cooperative ITS connectivity for vehicles with human drivers will likely be sufficient for automated vehicles as such in most cases.

Nonetheless, incoming data from cooperative ITS channels are important for automated driving systems. Getting information on accidents ahead from several sources: the sensors detecting and other vehicles sending information (V2V) on slow moving vehicles ahead or the traffic information provider and the network manager information on accident and its location through road side beacons or by other means, would strengthen the systems' confidence in the information and improve the overall system safety.

In order for the automated vehicles to drive safely and efficiently, they need a good world image which they can construct from several sources: their own sensors, digital maps and communication with other vehicles and the roadside. The added benefit of communication is that the so-called e-horizon can be extended (both in terms of direction and length) and allows for a more proactive behaviour. This can be demonstrated by comparing Adaptive Cruise Control (ACC) with Cooperative Adaptive Cruise Control (CACC). When several vehicles with ACC drive behind each other they will all react to each other with some system originated delay, resulting in string instability (or a "harmonica" effect). But when connectivity is added, those CACC vehicles can drive in a synchronised manner (because their intent is shared) without string instability, having also a positive effect on throughput. For a safe and efficient traffic flow it is better to have connected and automated vehicles.

9. External boundaries including weather conditions

Difficult weather (heavy rain, snow, fog) and road surface conditions (ice, snow, water on road) will have to be considered in the testing of automated vehicles and also in the homologation process. Level 5 automation requires this as the vehicle of that level needs to operate in all conditions, but also Level 2-4 vehicles should work in adverse road weather conditions to maximise safety benefits.

SAE (2016) introduces the concept of Operational Design Domain(ODD) related to external operating boundaries of automated driving (*Figure 2*). The extent of the ODD is determined by various factors, including (adverse) weather conditions and time-of-day, geographical restrictions, etc.

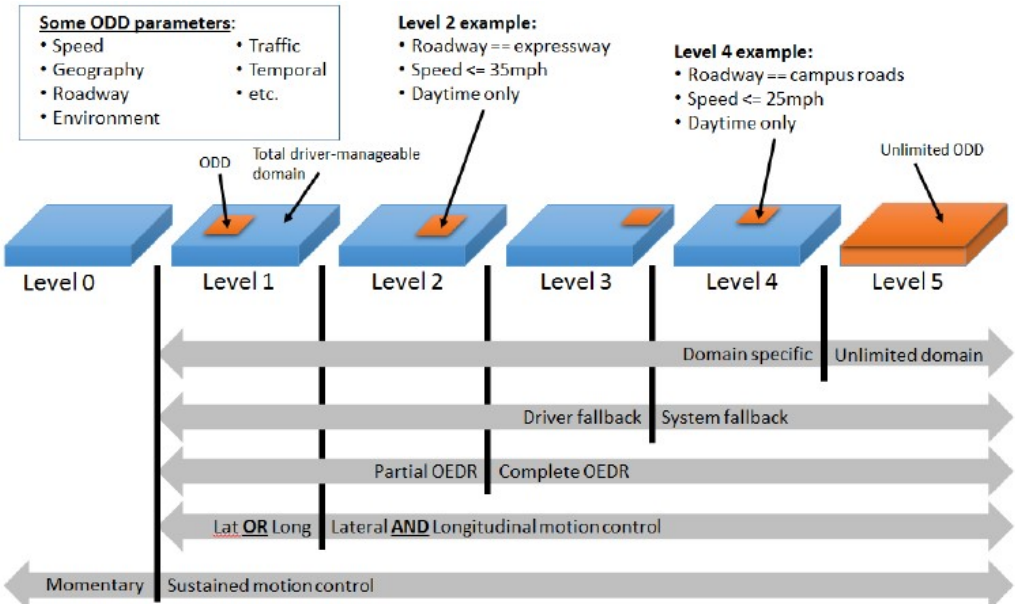

Figure 2. Operational design domain (ODD) relative to levels of automation (SAE 2016).

Accurate and real-time information on slipperiness can be acquired using data from the in-vehicle systems and sensors. One such method, called Grip, was tested in Finland in the winter of 2015–16 (Malmivuo, 2016). The Grip method utilizes information about the free rolling wheel speed, driving wheel speed and engine power. Tests demonstrated that the slip ratio (corresponding to friction between the tyre and the road surface) produced by the Grip method has a clear correlation to the reference friction measurements (performed using optical friction measurement devices). These results show that slipperiness information acquired from in-vehicle sensors and systems can be extremely useful in supporting automated driving functions in rainy, snowy and icy conditions.

To facilitate accurate vehicle positioning and trajectory planning, the road operator should ensure that road markings and traffic signs are detectable, visible and in sufficiently good condition via asset management and winter maintenance. This means increased costs. For example, in Nordic conditions, this could double the costs of winter maintenance, however (Innamaa, et al. 2015)

To facilitate vehicle positioning on roads with frequent snow and ice coverage, road operators should install well-fixed landmarks by the roadside. These could be specific poles or support structures for roadside equipment/furniture, and they should likely be equipped with sensor reflectors or radio beacons so that their position can be easily detected by automated vehicles. The detection of junctions, ramp heads, bus stops, and other specific locations along the road can be made easier by the use of landmarks. (Lumiaho & Malin 2016).

High definition maps provide important support here since they contain digital version of signs, markings and roadside landmarks. Thereby, automated driving systems have to be able to act based on degraded sensors information and matching the sensor observations, satellite positioning and maps. Up-to-date and accurate maps are crucial to handle difficult weather.

In addition to adverse weather, also locations with reflected position signals or signal fringe and shadow areas cause problems for automated vehicles. The positioning can be improved by fixed land stations emitting position signals, in addition to the solutions listed above. In addition to vehicle positioning, adverse weather's negative effects on sensor or communications performance may result in the need for redundancies for different actions related to sensing and communication.

Requirements toward road operators:

- Set up asset management and maintenance process to ensure good signs and markings visibility in difficult weather.
- Provide redundant landmarks for location, suitable communication channels hardened against adverse weather, etc.

10. Conclusion

This deliverable describes the state of the art of the automated driving, the expectations on it, and the expected requirements toward physical and digital infrastructure. In addition, it discusses topics related to legal and regulation framework, requirements on cooperative ITS, and external boundaries of automated driving.

While the general public mostly expects improved safety, comfort and to gain back some free time it invested in its travels, network operators expect safety and efficiency improvements from the roll-out of automated vehicles on their networks. To meet these expectations, car manufacturers and service providers will need to work together with road network operators in order to define the right balance between comfort, safety and efficiency. Furthermore, network operators need to comply with strict economic constraints and also have to provide service to all road users: automated vehicles, manual vehicles, public transport vehicles, bikes and pedestrians alike. Hence, they will not be able to undertake comprehensive network transformations in a short time period to accommodate automated driving vehicles.

Automated driving systems are still in heavy development and even if systems ranked up to Level 4 will be available on the general market in the upcoming decade. Level 5 systems are still a long way from being ready for commercialization.

The present report is based on what is currently known about advanced automated driving systems, on educated guesses by experts in the field of road transportation and not on requirements and needs expressed by car manufacturers and services providers. Those needs and requirements are just starting to emerge as progresses are made toward fully automated vehicles.

As automated vehicles will be introduced gradually, road operators will have to accommodate partially automated, fully automated and human drivers for a long time. It is important to find affordable solutions that accommodate also automated vehicles. Leveraging the advantages of automated driving systems should be done as soon as possible to offset the costs induced by having the different types of vehicles simultaneously on the network.

As long as there is a mix of automated and non-automated vehicles, design parameters for roads are obviously based on the manual operation of vehicles. This means that altering the roads in the sense that elements are taken away (e.g. lane markings, signs) or will have other dimensions (e.g. narrower lanes) is out of the question. However, adding elements to the existing infrastructure to facilitate or enhance automated driving without negatively affecting manual driving, is a possibility (e.g. connectivity, landmarks).

To reflect on the on-going fast progress and the accumulation of knowledge about automated vehicles and their requirements, the present work will be updated during the course of the EU ITS Platform project and an updated report will be delivered at the end of 2019.

10.1. Summary of requirements

10.1.1. ROAD NETWORK OPERATORS

- Consistency and continuity:

Car manufacturers need consistency within network but also between networks, without too much local particularities that would require special treatment, for things like road markings, signs, road surface quality, traffic management strategies and maintenance processes.

Network manufacturers may also have to set up some processes to ensure landmarks will be consistently visible and available for automated vehicles to position themselves on the road.

Adhering to European standards or guidelines will help to ensure cross-border interoperability and have the added benefit of avoiding the replication of work done elsewhere.

- Digital infrastructure:

Network operators will have to invest in the digital infrastructure, take a leading role in its development to ensure public expectations and objectives are met. They also will have to share their data (traffic, events, management strategies, circulation plans, etc.).

Together with relevant service providers, they will have an instrumental part to ensure the availability of good quality real-time information on road conditions, traffic, weather, incident and event. This will have to be done through a single access point.

Ensure sustainable service provision with long-lasting agreements and contracts with the relevant stakeholders will be necessary for the long term viability of the digital infrastructure and the safety of all road users.

- Maintenance and network management processes:

It is possible that upgrading procedures and quality controls to ensure that the expected level of service is indeed consistently reached on the network will be necessary.

Network operators will have to set up asset management and maintenance process to ensure good signs and markings visibility event in difficult weather. Furthermore, they will also have to ensure that redundant landmarks for location, suitable communication channels hardened against adverse weather, etc.

- Road classification:

If the choice to open only some road to automated driving system or to favour routing on certain roads while avoiding other, an extensive inventory and classification of the road network will have to be carried. Subsequent upgrades will have to be broadcast to autonomous driving stakeholders.

10.1.2. STATES AND EUROPEAN LEVEL: LEGAL AND NORMATIVE FRAMEWORK

A legal framework to proactively protect consumers and network operator rights and interest before overreaching “end user agreement” will certainly be needed, since it was needed in other similar field (telecommunication, software, etc.).

A legal framework to allow independent researchers to analyse and audit automated driving systems without have to risk facing legal action while allowing industry stakeholders to reasonably preserve their commercial interests would help strengthen the security and safety of the automated driving ecosystems.

A clarification of the repartition between stakeholders will be necessary to ensure industry members have incentives to design automated driving system with road safety as a key and overruling requirement. This should be done preferably at the largest possible level, ie. at the European level.

Since type homologation is done at European level, it should be also done so for automated vehicle type-homologation. Given that procedures will probably be more complex and expansive to design, this would avoid replicating costly work both for manufacturer and public stakeholders.

Data privacy agencies (ombudsmen) already exist in European countries. Specific regulation may be necessary for automated driving systems.

References

Azimi, R., Bhatia, G., Rajkumar, R. and Mudalige, P. 2013. V2V-intersection management at roundabouts. SAE Technical Paper No. 2013-01-0722.

Carsten, O. M. J. & Kulmala, R. 2015. White Paper II – Road Transport Automation as a Societal Change Agent. EU-US Symposium on Automated Vehicles, Washington D.C. 14-15 April 2015. 17 p.

CEC 2013. Commission Delegated Regulation (EU) No 886/2013 of 15 May 2013 supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users. Commission of European Communities. Official Journal of the European Union 18.9.2013, L247/6.

EU 2008. Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management. Official Journal of the European Union 29.11.20118, L 319/59-67.

EU EIP 2016. Facilitating Automated Driving and ITS, EU EIP A4.2 Workshop in Madrid, 21 – 22 September 2016.

Grierson, J. 2015. Security flaw affecting more than 100 car models exposed by scientists. Article in The Guardian. https://www.theguardian.com/technology/2015/aug/18/security-flaw-100-car-models-exposed-scientists-volkswagen-suppressed-paper.

Innamaa, S., Kanner, H., Rämä, P. and Virtanen, A. 2015. Automaation lisääntymisen vaikutukset tieliikenteessä (The impacts of increasing automation in road transport). Finnish with English abstract. Trafi Research Reports, Helsinki 2015. 84 p.

Lindqvist, M. & Skjetne, C. 2016. Demo of NordicWay Interchange Server. Presentaion givet at NordicWay Project Management Board 13 June 2016.

L'observatoire Cetelam 2016. Automated Vehicles: Motorists Prepare To Hand The Wheel To Silicon Valley.

Lumiaho, A. & Malin, F. 2016. Road Transport Automation Road Map and Action Plan 2016-2020. Finnish Transport Agency, Traffic and Information. Helsinki 2016. Research reports of the Finnish Transport Agency 19eng/2016. 82 pages and 2 appendices. ISSN-L 1798-6656, ISSN 1798-6656, ISBN 978-952-317-264-7, ISSN 1798-6664 (pdf), ISBN 978-952-317-263-0 (pdf).

Malmivuo, M. 2016. Testing a slipperiness detection system which utilizes vehicle data bus information. Finnish Transport Agency, Maintenance Department. Helsinki 2016. Research reports of the Finnish Transport Agency 49/2016. 42 pages and 2 appendices. ISSN-L 1798-6656, ISSN 1798-6664, ISBN 978-952-317-326-2.

SAE 2016. J3016A Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Revised version Sept. 30, 2016. http://standards.sae.org/j3016_201609/

TN-ITS 2016. http://tn-its.eu/documents/, visited 22 December 2016.

Törnqvist, J. & Kulmala, R. 2015. Telephone interview by Risto Kulmala of senior research scientist Jouko Törnqvist, a specialist in road engineering at VTT Technical Research Centre of Finland, 16 February 2015.

Wikipedia 2016. https://en.wikipedia.org/wiki/History_of_autonomous_cars, 12 Dec 2016.