The impact of automated transport on the role, operations and costs of road operators and authorities in Finland

EU-EIP Activity 4.2
Facilitating automated driving

Risto Kulmala, Juhani Jääskeläinen, Seppo Pakarinen

Traficomin tutkimuksia
ja selvityksiä
Traficoms
forskningsrapporter
och utredningar
Traficom Research Reports

6/2019

Co-financed by the Connecting Europe
Facility of the European Union

TRAFICOM
Liikenne- ja viestintävirasto

Julkaisun päivämäärä
12.3.2019

Julkaisun nimi The impact of automated transport on the role, operations and costs of road operators and authorities in Finland (Automaattiajoneuvojen vaikutukset tienpitäjien ja viranomaisten rooliin, toimintaan ja kustannuksiin Suomessa)	
Tekijät Risto Kulmala, Juhani Jääskeläinen, Seppo Pakarinen	
Toimeksiantaja ja asettamispäivämäärä Liikennevirasto ja Trafi 22.3.2018	
Julkaisusarjan nimi ja numero **Traficomin tutkimuksia ja selvityksiä 6/2019**	ISSN verkkojulkaisu) 2342-0294 ISBN (verkkojulkaisu) 978-952-311-306-0
Asiasanat Automaattiajaminen, tieliikenne, automaattiauto, vaikutus, tienpitäjä. viranomainen, rooli, kustannukset, toiminta, Suomi	

Tiivistelmä

Tämä kansallinen tutkimus tehtiin osana työpakettia ”Facilitating automated driving” EU:n CEF-ohjelman hankkeessa EU EIP keskittyen viiteen korkean tason automaattiajamisen sovellukseen: moottoritieautopilotti, automaattikuorma-autot niille osoitetuilla väylillä, automaattibussit sekaliikenteessä, robottitaksit sekä automaattiset kunnossapito- ja tietyöajoneuvot.
Raportti kuvaa automaattiajamiseen liittyvät säädöspuitteet ja viranomaisstrategiat eri puolilla maailmaa ja etenkin Euroopassa. Tutkimus arvioi tarkasteltujen sovellusten osuudet uusista autoista, koko autokannasta sekä ajetuista liikennesuoritteista Suomessa vuoteen 2040.
Tutkimus tuotti ehdotuksen automaattiajamisen suunniteltujen toimintaympäristöjen (Operational Design Domain, ODD) ominaisuuksien luokitukseksi ja sovelsi sitä valittuihin sovelluksiin. Tutkimus arvioi myös toimintaympäristöjen toteutuksen, ylläpidon ja käytön aiheuttamat kustannukset vuoteen 2040 mennessä. Lisäksi tarkasteltiin korkean tason automaattiajamisen vaikutuksia autonomistukseen, liikkumiseen, tieverkkoon, tien ominaisuuksiin ja tiensuunnitteluun, liikenteenhallintaan, liikenteen turvallisuuteen, sujuvuuteen ja ympäristövaikutuksiin sekä talouteen ja työllisyyteen. Lopuksi raportti käsittelee vaikutuksia tienpitäjien ja viranomaisten rooliin ja vastuisiin.
Tutkimus perustui kirjallisuuteen, kirjoituspöytäanalyyseihin, asiantuntijahaastatteluihin ja kahteen asiantuntijatyöpajaan, vuoden 2018 aikana pidettyjen alan kongressien ja tapahtumien sekä käynnissä olevien tutkimusten tuloksiin.

Yhteyshenkilö	Raportin kieli	Luottamuksellisuus	Kokonaissivumäärä
Alina Koskela/Eetu Pilli-Sihvola	Englanti	Julkinen	137

Jakaja	Kustantaja
Liikenne- ja viestintävirasto Traficom, EU EIP	Liikenne- ja viestintävirasto Traficom

Finnish Transport and Communications Agency

Date of publication
12.3.2019

Title of publication	
The impact of automated transport on the role, operations and costs of road operators and authorities in Finland	

Author(s)
Risto Kulmala, Juhani Jääskeläinen, Seppo Pakarinen

Commissioned by, date
Finnish Transport Agency and Finnish Transport Safety Agency 22 March 2018

Publication series and number
Traficom Research Reports 6/2019

ISSN (online) 2342-0294
ISBN (online) 978-952-311-306-0

Keywords
Automated driving, road vehicle, automation, impact, road operator, authority, role, cost, operation, Finland

Abstract
This national study was a part of the subactivity ”Facilitating automated driving” of the EU EIP project funded by the CEF programme of the EU, and focused on five use cases of highly automated driving: Highway autopilot, highly automated freight vehicles on dedicated roads, automated public rapid transit/shuttles in mixed traffic, robot taxis, and driverless maintenance and road works vehicles.
The report describes the automated driving related legal frameworks and the strategies of regulatory authorities globally, and especially in Europe. The study provides a forecast for the penetration of the chosen functionalities and use cases of automated driving in new vehicles, vehicle fleets, and vehicle kilometres driven in Finland up to 2040. A systematic classification for the features of operational design domains (ODDs) is proposed, and then used for the chosen functionalities of automated driving. The report also estimates the costs associated with the implementation, maintenance and operation of the chosen ODDs up to 2040. In addition, it discusses the impacts of highly automated driving on vehicle ownership, mobility, road network, road properties and planning, traffic management, road safety, efficiency, environment, economy and employment. Finally the report addresses the impacts on the role and responsibilities of the road operators and authorities.
The study was carried out using literature and desktop analysis, expert interviews and two expert workshops, building on the results of various 2018 congresses and events in automated driving as well as ongoing research projects.

Contact person	Language	Confidence status	Pages, total
Alina Koskela/Eetu Pilli-Sihvola	English	Public	137

Distributed by	Published by
Finnish Transport and Communications Agency Traficom, EU EIP	Finnish Transport and Communications Agency Traficom

PREFACE

This is a pathfinder study for the Finnish Transport Agency and Finnish Transport Safety Agency. The study will provide background national information from Finland for the use of the Sub-Activity 4.2 ”Facilitating automated driving” of the EU-EIP project funded by the CEF-programme of the EU, in particular its Task 2 ”Impacts and economic feasibility of automated driving” and Task 3 ”Roadmap and action plan”.

The study was carried out using desktop analysis, expert interviews and two workshops (the first with the launch of the study focusing on regulatory framework, fleet penetration and operational design domain of automated vehicles, and the second for the validation of the results), and building on the results of various 2018 congresses and events in automated driving (such as the CAD Symposium in April 2018, AVS 2018 in July 2018 ITS World Congress in September 2018 and the SIP-ADUS in November 2018).

The study was supervised by a national steering group including Asta Tuominen and Petri Antola from Finnish Transport agency, Alina Koskela, Anna Schirokoff, Eetu Pilli-Sihvola and Aki Tilli from Finnish Transport Safety Agency, Maria Rautavirta from the Ministry of Transport and Communications, Johanna Nyberg from the City of Espoo, Mika Kulmala from the Ciity of Tampere, Harri Santamala from Sensible4, and Timo Saarenketo from Roadscanners.

The study was carried out by Risto Kulmala from Traficon, Juhani Jääskeläinen from MHR Consulting, and Seppo Pakarinen from Ramboll.

Helsinki, 25 January 2019

Alina Koskela
Special Adviser
Finnish Transport and Communications Agency Traficom

Table of contents

Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
3GPP	3G (3rd Generation) Partnership Project
5GAA	5G Automotive Association
ACC	Adaptive Cruise Control
ACSF	Automatically Commanded Steering Functions
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
ART	Automated Road Transport
AV	Automated Vehicle
CACC	Cooperative Adaptive Cruise Control
CAD	Connected (and) Automated Driving
CEDR	Conference of European Directors of Road
CEF	Connecting Europe Facility
C-ITS	Cooperative ITS
CMVSS	Canada Motor Vehicle Safety Standards
DDT	Dynamic Driving Task
DGNSS	Differential GNSS (Global Navigation Satellite System)
DOT	Department of Transportation
eCall	Automatic emergency call (for vehicles)
EEA	European Economic Area
ERTRAC	European Road Transport Research Advisory Council
ESC	Electronic Stability Control
ETSI-ITS G5	Standardised short-range communications on the 5.9 GHz band
EU EIP	European ITS Platform (CEF-supported project 2015-2020)
FMVSS	Federal Motor Vehicle Safety Standards (USA)
FOT	Field Operational Test
FTA	Finnish Transport Agency
FTIA	Finnish Transport Infrastructure Agency
GDPR	General Data Protection Regulation
GEAR 2030	High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union
GIS	Geographical Information System

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAHS	Highly Automated Hybrid System
HD	High-Definition
HMI	Human Machine Interface / Interaction
HOV	High Occupancy Vehicle
HTC	Human Type Communications
ICT	Information and Communication Technologies
IoT	Internet of Things
IT	Information Technologies
ISA	Intelligent Speed Adaptation
L4	Level 4 (in the SAE road vehicle automation levels)
LiDAR	Light Detection And Ranging
LoS	Level of Service
LTE	Long-Term Evolution (4G standard)
MaaS	Mobility as a Service
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
MSD	Minimum Set of Data
MTC	Machine Type Communications
NGO	Non-Governmental Organisation
NHTSA	National Highway Traffic Safety Administration (USA)
NRA	National Road Authority
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer (Vehicle manufacturer)
PLD	Product Liability Directive
POLIS	A network of European cities and regions for transport innovation
PRT	Public Rapid Transit
PU/DO	Pick-Up/Drop-Off (of passengers)
SAE	Society of Automotive Engineers
TEN-T	Trans-European Network - Transport
TM	Traffic Management
ToR	Terms of Reference
TSR	Traffic Sign Recognition

UITP	Union Internationale des Transports Publics (International Association of Public Transport)
UNECE	United Nations Economic Commission for Europe
V2I	Vehicle to Infrastructure communication
V2V	Vehicle to Vehicle communication
V2X	Vehicle to anything communication
VKT	Vehicle Kilometres Travelled
WEF	World Economic Forum
WG	Working Group
WP	Working Party
WVTA	Whole Vehicle Type-Approval system

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.

The objective of this pathfinder study is to assess the following questions from the perspective of road operators and road authorities:

- What will be the extent of penetration and use of the Level 3 and Level 4 automated functionalities (platooning, motorway driving, inter-urban driving, urban driving, automated public transport, robot taxis) in the vehicle fleets in Finland and Europe up the year 2040?
- What will be the requirements for the operational design domain (ODD) stipulated by these functionalities (physical infrastructure, digital infrastructure) taking into account also the possible discontinuities in ODD, for example transfer of control to remote operations centre?
- What are going to be the investment, maintenance and operational costs for example per road/street km to the road operators, and what will be the most probable implementation roadmap (when, where, what) up to the year 2040?
- What are the other possible operational and cost impacts of the implementation of this functionality, and when they will be realised up to the year 2040?
- What will be the impact of the implementation, maintenance and use of this functionality on the roles and tasks of road operators and road authorities up to the year 2040?

Due to restrictions in time and budget, the study focuses on five automation use cases only. The selection was made from a tentative list of automation use cases with a potential of being commercially available in Finland in 2030. See ERTRAC (2017) for most use case definitions. This tentative list is given below:

- Highway chauffeur (L3)
- Highway autopilot including highway convoy (L4)
- Urban and suburban pilot (L4)
- Highly automated (freight) vehicles on dedicated roads (L4)
- Highly automated (freight) vehicles on open roads (L4)
- Automated truck platooning (L2)
- Automated urban bus chauffeur (L3)
- Automated buses on dedicated roads (L4)
- Automated PRT/shuttles on dedicated roads (L4)
- Automated buses in mixed traffic (L4)
- Automated PRT/shuttles in mixed traffic (L4)
- Commercial driverless vehicles (L4) as taxi services
- Driverless maintenance and road works vehicles (L4)
- Automated traffic management systems ("EU EIP L4-5")
- Fleet management of L4 vehicles outside operational design domain (ODD)

In the national steering group meeting on June 2018, the following use cases were selected for this study:

- **Highway autopilot including highway convoy (L4)**
- **Highly automated (freight) vehicles on dedicated roads (L4)**
- **Automated PRT (Public Rapid Transit)/shuttles in mixed traffic (L4)**
- **Commercial driverless vehicles (L4) as taxi services**
- **Driverless maintenance and road works vehicles (L4)**

The purpose of this deliverable is to describe the legal frameworks and the strategies of regulatory authorities (Chapter 2), a forecast for the penetration of the chosen functionalities and use cases of automated driving in the vehicle fleets in Finland and in the EU (Chapter 3), and the operational design domains (ODDs) of the chosen functionalities of automated driving (Chapter 4). The deliverable also estimates the costs associated with the implementation, maintenance and operation of the chosen ODDs (Chapter 5). In addition, it discusses other impacts of automated driving (Chapter 6) and the impacts on the role and responsibilities of the road operators and authorities (Chapter 7). In the end, conclusions are made (Chapter 7).

2 Legal frameworks and strategies of regulatory authorities

2.1 General

2.1.1 Automation – the future of transport

Increased automation and connectivity are major trends that are shaping the future of road transport and mobility. They hold the promise of addressing many of the major challenges today's transport system is facing, such as user safety, energy efficiency, air quality, traffic congestion, and enhancing the drivers' comfort and convenience. The combination of advanced connectivity systems and automated vehicles could disrupt the entire automotive ecosystem. The impact of automated and connected vehicles could be huge. On the transport system, these vehicles could drastically reduce road fatalities as 90% of road accidents come from human error. In addition, automated and connected vehicles could provide new mobility on demand services e.g. for elderly or impaired people. In public transport autonomous vehicles can result in a cost reduction of approximately 50 %. Instead of a driver in each vehicle one person in a control centre can monitor and, if needed, manoeuvre, several vehicles.

Automation and connectivity will provide new business models and the development on a large scale of new technologies (e.g. sensors, big data and communication technologies) for the automotive sector will also decrease the cost of these technologies and create spill over for other sectors. In the long run, automation could have a revolutionary impact on travel behaviour, social inclusion and urban development, environment, entertainment and commerce, growth and jobs.

Automated vehicles are vehicles that can replace the driver for some or all of the driving tasks. Vehicles acting automatically on the brakes, the accelerator or/and the steering control under the constant supervision of the driver ('SAE level 2' – see Table 1) are already available on the EU market. According to ERTRAC (2017), automated vehicles allowing the driver to perform secondary tasks (SAE levels 3-4) should be available by 2020 on the EU market for a limited number of driving situations (e.g. automated cruising on the motorway or urban shuttles for dedicated trips). Vehicles able to drive autonomously door-to-door (SAE level 5) in any traffic conditions are not expected to be available before 2030 except for testing.

Table 1. SAE automation levels (SAE 2016)

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

2.1.2 The need for coherent legal framework

To leverage and realise the foreseen impacts for society through automated and connected vehicles, stakeholders need to work together and remove hurdles to implementation, address key challenges and build an innovation-friendly environment accelerating market-uptake. Automated and connected vehicles in particular bring new challenges for regulators and policy makers concerning e.g. road safety, environmental, societal and ethical issues, cybersecurity protection of personal data, competitiveness and jobs, etc. which need to be addressed. The big question is how to develop a new coherent legal framework for some vehicles that have not yet been built. These challenges need to be tackled by both Member States and the European Commission.

2.1.3 Connected automated driving (CAD)

In parallel, vehicles (automated or not) are getting more and more connected in particular through the cellular networks for communication and the GPS network for positioning. In the future automation and connectivity will reinforce each other. On one hand, automated vehicles could increase the use of the cellular network through the large amount of data they will share (big data). On the other hand with increased performances, existing short-range communication technologies (ETSI-ITS G5), forthcoming communication technologies (e.g. 4G, LTE) and future technologies (5G) could better support automated vehicles in particular for cooperation between vehicles (V2X) (Voege et al., 2017). Several manufacturers have already committed to fit short-range communication devices (WiFi based: ETSI-ITS G5) on vehicles from 2019 while some others are also considering equipping their cars with LTE-V2X or using cloud-based solutions.

2.1.4 Regulatory aspects

Regarding regulatory aspects, responsibilities are split amongst Member States and the EU. It is important to link policy initiatives and regulatory initiatives to ensure the best framework for the development of these fast evolving technologies while at the same time being able to cope with the associated challenges. Recognizing the need to work together, Transport Ministers agreed on 14-15 April 2016, in the Declaration of Amsterdam (Dutch EU Presidency, 2016) to strengthen cooperation in the field of automated and connected driving and called on the Commission to develop a shared European strategy on connected and automated driving, to review, and where necessary, adapt the EU regulatory framework, to develop a coordinated approach towards research and innovation and to consider the continuation of the C-ITS platform for the deployment of interoperable C-ITS in the EU.

2.1.5 Focus of this study

In this study we address especially the current situation in regulation which apply to automated vehicles, the split of responsibilities between the Member States and the EU, and in particular, the possible impact to the activities, strategies and role of the road network operators and road authorities.

2.2 The EU legal frameworks and regulations

2.2.1 General

Based on a number of reviews of the EU legislation applicable to Automated Road Transport and on the work of various Groups such as GEAR 2030 High-Level Group, and ERTRAC (2017), it can be concluded that the legislation includes the following main elements:

1. Vehicle approval regulation, vehicle certification and maintenance
2. Vienna convention and its impact on the introduction of automated vehicles
3. Road safety, driver behaviour and driving license
4. Traffic rules and large-scale testing on open roads
5. Liability, insurance and defects
6. Infrastructure and requirements to road operators
7. Connected vehicles, communication and data security
8. Data ownership and privacy

It should be noted that both the Member States and the industry have requested the European Commission to take the necessary actions to enable the introduction of automated vehicles in Europe, including recommendations for the review of the existing regulations, initiating updates and new regulation as necessary, and working together with the Member States in the international bodies such as UNECE WP.29. For example, the GEAR 2030 HLG adopted in 2017 the following recommendations:

1. Inclusion of data storage requirements in the type-approval legislation to clarify liability as to who was the driver (system or driver) in case of an accident. The Commission should monitor and evaluate the need to revise the motor insurance and product liability directives as well as the need for additional EU legal instruments to take account of future development of technologies.

2. Preparation by the European Commission of the EU type-approval framework for the certification of automated vehicles, including alternative assessment methods and identification of work priorities at the UNECE, EU and Member State levels. Development by the European Commission of appropriate EU implementing rules in 2018 for new technologies fitted in vehicles currently covered by an EU exemption procedure.

3. Initiation of work on possible modification of the EU legal instruments such as the driving licence directive, professional driving directive, the directive on roadworthiness testing, etc.

4. Regarding connectivity, the Commission and Member states should agree on Regulatory approaches that foster the investments on connectivity in vehicles and infrastructure (e.g. road and telecoms) in a sustainable manner across the EU in line with public policy priorities. This should be implemented in the context of current work on the 5G Action Plan and discussions on the European Electronic Communications Code.

In this study we focus on the current situation in EU legislation but discuss also the ongoing work on the regulatory front. All the regulatory elements are discussed, and the following areas in-depth:

1. **Vehicle certification**
2. **Driving license**
3. **Traffic rules and large-scale testing on open roads**
4. **Infrastructure and requirements to road operators**
5. **Data security**
6. **Data ownership and privacy**

2.2.2 Vehicle approval regulation, vehicle certification and maintenance

The Whole Vehicle Type-Approval System

The fundamental requirement for automated cars is that law permits their use on public roads. Production vehicles require EU type approval which is based on the Whole Vehicle Type-Approval System (WVTA, 2018). Under the WVTA technical harmonisation rules, a manufacturer can obtain certification for a vehicle type in one EU country and market it EU-wide without further tests. The certification is issued by a type-approval authority and the tests are carried out by the designated technical services. Directive 2007/46/EC (2007) sets out the safety and environmental requirements that motor vehicles have to comply with before being placed on the EU market. The directive makes the EU-WVTA system mandatory for all categories of motor vehicles and their trailers. A large number of UNECE regulations are also made mandatory. These replace 38 directives previously in force.

Type approval authorities

Type approval authorities (e.g. Finnish Transport Safety Agency in Finland) are national public authorities in charge of officially approving vehicles before they can be put on the EU market. The decision to approve a new vehicle type is based on compliance tests that are carried out by testing bodies and laboratories (‘technical services’) that are either in-house or, in most cases, specifically designated by the type approval authorities. In some Member States where neither the type approval authorities nor the technical services has their own laboratories, the type approval authorities can decide that the compliance checks are carried out at the vehicle manufacturer's premises, under the control of type approval authorities' or technical services' representatives.

Technical services

Technical services are the test bodies and laboratories that are specifically designated by the Member States' type approval authorities to carry out the type approval tests in accordance with EU legislation. Most type approval authorities designate external technical services, but there are also type approval authorities that have them in-house (e.g. the United Kingdom).

Review of Directive 2007/46/EC

Review of Directive 2007/46/EC: in December 2017, the European Parliament, the Council and the Commission reached a political agreement on a major overhaul of the EU type-approval framework for motor vehicles (WVTA, 2018). The new regulation will make vehicle testing more independent and increase surveillance of cars already in circulation. After the adoption of the Council it becomes mandatory for all new vehicle models as of 1 September 2020.

Type approval and automated Vehicles

Type approval and automated vehicles: Directive 2007/46/EC (2007) sets up a fully harmonised EU-wide framework for the approval of motor vehicles. This directive may refer to international regulations, such as regulations from United Nations (UN) and allow derogations to limited national approvals. Highly automated vehicles could comply with type approval, with the exception of UN Regulation 79 (Steering systems), which does not permit "Automatically commanded steering" (or automated steering) above speeds of 10km/h. In addition, UN Regulation 13 (Braking systems) does cater for "Automatically commanded braking" but may require some examination to confirm its suitability. Discussions to amend these regulations are on-going in the UN. Therefore it is widely accepted that the type-approval system as it currently stands will have to be supplemented for automated and connected vehicles.

Certification of automated vehicles

The replacement of some driver's task as well as connectivity will require new areas to be regulated (e.g. acceleration or distance keeping, interoperability for multi brand platooning are not regulated for vehicles today). In addition, the certification of functions of vehicles (braking, steering, field of vision) are currently regulated in separate regulations as the combination of these functions is done by the driver. **With automated vehicles, this combination will be done by the system** which may call for a specific regulation on the combination of these functions. New vehicle design should also be brought by automation, which may need new categories of vehicles and new specific requirements (e.g. shuttles of less than 8 seating passengers, front seat occupants to face the rear).

Some topics are already being discussed (e.g. cybersecurity, software update, automated steering etc) in UNECE (2017). What is missing is a comprehensive approach and priorities. Issues that should be addressed by use cases should be identified (e.g. Human Machine Interface) as well as those that should be approached horizontally (e.g. cybersecurity). The development of increasing electronics able to adapt the behaviour of the vehicle to a large variety of situations as well as the possibility **of improving these systems in the course of the vehicle lifetime (i.e. software updates)** challenge the traditional approach of vehicle approval based on pre-market harmonized tests. **Alternative methods to assess vehicles** such as risk analysis, hardware in the loop tests, in service conformity rules, etc. could be used. In this respect, technical services and authorities need to update their competence in electronic system certification. The extension of the EU type-approval concept to software updates of used vehicles/aftermarket currently regulated nationally should be considered to avoid market fragmentation and to keep track of vehicle changes over the lifecycle. More information will have to be provided by manufacturers to complement the type-approval tests and assess the systems as there are limits to what can reasonably be tested safely by technical services (GEAR2030, 2017). More information may also be needed for the registration process. The European Commission should make the necessary proposals to supplement the EU type approval framework for the certification of mass market automated and connected vehicles, look for alternative assessment methods and identify areas relevant for UNECE, EU and Member State levels. Member States may still have their own rules for vehicles produced in small series. In particular rules for vehicles designed for a specific local trip (e.g. shuttles) rules may not need to be harmonized at EU level (at least in the first stage) but vehicles could be approved locally to meet the infrastructure needs and provide flexibility (Edwards et al., 2017).

Roadworthiness

Before highly automated vehicles can enter mass production it is anticipated that EU type approval standards would need to be updated to cover the new technologies and vehicle capabilities and that these would flow through to updated roadworthiness requirements. It would be expected that the **EU Roadworthiness Directive 2014/45** (2014) would be updated. Development of type approval standards should ensure that the performance of automated systems within vehicles can be easily and cheaply verified at the roadworthiness test. It may be that the current roadworthiness test format would be insufficiently sophisticated to cater for highly or fully automated vehicles.

Maintenance

As vehicles become more complex, there is increasing concern as to the ability of parties other than franchised dealers to repair them, and this is likely to have an impact on the costs of repair. In addition, an automated vehicle is likely to be particularly complex and utilise proprietary technology extensively so that the manufacturers may not wish to permit or enable repair by other parties (Alonso et al., 2018). However, connectivity will provide also completely new possibilities for over the air maintenance, services, and updates. Therefore, independent repairers should by default be given fair, reasonable and non-discriminatory access to all relevant data and the possibility to enter the market

2.2.3 Vienna convention and its impact on the introduction of automated vehicles

International agreements and UNECE

Motor vehicles are highly complex systems which need advanced technical and legal standards in terms of road safety requirements. The technical requirements and the international traffic rules are agreed by Member States of the United Nations in the framework of the UN transport Conventions and Agreements administered by UNECE, as explained above.

The World Forum for harmonization of vehicle regulations (WP.29)

The World Forum for harmonization of vehicle regulations (WP.29; UNECE, 2012) has been working on automated driving functions (advanced driver assistance systems) for several years. Overall, the regulatory framework developed by the World Forum WP.29 allows the market introduction of innovative vehicle technologies, while continuously improving global vehicle safety. The framework enables decreasing environmental pollution and energy consumption, as well as the improvement of anti-theft capabilities.

The Vienna Convention on Road Traffic

The Convention on Road Traffic, commonly known as the Vienna Convention on Road Traffic, is an international treaty designed to facilitate international road traffic and to increase road safety by establishing standard traffic rules among the contracting parties. The convention was agreed upon at the United Nations Economic and Social Council's Conference on Road Traffic (7 October – 8 November 1968) and concluded in Vienna on 8 November 1968 (UN 1968). It came into force on 21 May 1977. The convention has been ratified by 74 countries, but those who have not ratified the convention may still be parties to the 1949 Convention on Road Traffic. This conference also produced the Convention on Road Signs and Signals.

UNECE paves the way for automated driving by updating Vienna convention

A major regulatory milestone towards the deployment of automated vehicle technologies was attained on 23 March 2016 with the entry into force of amendments to the 1968 Vienna Convention on Road Traffic. As of that date, **automated driving technologies transferring driving tasks to the vehicle will be explicitly allowed in traffic**, provided that these technologies are in conformity with the United Nations vehicle regulations or can be overridden or switched off by the driver. As a conclusion, the 1968 Vienna Convention as amended allows upcoming automated systems provided that a driver is present and can take control of the vehicle (UNECE, 2016).

A second major regulatory aspect currently under discussion is the introduction of technical provisions for self-steering systems. These include systems that, under specific driving circumstances, will take over the control of the vehicle under the permanent supervision of the driver, such as lane keeping assistant systems (e.g. when the car will take corrective measures if it detects that it is about to cross a lane accidentally; self-parking functions and highway autopilots (e.g. when the vehicle would be self-driving at high speeds on highways).

One of the biggest hurdles in the introduction of automated vehicles is UN Regulation 79 (2008), Uniform Provisions Concerning the Approval of Vehicles with regard to Steering Equipment. The informal working group on Automatically Commanded Steering Functions (ACSF) is working on amendments to enable the approval of automated systems for use at speeds above the current 10 km/h limit of the regulation. With the proposed amendments automated steering functions will be allowed to operate up to a maximum speed (130 km/h is under discussion), and the driver must be able to deactivate or override the system at all times. Conversely, upon reaching the limits of its capabilities (e.g. end of the motorway, roadworks, failure of a sensor), the system will alert the driver at least four seconds before he needs to resume control of steering. In order to guarantee that the driver only carries out other activities that allow a timely resumption of control of the vehicle, and to prevent the driver from falling asleep or leaving the driver's seat, a "Driver Availability Recognition System" will be compulsory. If the driver fails to respond to the alert, the system must carry out a "Minimal Risk Manoeuvre" – for example, safely bringing the vehicle to a stop on its own.

In 11 December 2017 the UK delegation submitted a proposal for amendments, and on 19 Jun 2018 a Proposal for amendments was submitted to WP.29. The discussions are still ongoing.

Further work on the Vienna Convention

No new major changes are expected for mass market systems by 2020 as most of them will still require a driver. However, some issues have to be addressed for some cases (e.g. authorisation for urban shuttles, safety distance for truck platooning). **However, vehicles with no driver may require fundamental changes** as the current rules are designed on the assumption that a vehicle is always driven by a driver. This case should however concern, at least in the first stage, a limited number of driving situations (e.g. shuttles motorway application) which gives time to adapt the relevant pieces of legislation. The international level can support converging approaches on traffic rules, in particular Member States should confirm as rapidly as possible in the UNECE that the 1949 Geneva Convention and the 1968 Vienna Convention on Road Traffic are compatible with the safe use of automated vehicles with a driver expected by 2020 (level 3 and 4), and should speed-up the discussion on driverless vehicles (level 4/5) as some use cases could soon be available (e.g. shuttles).

2.2.4 Road safety, driver behavior and driving license

Safety of road transport

Automated vehicles are expected to improve road safety. Automated cars will, in many cases, have a quicker reaction time than drivers but, as many of them will still require actions from the drivers, they can also raise new road safety concerns such as risks of driver confusion/distraction, misuse of the systems and liability issues. These issues have to be addressed in order to ensure safe introduction and use of automated vehicles in our transportation system.

Traditionally road safety is addressed through measures on the vehicles, drivers and the infrastructure. Regarding the vehicles, the 1968 Vienna Convention on international road traffic (and its amendments) address safety. Further work is ongoing in the UNECE WP.1. National traffic rules apply to drivers and infrastructure.

Furthermore, at EU level there is the Directive 2006/126/EC (2006) on driving license.

The Working Party on Road Traffic Safety (WP.1)

The Working Party on Road Traffic Safety (WP.1, 2018) is the only permanent body in the United Nations system that focuses on improving road safety. It is the forum where Member States exchange views and experiences on road safety, and discuss amendments to the United Nations legal instruments, such as the Vienna Conventions on Road Traffic and on Roads Signs and Signals of 1968.

Driver behavior

In most of the Member States, the driver behaviour is covered by traffic rules, civil and criminal law, in particular for ensuring road safety. Generally, road users owe a duty of care to other road users and will be liable in negligence if breach of that duty causes damage. The current law is based on the assumption that when a vehicle is used on the roads there is a natural person who is the driver of that vehicle. Therefore, as long as a driver is present in the car, he will be considered responsible for the safe operation of the test vehicle whilst on public roads. The traffic rules of Member States will need to be updated in due course to take into account the use of highly automated vehicles on the roads. It may be necessary to wait until experience has been gained with these vehicles and possibly research has been conducted into the interactions between such vehicles and other road users.

Driver behaviour and driving license

In most of the Member States, the driver behaviour is covered by national traffic rules, civil and criminal law, in particular for ensuring road-safety.

In March 2006, the Council of Ministers adopted a directive proposed by the European Commission to create a single European driving licence to replace the 110 different models currently in existence throughout the EU/EEA (European Economic Area). The European Parliament adopted the directive in December 2006. Directive 2006/126/EEC was published in the Official Journal of the European Union on 30 December 2006. Its provisions took effect on 19 January 2013; Directive 91/439/EEC was then concurrently repealed.

The directive stipulated that all 31 EEA member states had to adopt laws implementing the directive no later than 19 January 2011. Those laws should take effect in all EEA member states on 19 January 2013. As of 2013, the 31 member states of the EEA participate. This coincides with the 28 EU members plus 3 of the 4 member states of the European Free Trade Association (EFTA).

Consequently, since 2013, all driving licences issued in the EU have a standard format. You can still use your old-style licence, but you will be issued with the new format when you renew your existing licence and in any case at the latest by 2033. All licences issued before that date will become invalid by 2033.

How to address the safe conduct of automated vehicles?

For automated vehicles, the vehicle would need to be fully programmed to respect all the specific obligations and safety considerations that are set out in the different traffic laws. This includes guarantees for the safety both of those inside and of those outside of the vehicle and in all scenarios including interaction between manually driven and automated vehicles and between automated vehicles and vulnerable road users.

Automated vehicles will blur the traditional distinction between rules applying to drivers (mainly national traffic rules) and rules applying to vehicles (mainly harmonized EU vehicle approval legislation as discussed above). Automation technology is intended to partially or completely replace the driver; this has created a new situation, where the requirements for vehicle automation systems overlap with the rules for driver behaviour. Close coordination is therefore needed between the work on the two, until now separate domains, of road traffic legislation: the vehicle and the driver. This is urgent as some systems are expected to enter the market on the next few years. This should also include driver training and information to ensure that the driver is not confused or does not misuse the system (e.g. doing secondary tasks, overconfident with vehicle capabilities "Autopilot syndrome").

Human machine interface (HMI)

Human machine interface (HMI) is particularly important for automated vehicles with a driver (levels 2 to 4) and rules should ensure a high level of commonality. Communication (e.g. through external HMI) with other road users (e.g. vulnerable road users) and Authorities (e.g. police) will be important in particular for driverless vehicles and should also be considered. Principles for HMI have been developed by the, e.g., EU supported research (ERTRAC, 2017). Some of these issues need further research and testing.

HMI is very important for safety, particularly in relation to the level of attention required for a safe operation of an automated function (the vehicle shall ensure that the driver is active/aware if needed) and for the safe transfer of control between driver and vehicle of SAE levels 3/4. Therefore, the tasks of the vehicle and the driver have to be clarified or regulated.

2.2.5 Traffic rules and large-scale testing on open roads

Large-scale tests are a major tool to make progress on the technology for automated vehicles, to develop relevant rules, to increase public acceptance and to develop co-operation between the different actors. Therefore, tests are underway in a large number of Member States in different environments (highways, inter-urban and urban areas). The industry is conducting its own tests, first in closed areas and then moving on to open roads in collaboration with different partners. Furthermore, the European Commission supports cross boarder trials through Horizon 2020 ART program and the Connecting Europe Facility (CEF).

The applicable legislation for testing of highly automated vehicles on open roads is mainly the national traffic law (traffic rules). Derogations to the normal traffic rules are generally possible and issued by the Member State authorities as allowed by the 1968 Vienna Convention discussed above.

Regarding the tests on open roads, each Member State is applying its own rules on how the test license is obtained, what has to be recorded and reported, and how the licence is invoked in case of non-compliance. In the USA the situation is the same at state level, as federal rule do not exist. In most of the cases a trained test driver will be required to monitor the operations as well as an event data recorder. In some countries (e.g. Finland) remote monitoring is possible.

Regardless of the very complex and sometimes confusing situation on the rules for tests on open roads, the industry is not asking of legally harmonised national testing requirements at this stage. The Member States are typically trying to manoeuvre to be in the lead in automation and to have an advantage to their own industry, and therefore are not pursuing harmonization either. The best what could be obtained at this stage could be establishing a mechanism for the management of national tests with one EU wide focal point in order to better coordinate open road testing, exchange on lessons learnt during testing and possibly common building blocks for the voluntary mutual recognition of approval of vehicles used for testing.

2.2.6 Liability, insurance and defects

Product liability

Product liability is covered by the Directive 85/374/EEC (1985) (PLD) and national rules. It is anticipated that at least in the short run the legal position for liability in relation to features on vehicles which incorporate higher levels of automation **would not be significantly different** to those presently assisting the driver. In case of accident, each of the parties involved (manufacturer, driver, etc) may be found to be civilly (or in some cases criminally) liable to a greater or lesser extent depending on the exact circumstances of the situation. A judge would assess whether each party is liable in law and the extent to which their fault had contributed to the loss. He will have to consider the criteria for determining liability. Due to the number of participants there is also the question whether each individual is liable or whether there should be a kind of joint liability, perhaps depending on contributions to the risk which materialised in the damage.

Besides this harmonised EU product liability regime, there are some differences between the liability regimes in the Member States (e.g. road and traffic law, civil law, strict liability regime, and implementation of product liability). There are diverging views as to whether it is necessary, or even desirable, to harmonise more the different national liability regimes. Some stakeholders consider that the conclusion on the PLD (Product Liability Directive) may need to be revised at some point with development of future technologies. The European Commission is monitoring the need for additional EU legal instruments with the ongoing development of technologies. In all cases, the liability system has been and will be formed by jurisprudence and situations will and must be considered on a case by case basis.

Liability of automated vehicles

Questions about liability become even more pertinent for completely autonomous systems like self-driving cars. In general and in case of normal operation of a vehicle with no defects, the behavior of the vehicle can be determined or influenced **by driver or automated vehicle/system**. The actual cause of events (who has influenced the behavior) that lead to damage or incident is decisive for the attribution of liability. As automated vehicles will be taking over driver's tasks, one could argue that it could become more complicated to assign liability in case of an accident and that victims of an accident with an automated vehicles would have problems to be compensated. Therefore, it is considered that **event data recorders** (i.e. black boxes) should be required in the type-approval legislation to clarify who was driving (the car or the driver) in case of accident to help assign liability. The legislation should cover the minimum set of data needed to clarify liability and mechanisms to regulate the data access from a technical point of view (EC 2018a).

There is also a need to clarify liability issues in the context of Internet of Things (IoT), in particular extra-contractual liability. For example, in case of bodily injury, death, damage to property and other type of losses, identifying the primary cause of the damage, establishing the causation link and finally establishing the liability between various participants i.e. between product manufacturers, sensor manufacturers, software producers, data analytics companies and other actors involved in the supply of different services can be difficult.

Insurance and defects

Directive 2009/103/EC (2009) obliges the use of all vehicles in the EU to be insured against third party liability and sets minimum thresholds for personal injury and property damage cover. In the case of highly automated vehicles being operated autonomously, the question arises whether a compulsory insurance cover requirement on manufacturers for their liabilities would be needed.

Whilst the question of legal liability for defects may remain as it is currently at least for the short run, the question of what legally constitutes a 'defect' in a vehicle may be much more difficult to resolve due to the increasingly complexity of automated vehicles. As automated vehicles gain market share, issues concerning liability and defects may need to be monitored to ensure that existing legislation is working correctly to protect consumers and the general public.

Regarding compensation of victims, it is considered that motor insurance and product liability directives are sufficient at this stage. The Motor Insurance Directive (MID) ensures a fast, simple and efficient means of compensation by insurers for victims of road traffic accidents, even where an automated vehicle is involved. The insurer (having settled the traffic victim's claim) can then take legal action vis-à-vis a vehicle manufacturer in case of a malfunction/defective product of the automated driving system in the context of the Product Liability Directive (PLD).

2.2.7 Infrastructure and requirements to road operators

Physical and digital infrastructures

The pertinent question to the road authorities and operators is how the physical and digital road infrastructures should evolve to support connected automated driving, and at what cost. This is related to the definition of ODD, where the assumption is that for each automated function/use case available in the vehicle its ODD has to be defined. It is clear that the ODD depends both on the performance of the vehicle's onboard systems (sensors and data fusion) as well as the infrastructure.

Consequently, before the large-scale take-up of automated vehicles, we need to find answers to the following questions:

1. What are the roles and responsibilities of the different stakeholders for physical and especially digital infrastructure?

2. Should the vehicle cope with any road infrastructure, and if not, what demands can be set to adapt the existing physical infrastructure – including planning, building, operation and maintenance? How to ensure continuity between different environments (motorways, rural roads, urban areas, inter-urban areas), and transfer of control?

3. Who should pay and how for the implementation, maintenance and operation of the infrastructures?

More generally, automated vehicles need infrastructure support in its main tasks: positioning, perception, mapping and dynamic motion. Regardless of where the future balance will lie between vehicle capabilities and infrastructure support it is well understood that the two have to support each other. For example, road infrastructure is also expected to play a role in delivering the high positioning accuracy and reliability required by CAD. This may include also physical infrastructure or recognition of landmarks, in particular in temporary work zones and other higher risk road sections. This could also mean that SAE level 4 or 5 vehicles may never work in the entire road network (see ODD discussion later).

Physical infrastructure

The existing legislation is the Directive 2008/96/EC (2008) on infrastructure safety management. However, the deployment of partially or fully automated vehicles is expected to introduce minimum requirements for the road infrastructure. This could include e.g. minimum standards for road signs and markings, digital mapping of speed limits, common agreement for readability of temporary structures e.g. around road works, etc. Therefore, there may be a need for the revision of the existing Directive 2008/96/EC to include the requirements of automated vehicles. This could include the update and adding of the following (ERTRAC, 2017):

- clear road and lane markings
- adapted and equipped intersections.
- conditions for dedicated lanes/roads/areas allocated to automated vehicles
- management of the changes made to the physical infrastructure, and guarantee the level of quality.

The automated vehicle will use road and lane markings for positioning, if they are available and visible. However, they will never be available on the whole road network, may be of inadequate quality or not visible due to extreme weather conditions. Extreme conditions are the situations in which the air is full of some form of water (rain, fog, snow), pollution, sand or other substances impairing the visual sensor systems. Additionally, heavy snow or flooding may change the surrounding of the road in such way that the previous map is no longer recognized. Furthermore, low friction, or unstable friction (slush) conditions create whole set of new problem to the control of the vehicle.

This is why lot of research and testing is ongoing on positioning techniques which include

- use of DGNSS, real-time kinematic GNSS, precise point positioning (PPP) for navigation.
- use of inertial measurement unit (IMU), wheel angles and dead reckoning,
- positioning using road paintings

- use of additional signals
- use of simultaneous localization and mapping (SLAM)
- use of High-Definition (HD) maps.

Good examples of the ongoing work are the Aurora, Arctic Challenge and Aurora Infra Challenge in Finland (FTA, 2018).

Digital infrastructure

The EU is supporting digital infrastructure for transport as part of its Digital Single Market Strategy. To a large extent, the infrastructure required by the connected automated vehicles is the same as for C-ITS, as defined in the final report of the C-ITS Platform (C-ITS, 2017). The digital infrastructure is composed of data bases and geographical data as well as the related back-office functions. It contains both static and dynamic data and connects and interacts with vehicles through hybrid communication equipment incorporating at least short-range and long-range communication systems

The automated vehicles need efficient data exchange between the vehicles and the digital road infrastructure (V2X). The cooperative and connected elements will allow vehicles to receive, in real-time, in addition to the knowledge of the environment already available in the vehicle through sensors, the key attributes of road relevant for automated driving, with the aim of adding predictability on what to expect on the road ahead and enlarging the decision base for using automatic mode.

The cooperative element is required to handle the complex traffic situations. This means that automated vehicles will depend on the **full implementation of the C-ITS services** as defined by the C-ITS Platform (C-ITS, 2017).

To go beyond awareness realised by the Day 1 & Day 1.5 C-ITS services, a new set of technology agnostic C-ITS messages for collective perception needs to be standardised. This means that future vehicles will share what they see and all vehicles in range will see what they see collectively. To make this work a common operational environment for sharing such messages will need to be developed, including the context and the interpretation boundaries (such as the quality assumptions to quantify trustworthiness, precision, timeliness and reliability of information) for the receiving vehicle and the definition of the terms conditions and roles for service provision, collection of, and access to data from especially automated vehicles.

As the need for support from the digital infrastructure increases, so does the need to ensure consistency between the physical and the digital infrastructure and quality of data. Increased requirements in terms of Quality of Service and Functional Safety imply also a need to investigate regulation is needed to assure information sharing. Finally, as a starting point to further develop the digital infrastructure, it is recommended that all actors that possess, control or own data need to work on the accelerated and joint implementation – by public and private stakeholders –of fair conditions for sharing data, taking into account the costs related to transforming raw data into useful information. More work is needed also in order to clarify responsibilities with all stakeholders involved for generating, updating and accessing relevant data on local and national level, and especially in cities.

Operational design domain

The operational design domain (ODD) describes the specific operating domain in which the connected automated vehicle is designed to properly operate. The definition of ODDs, the implementation of the possible improvements in the infrastructure and safe operation of vehicles inside their ODD and transition of control needs extensive cooperation between the vehicle manufacturers and road authorities. The current assumption is that connected automated vehicles need the definition of ODD for each automated function/use case available in the vehicle. The ODD definition should include at least the following information:

- roadway types on which the automated function/use case is intended to operate safely
- geographic area
- speed range
- environmental conditions in which the automated vehicle will operate (weather, daytime/night time, etc.)
- other domain constraints.

For each ODD - automated function/use case, the manufacturer should have a documented process and procedure for the assessment, testing, and validation of the system's capabilities. As for the vehicle type approval, these tests can be carried out by certified technical services.

Manufacturers with type approval authorities should develop tests and verification methods to assess their vehicles capabilities to ensure a high level of safety. In the future, authorities may promulgate specific performance tests and standards. Presently, manufacturers themselves should develop and apply tests and standards to establish the safe ODD for each automated function/use case

An automated vehicle should be able to operate safely within the ODD for which it is designed. In situations where the automated vehicle is outside of its defined ODD or in which conditions dynamically change to fall outside of the vehicle's ODD, the vehicle should move to a minimal risk condition with transition of control. The vehicle should give a clear indication of that it is switching to a minimal risk condition and that the automated function/use case is not available. The current assumption is that each journey has multiple ODDs, automated sections and transitions of control.

2.2.8 Connected vehicles, communication and data security

Connectivity for automation

Vehicle-to-everything (V2X) connectivity, in its various forms (mobile and short range), should act as an additional enabler for the highly and fully automated vehicles. While it is expected that basic safety and automation functions will be performed by vehicles through the use of on-board sensors, cameras, radars and other technologies, V2X will help in some cases, and will be essential in other cases (e.g. platooning). It enables collective and collaborative driving, adding perception and prediction with non-line of sight sensing and coordinated resolution of complex situations (CAR 2 CAR, 2007). The most promising combination for the deployment is the mix of existing cellular networks and short-range communication. Connectivity can improve the overall efficiency of transport flows, including in an intermodal perspective, e.g. buses and trams.

The different types of connectivity technologies have their advantages and disadvantages (e.g. coverage, speed, latency, security, etc.) for the different uses of automated vehicles and may have to be combined. While most of the investment should come from the private sector, the EU can help in providing regulatory approaches that foster the investments needed to deploy V2X connectivity in vehicles and communication infrastructure (road and telecoms) in a sustainable manner across the EU, in line with public policy priorities. The European Commission is also working with Member States and industry stakeholders (e.g. 5GAA, 2018) towards the establishment of a common timetable for the launch of early 5G services.

Big data, artificial intelligence and their applications

The sensors of automated and connected vehicles produce huge amounts of data. In addition, similar if not larger amount of information is gathered from road infrastructure sensors, e.g. cameras. This big amount of real-life traffic data can be analysed to enhance the rapid growth and development of smart road technologies and automated driving systems, will enable many advanced applications. In combination with big traffic data artificial intelligence (AI) techniques, such as machine learning including deep learning, are expected to play a major role in both data analytics and development of (AI) automated driving functions/applications (ERTRAC, 2017). The challenges in AI development are however huge (building the data processing chain, understanding of scenarios, prediction of behaviour and driving strategies).

Radio frequencies and standards

Since 2008, the EU has had a specific frequency band (5.9 GHz) (RSC, 2017) allocated to safety-related communication, which will now also be open to connected automated vehicles. It is essential to ensure the technological neutrality coupled with interoperability in the ITS band to allow the best solutions be developed by the market, and to ensured that introducing V2X messaging to this frequency does not interfere with road tolling, which uses an adjacent frequency (5.8 GHz). EU short-range communications will be based on the ETSI ITS-G5 standard, which is compatible with the US standard (IEEE802.11p). While the ITS-G5 is well-designed for messaging within 300-500metres, other types of communication may be used for longer distances.

Next Generation - 5G

5G is the next generation of mobile communication technology. It is expected to offer the following advantages:

1. Increased performance of mobile technology in terms of more throughput, lower latency, ultra-high reliability, higher connectivity density, and higher mobility.

2. Support for the convergence of vertical applications onto a single common wireless network. This is enabled by a flexible usage and configuration of network functions to enable use cases with very diverse requirements by means of network slices. 5G should become the first radio communication system designed to smoothly integrate Human Type Communications (HTC) with Machine Type Communications (MTC), thus becoming an enabler for the Internet of Things (IoT).

3. A new flexible radio interface or radio interfaces as enabler for the items above, for deployment both in current mobile bands and new spectrum that could go as high as up to the millimeter wave range.

The 5G Automotive Association (5GAA, 2016) has published a White Paper in which it elaborates on why Cellular-V2X (C-V2X) technology is an essential enabler to transformational connected transportation services throughout the world. The 5GAA perspective is that 3GPP-based cellular technology offers superior performance and a more futureproof radio access than IEEE 802.11p. The 5GAA recommends that the Commission and Member states agree on Regulatory approaches that foster the investments on connectivity in vehicles and infrastructure (e.g. road and telecoms) in a sustainable manner across the EU in line with public policy priorities. This should be implemented in the context of current work on the 5G Action Plan (2018) and discussions on the European Electronic Communications Code.

Data security

V2X communication is the enabler for the correct and robust operation of connected highly automated vehicles. Although some of the applications could rely on simple message propagation, in most applications and situations it is necessary to send data to one or more specific nodes, identifiable through an identifier. However, anonymity of the vehicle and its driver must be protected in all situations. One of the technical approaches to accomplish anonymity is based on the use of temporary identifiers instead of fixed ones.

Furthermore, communication must offer a reliable system with a high availability. In case a driver would receive incorrect data several times, the driver would not trust its technical features. Such incorrect data can be caused by malfunctioning or malicious users and could have a severe effect on the automated vehicle. A technical approach to accomplish this feature is based on digital signatures and certificates.

The introduction of greater connectivity into vehicles, accompanied by increasing levels of electronic control and automated operation capabilities, leads to potentially more complex security issues. Today all new cars must be approved in accordance with UN Regulation 116 (Protection of motor vehicles against unauthorised use), which requires both a mechanical anti-theft device (in practice normally a steering lock and an electronic immobiliser. UN Regulation 116 (2014) is formulated to ensure that vehicle manufacturers put in place measures to prevent unauthorised use. If it is felt that further regulation is required to ensure that manufacturers adequately address cyber security issues then it may be appropriate to update this Regulation.

2.2.9 Data ownership and privacy

Data – enabler of new mobility services and automation

Data is one of the key enablers for connected and autonomous vehicles but data ownership, processing of private data and liability are some of the key challenges for the regulatory authorities in the EU and in the Member States, and the automotive industry itself and some new to the market are all chasing connected car data.

The free flow and processing of personal data in the EU has been provided for under Directive 95/46/EC. This directive is now replaced by the **General Data Protection Regulation (GDPR) (EU) 2016/679** (Regulation (EU) 2016/679, 2016) which became enforceable in all EU Member States and the European Economic Area on 25 May 2018. The Commission is looking also at more universal rules for a **European Data Economy** (EC 2017a) covering the topic of data ownership and access, portability, interoperability and liability. The question on access to data was further elaborated by the Commission (EC 2018c and EC 2018d), proposing principles to data sharing.

In order to ensure fair markets for IoT objects and for products and services relying on data created by such objects, the Commission defines the following principles to business-to-business data sharing (EC 2018d):

a) Transparency: The relevant contractual agreements should identify in a transparent and understandable manner (i) the persons or entities that will have access to the data that the product or service generates, the type of such data, and at which level of detail; and (ii) the purposes for using such data.

b) Shared value creation: The relevant contractual agreements should recognise that, where data is generated as a by-product of using a product or service, several parties have contributed to creating the data.

c) Respect for each other's commercial interests: The relevant contractual agreements should address the need to protect both the commercial interests and secrets of data holders and data users.

d) Ensure undistorted competition: The relevant contractual agreements should address the need to ensure undistorted competition when exchanging commercially sensitive data.

e) Minimised data lock-in: Companies offering a product or service that generates data as a by-product should allow and enable data portability as much as possible . They should also consider, where possible and in line with the characteristics of the market they operate on, offering the same product or service without or with only limited data transfers alongside products or services that include such data transfers. The Commission's Digital Single Market strategy recognises the importance of clarifying liability issues for the roll-out of IoT which is relevant in the context of connected and even more automated cars. Furthermore, the Directive 2002/58/EC (2002) on privacy in electronic communications applies. The Commission has proposed to revise these rules with a proposal for an ePrivacy Regulation.

The General Data Protection Regulation

The General Data Protection Regulation (GDPR) (EU) 2016/679 "Regulation on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (Commission proposal COM/2012/010 final, Journal reference L119, 4 May 2016, p. 1–88) entered into force after two years of preparation on 25 May 2018. The GDPR is repealing the Directive 95/46/EC (Data Protection Directive) and applies in particular to all transport and vehicle data that can be considered as personal data. Because the GDPR is a regulation, not a directive, it does not require national governments to pass any enabling legislation and is directly binding and applicable. However, unlike most regulations, it does leave the Member States with a certain room to pass national legislation in the field of personal data protection.

The GDPR is a regulation on data protection and privacy for **all individuals within the European Union and the European Economic Area (EEA)**. It also addresses the export of personal data outside the EU and the EEA. The GDPR aims primarily to give control to citizens and residents over their personal data and to simplify the regulatory environment for international business by unifying the regulation within the EU. It applies also to transport and vehicle data, when that data is personal data.

Superseding the Data Protection Directive, the regulation contains provisions and requirements pertaining to the processing of personally identifiable information of data subjects inside the European Union, and **apply to all enterprises, regardless of location, that are doing business with the EAA**. Business processes that handle personal data must be built with data protection by design and by default. No personal data may be processed unless it is done under a lawful basis specified by the regulation, such as if the data controller has received an explicit, opt-in consent from the data subject. The data subject has the right to revoke this permission at any time. A controller of personal data must clearly disclose any data collection, declare the lawful basis and purpose for data processing, how long data is being retained, and if it is being shared with any third-parties or outside of the EU.

GDPR and automated vehicles

The GDPR is a positive development to connected and automated vehicles as manufacturers and others (such as traffic information providers) will no longer have to ensure compliance with 28 different national data protection laws. Access to data from the vehicles (but also public transport data, car sharing data, etc.) will change the way services are proposed to customers within the privacy boundaries of the GDPR and will enable all actors of the value chain to develop new services and business models and to create additional value for users and society. Nevertheless, potential threats from cyber security as well as vehicle integrity and safety need to be analysed and taken into account.

To comply with the fair processing requirements of the GDPR, drivers and the registered keepers (and potentially passengers) of vehicles should be provided with sufficient and clear information about who is collecting the data, the intended purposes of processing and any other necessary information to guarantee that they are made aware of the data that their vehicle is collecting, and the purposes for the data which are intended. Individuals may expect that their personal data will not be shared or used for other purposes unless there is an accident, which might require the sending of certain data to emergency services (for example Minimum Set of Data (MSD) of eCall). Manufacturers and insurance companies (among others) have an interest in obtaining data which is not limited to a short period prior to a collision, any such sharing or further processing of personal data will need to comply with the data protection rules.

Event data recorders

There are various devices capable of recording data that relate to an identified or identifiable individual. The vehicle’s own electronic control units (ECUs) or event data recorders (EDR) may provide this possibility. The increasing number of sensors on a vehicle means that a wide range of different datasets could be collected which can provide information about how and where the vehicle was driven. This information can potentially be sent from the vehicle via the internet to remote server storage. Other actors may be interested by this data (e.g. IT service provider, traffic managers). So the issue of non-personal data sharing is also important, but is not regulated at the moment except repair and maintenance information (Regulation (EC) 715/2007, 2007).

In addition, data produced by the sensors on a vehicle may also be classified as nonpersonal data or machine-generated data in so far as they do not relate to an identified or identifiable individual, which are not covered by data protection legislation. Regarding data other than personal data, the free flow of data initiative mentioned in the DSM strategy will, inter alia, tackle emerging issues e.g. 'ownership', (re)usability, access linked to such non-personal data.

The way forward in data ownership and privacy

The GEAR 2030 high level group has identified the following key areas where the EU will need to act.

1. The EU will need to ensure safe and secure access to transport and vehicle data, taking into account the principles set out in the Communication on Building a European Data Economy and Towards a Common European Data Space on data location as well as the guiding principles laid down in the C-ITS platform report namely; data provision based on consent, fair and undistorted competition, data privacy and data protection, tamper-proof access and liability, data economy. Transport and vehicle data will change the way vehicles are operated and serviced today.

2. Second, the EU will need to evaluate whether or not a framework allowing access to transport and vehicle data needs to be established. In addition, the European Commission would need to consider how to ensure an effective stakeholder dialogue on issues related to data. It is essential that this process is underpinned by the industry and service providers guaranteeing fair access, storage and sharing of vehicle data. Consumers must have control of their personal data.

3. The protection of privacy and personal data is critical to ensuring acceptance of the new services by end-users. As C-ITS messages can indirectly lead to the identification of users, they are considered 'personal data' and must therefore comply with the EU data protection rules, and be processed only with the informed consent of users. The Commission will publish guidance on data protection in 2018, consult the EU data protection authorities and develop a data protection assessment template.

2.3 The global legal frameworks and regulations

2.3.1 United States automated driving regulation

General

Of the existing regulations in the US, the most interesting ones and those with most impact to Europe (in particular considering global automotive and transport markets) are the federal motor vehicle safety regulation, and the current and planned regulation for testing of automated vehicles (mostly state laws, different in each state). It should be noted that especially the state laws are constantly changing so we can only have a snapshot on the situation.

Federal Motor Vehicle Safety Standards (FMVSS)

Federal Motor Vehicle Safety Standards (FMVSS, 1999) are U.S. federal regulations specifying design, construction, performance, and durability requirements for motor vehicles and regulated Automobile safety-related components, systems, and design features. They are the U.S. counterpart to the UNECE Vehicle Approval Regulations in use in Europe and most countries except the United States. Canada has a system of analogous rules called the Canada Motor Vehicle Safety Standards (CMVSS, 2018).

FMVSS are developed and enforced by the National Highway Traffic Safety Administration (NHTSA, 2018) pursuant to statutory authorization in the form of the National Traffic and Motor Vehicle Safety Act of 1966. FMVSS are divided into three categories: crash avoidance, crashworthiness and post-crash survivability.

Before a car can be introduced into the market, the manufacturer must certify that the vehicle meets all of the requirements in the current version of the FMVSS/CMVSS. The FMVSS/CMVSS requirements differ significantly from the international UN requirements, so private import of foreign vehicles not originally manufactured to North American specifications is difficult or impossible.

NHTSA Federal Automated Vehicles Policy

NHTSA will continue to exercise its available regulatory authority over automated vehicles using its existing regulatory tools: interpretations, exemptions, notice-and-comment rulemaking, and defects and enforcement authority. NHTSA has the authority to identify safety defects, allowing the Agency to recall vehicles or equipment that pose an unreasonable risk to safety even when there is no applicable Federal Motor Vehicle Safety Standard (FMVSS).

To aid regulated entities and the public in understanding the use of these tools (including the introduction of new automated vehicles), NHTSA (2017) has prepared a new information and guidance document. This document provides instructions, practical guidance, and assistance to entities seeking to employ those tools. Furthermore, NHTSA has streamlined its review process and is committing to issuing simple automation-related interpretations in 60 days, and ruling on simple automation-related exemption requests in six months. NHTSA will publish the section—which has wider application beyond automated vehicles—in the Federal Register for public review, comment and use.

The more effective use of NHTSA’s existing regulatory tools will help to expedite the safe introduction and regulation of new automated vehicles. However, because today’s governing statutes and regulations were developed when automated vehicles were only a remote notion, those tools may not be sufficient to ensure that automated vehicles are introduced safely, and to realize the full safety promise of new technologies. The speed with which automated vehicles are advancing, combined with the complexity and novelty of these innovations, threatens to outpace the NHTSA’s conventional regulatory processes and capabilities.

Meanwhile, the US Congress continues to mull over legislation that could open the door wide for more self-driving cars. A bill in the Senate is stalled, though, after several senators put it on hold citing safety concerns. (Verge 2018) The new legislation would allow broad exemptions from the FMVSS for driverless cars and require manufacturers to submit a "safety report" explaining key safety features of self-driving vehicles.

The US DOT is examining whether the way DOT has addressed safety for the last 50 years should be expanded to realize the safety potential of automated vehicles over the next 50 years. DOT recently hosted a Public Listening Summit on Automated Vehicle Policy. DOT is also expected to examine if NHTSA needs new tools or regulatory structures to be more nimble and flexible. It is likely that additional regulatory tools along with new expertise and research will be needed to allow the NHTSA to more quickly address safety challenges and speed the responsible deployment of lifesaving technology.

Federal regulations for testing of driverless cars

Federal regulations don't say much about how companies develop and test cars before bringing them to market. In the era of conventional cars, they didn't need to. Development and testing was generally conducted on private test tracks where they posed no danger to the public. Then car companies would provide the government with documentation that the car met the standards in the FMVSS before putting them on the market.

But that approach doesn't work for driverless cars. Companies can do some testing of driverless cars on a closed course, but it's impossible to reproduce a full range of real-world situations in a private facility. So at some point, carmakers need to put self-driving cars on public roads for testing purposes—before a manufacturer is able to clearly demonstrate that they're safe. In effect, this makes the public involuntary participants in a dangerous research project. This is exactly what happens in US at the moment, and this has caused some fatal accidents and a lot of criticism to all (federal authorities, state authorities and vehicle/automated system manufacturers).

State regulations for testing of driverless cars

So far, 21 US states plus the District of Columbia have enacted legislation related to autonomous vehicles, according to the National Conference of State Legislatures. Nevada was the first to authorise operation of autonomous vehicles in 2011. Arizona and Michigan have opened its arms to companies testing self-driving vehicles as a means to economic growth and jobs. California, the District of Columbia, Florida and Nevada have also passed laws allowing and setting the conditions for the testing of automated and highly autonomous vehicles, including requirements for reporting and repealing the licence in case of non-compliance. State of California (2017) is requiring the companies to submit disengagement reports. In 2017 twenty companies submitted such a report. Eleven more states are considering legislation addressing the testing of these vehicles and an equal number of states have failed to pass bills allowing the on-road testing of autonomous vehicles.

There is, as of yet, no uniform approach to regulating autonomous vehicles among those states that have passed legislation. All states that have passed autonomous vehicle legislation allow non-testing use of those vehicles, though in the case of Michigan, the driver/operator must be a representative of the manufacturer. In California, Nevada and Florida, vehicles must meet Federal Motor Vehicle Safety Standards. California, Nevada and the District of Columba require autonomous vehicles to have an easy to trigger auto-drive disengage switch and an alert system for system failures. Both California and Nevada require vehicles to store sensor data 30 seconds before a collision. Nevada restricts testing to specific geographic contexts and California reserves the right to do so. Neither Florida nor the District of Columbia impose geographic restrictions. Nevada only issues registration permits explicitly for testing whereas Michigan only issues registration certificates to manufacturers.

Ride sharing

Some states like California are also considering giving permits to "robo-taxis", automated vehicles which can be hailed for a ride. This is a complicated issue, as for example in California the Department of Motor Vehicles oversees autonomous vehicle licensing and testing, the federal government looks after vehicle design, and the Public Utilities Commission (CPUC 2018) regulates transportation services like buses, limos, taxis, and ride-hailing, along with telecommunications and electric utilities.

The Commission position in California is that it wouldn't allow companies to charge for rides or run shared, "pooled" rides. It would require any specific vehicle carrying passengers to first undergo 90 days of on-road testing and it would demand reams of data from developers, miles travelled, miles travelled without passengers (aka "deadheading" miles), collision and disengagement reports, and transcriptions of any communications between riders and driverless vehicles' remote operators within 24 hours. As California is setting a template for other states, cities and towns, the industry is taking these issues very seriously.

Future role of authorities in the introduction of automated vehicles in US

Due to the States allowing testing of automated vehicles, in the US the public is already sharing the road with potentially dangerous driverless cars. Car drivers do not always understand the performance of the car (e.g. its Autopilot) and public at large is quickly losing confidence in the benefits of automated vehicles (e.g. safety). The authorities should at least assure that road users have timely and detailed information about how those vehicles are performing and what steps companies and they are taking to protect public safety.

Updating the FMVSS may neither be necessary nor sufficient for effective regulation of driverless cars. It's perfectly possible to make an FMVSS-compliant driverless car by starting with a conventional car (which already meets all FMVSS requirements) and adding self-driving gear to it. In fact, Waymo is planning to do exactly that. However, there are many important aspects that aren't addressed at all by the FMVSS and have to be resolved at Federal or State level (NHTSA, 2017).

- Protecting driverless cars from cyberattacks not only depends on the architecture of cars themselves, it also depends on the operational security of the systems used to update the car's onboard software.
- Driverless car safety will depend on the accuracy of cars' onboard maps.
- Companies need a rigorous process for testing safety-critical components on cars in the field and replacing them when they fail.
- Companies need a system for thoroughly investigating crashes and other anomalies and updating the car's software to make sure problems don't get repeated.
- During the testing phase, safety depends on the training and supervision of safety drivers.
- Once the commercial service is launched, safety may depend on the competence of staffers overseeing cars from a remote operations center.
- Driverless car companies need plans for dealing with emergency situations and interacting with first responders.

Moreover, these technologies are so new that it would be a mistake to write detailed regulations on any of these topics now.

2.3.2 Japan

Public road tests of AVs have been carried out in Japan from 2013. The testing rules are developed by Japan's Ministry of Transport (Road Transport Bureau, Ministry of Land, Infrastructure, Transport and Tourism MLIT) and the National Police Agency (NPA).

Japan wants to catch up in automated road transport and has set up public areas for autonomous vehicle testing. So far, the Japanese government has focused on special testing areas isolated from public traffic. For the summer Olympics in Tokyo in 2020 the government has launched an ambitious project aiming at fully automated transport services for the Olympic and Para-Olympic games, drafted by government panel on future investments chaired by the Prime Minister. The plan set a goal of increasing the number of locations where automated services can be tested to over 100 across the country by 2030.

In order to test and learn under realistic conditions MLIT (2018) has developed and published guidelines. The industry should evaluate the guidelines before hard rules for testing would be formulated. To get the testing license for public traffic the autonomous cars have to be examined by the police (NPA) which checks if technical requirements are met and takes a test drive. The vehicle has to maintain contact with the testing company at all time and can be controlled remotely by a human driver. The person doesn't need to sit inside the car all time. The driver's rights and obligations are the same as with a traditional car. They must have valid driving license.

Routes and Residents: Several routes are excluded from the testing program. Autonomous testing is also prohibited if the traffic density is getting too high at certain periods of the day. Residents have to be informed if tests are planned in their neighbourhood. License allocation is also undertaken by the Japanese police. A license is always assigned to one vehicle and valid for half a year.

2.3.3 China

China wants to ne the world leader in automated vehicles. China's aspiration to deploy 30 million autonomous vehicles within a decade. In December 2017, China issued the first guidelines for road tests of autonomous vehicles and some testing have been conducted under these guidelines (China Money Network, 2018).

China released national regulations on road tests for self-driving or autonomous vehicles on 12 April 2018 (CIO 2018). This is part of a broader drive to accelerate the development of the technology and develop an advantage in the commercialization of autonomous driving technology.

The guidelines were jointly issued by the Ministry of Industry and Information Technology, the Ministry of Public Security and the Ministry of Transport. The guidelines allow local authorities to evaluate local conditions and arrange road tests for autonomous vehicles. The guidelines state that the test vehicles should be passenger or commercial automobiles, not low-speed vehicles or motorcycles.

The regulation, which took effect on May 1 2018, state that test vehicles should be able to switch between self-driving and conventional driving, in order to ensure the test driver can quickly take over in case of a malfunction. In addition, test applicants must be independent legal entities registered in China, and have to first complete tests in designated closed zones before conducting road tests. The Ministry of Transport is also studying how to improve road infrastructure in order to better adapt to self-driving vehicles.

Besides the efforts at the state level, the authorities in Beijing and Shanghai, and some other cities like Guangzhou, are very active and are developing their own regulations or rules for testing.

Beijing

In March 20818 Beijing authorities issued temporary license plates for self-driving vehicles for the company Baidu for public road testing (Technology Review, 2018). The city has opened 33 roads adding up to a total length of 105 kilometres for autonomous car testing outside the Fifth Ring Road and away from densely-populated areas on the outskirts.

The vehicles are eligible for public road testing only after they have completed 5,000 kilometres of daily driving in designated closed test fields and passed assessments. The test vehicles must be equipped with monitoring devices that can monitor driving behaviour, collect vehicle location information and monitor whether a vehicle is in self-driving mode. Test drivers must have received a minimum of 50 hours of self-driving training.

Shanghai

The Shanghai Declaration signed in November 2017 by seven parties set out an aim to jointly direct efforts to build an intelligent connected transport system that causes no emissions or casualties, and is energy-efficient, comfortable and convenient. The signatories included the Ministry of Industry and Information Technology, the Shanghai government, the United Kingdom Embassy in China, the UK's Centre for Connected and Autonomous Vehicles, the International Transportation Innovation Center, Nomura Research Institute, and the Netherlands Organisation for Applied Scientific Research.

On March 1 2018, the authorities in Shanghai issued a road test licenses (KWM, 2018) to two smart-car makers, SAIC Motor Corp Ltd and electric vehicle start-up, Nio Auto. The licenses allow the operators to use a 5.6-km public road in Jiading District of Shanghai for testing smart cars. Shanghai has been investing in building world-class facilities for testing of autonomous vehicles.

2.3.4 South Korea

Korea expects to commercialize Level 3 technology on local roads by 2020. Korea's transport ministry began the provisional permit system in February 2016 and has approved provisional permits for 41 self-driving cars as of March including 14 for Hyundai Motor Co, two for Kia Motors, and one for Audi-Volkswagen. Audi-Volkswagen is the only foreign company with a provisional permit in South Korea.

The government is hoping its infrastructure developments will give a boost. The transport ministry laid out a $24.5 million budget for 2017 for autonomous vehicle infrastructure. Another important project is the K-City, an "experimental city" modelled after University of Michigan's Mcity used for autonomous driving tests and claimed to be world's largest facility for testing driverless cars (BusinessKorea 2017).

2.3.5 Singapore

In August 2014, the Singaporean Ministry of Transport announced the launch of CARTS (2014) – the Committee for Autonomous Road Transport for Singapore. CARTS' stated goals include "studying and testing the various AV technologies in our environment, laying the legal, regulatory and liability framework to govern the operations of AVs, and exploring industry development and business opportunities".

Furthermore, the Singapore Land Transport Authority (LTA) is working towards a framework that will allow the testing of AVs on the public road network in Singapore. According to this framework, Singapore requires that all autonomous test vehicles undergo a vehicle safety assessment before they are approved for on-road trials. Test vehicles can only be driven in autonomous mode within an approved test-site. All test vehicles are required to have a qualified safety driver who is ready to take control, until autonomous vehicle trials demonstrate that the technology is ready for fully autonomous operations. All trial participants are also required to have third-party insurance for test vehicles and must share data.

2.4 The legal frameworks and strategies of the Member States

2.4.1 The EU and national regulatory frameworks

As explained above, there is already a very extensive regulatory framework at the EU level. The production vehicles require EU type approval which is based on the Whole Vehicle Type-Approval System (WVTA). Directive 2007/46/EC sets out the safety and environmental requirements that motor vehicles have to comply with before being placed on the EU market. The recently amendments to the 1968 Vienna Convention on Road Traffic, allowing automated driving technologies transferring driving tasks to the vehicle, paving the way to testing of automated vehicles in Europe. Furthermore, at EU level there is Directive 2006/126/EC on driving license.

The national regulatory frameworks have evolved during the time when automation was only a remote possibility. Many Member States have either started or are planning to start regulatory process which will introduce the necessary modifications to the existing regulations, or even introducing new elements (ERTRAC, 2017). According to Flament (2015) the national regulations cover typically driver behaviour and driving licence (national traffic rules, civil and criminal law, in particular for ensuring road-safety), and the permissions for testing automated vehicles on open roads including possible derogations to the normal traffic rules.

It is clear that adaptation of traffic rules in different Member States should follow a coherent path. The European Commission is looking how to support the development of harmonized EU rules when needed, but currently there is no work ongoing yet, the Member States are only asked to report when they intend to develop national rules on automated vehicles (e.g. safety distance) to support converging approaches across the EU.

In this situation, it is not seen possible or useful to review the regulatory situation in all Member States. We therefore focus on those which either have advanced further, or are interesting cases of good practises to share.

2.4.2 Driver in the vehicle – the key issue

As explained above, the Vienna Convention which is used by most Member States is already amended to allow higher level of automation. Automated driving technologies transferring driving tasks to the vehicle will be explicitly allowed in traffic, provided that these technologies are in conformity with the United Nations vehicle regulations or can be overridden or switched off by the driver.

This amendment is interpreted differently by different Member States. In most cases a trained test driver/supervisor will be required to be physically present in the vehicle to monitor the operations. Some Member States including Finland allow remote supervision. Supervision includes in all cases remote monitoring, and some mechanism for remote control (e.g safe stopping of the vehicle). The assumption is then that when the vehicle is used on the roads there is a natural person who is the driver of that vehicle. Therefore, as long as a driver is "present" in the car, he will be considered responsible for the safe operation of the vehicle whilst on public roads.

2.4.3 EU member states approach to testing of automated vehicles

The regulatory authority is in all Member States the government ministry, for example Ministry of Transport and Telecommunications in Finland. The automated vehicles tests are authorized under experimental licenses with various degrees of responsibilities.

Most Member States are working towards legislation on the granting of license the operations and the responsibilities of the license for testing on open roads. They will cover both the safety of the vehicle and the trial/demonstration planning including certification, auditing and reporting.

There is a lot of uncertainty on up to what SAE level testing of vehicles is allowed and if remote supervision (driverless vehicle) is allowed, with different interpretations of the Vienna convention, UNECE regulations, and the meaning of the SAE levels and what is required from the remote supervision. Also, the regulations may apply to different vehicle classes. Before there is international harmonization, Finland has an advantage as it allows testing of vehicles up to Level 5 and Remote Supervision. Table 2 summarises the current situation in six Member States.

Table 2. List that describes up to which SAE class the testing of vehicles is allowed and whether remote supervision (driverless vehicle) is allowed.

Member State	Testing up to SAE level ?	Remote supervision (Y/N) ?	Remarks on testing on open roads
United Kingdom	4/5	N	Allowed in 2015 when a Code of Practise was published
France	4	N	Allowed end of 2018 / beginning of 2019, but only for M1 & N1 vehicles on highways or separated 2-way roads.
Netherlands	4/5	Y	In 2015 the public roads were opened to large-scale tests with self-driving passenger cars and lorries
Germany	3	N	Tests are ongoing while there is a Working Group working on adjustments to the legal framework
Finland	5	Y	Existing regulation covers what is needed for testing on open roads
Sweden	4/5	Y	Testing is allowed under the current regulatory framework, but work is ongoing to review the regulatory and legal issues

United Kingdom

UK is one of the first movers in driverless cars. As part of the 2013 National Infrastructure Plan (GOV.UK 2013), the UK's government announced its plan to review the legislative and regulatory framework for developing and testing driverless cars on UK roads. The 2013 Autumn Statement, stated that government "will work to encourage the development and introduction of autonomous vehicles". The importance of this issue – not only in terms of potential transport benefits – was reaffirmed by the UK Automotive Council which recognises that autonomous vehicles are a key technology for the UK - especially so, given the strength of UK based automotive research and development, and industrial output.

In 2014, the UK Department for Transport (DfT) launched a Call for Evidence to support the regulatory review on driverless cars to help identify any issues, including regulatory, safety and social issues, which need to be addressed whilst maintaining existing high levels of road user safety, the best ways to trial cars with qualified drivers and, looking further ahead, fully autonomous vehicles

As a result of the review the **"Pathway to Driverless Cars"** (GOV.UK 2015) was published in February 2015. The publication highlights that there are, in fact, few obstacles to the testing of highly and fully automated vehicles on UK roads. In addition there is also no requirement for special permits or bonds to be put in place unlike in many other countries. The Pathway set out a number of actions for government, and others, to facilitate the development, testing, sale and ultimately use of connected and autonomous vehicles.

In February 2015, the UK Department for Transport released the results of this consultation in a set of reports under the heading of **"Driverless Cars in the UK: A Regulatory Review"** (GOV.UK 2018). This review found that those wishing to test automated and highly autonomous vehicles are not limited to test tracks or specific geographic areas, nor are they required to obtain special certificates or permits. Further, they are not required to post surety bonds provided they have adequate insurance coverage.

The first set of actions were delivered with the publication of **the Code of Practice for testing of automated vehicle technology** (GOV.UK (2) 2015) in July 2015, which was developed in collaboration with industry, academia, and all levels of government, including local authorities and devolved administrations. The Code of Practice is a light touch approach to regulation, helping making the UK a world leading place to test driverless cars, while maintaining safety without placing additional regulatory burden on industry. The key requirements are:

- Vehicles under test on public roads must be road worthy;
- Vehicles should be insured and obey all relevant road traffic laws;
- when tested on public roads or in other public places there should be a test driver (or test operator) who supervises the vehicle at all times and is ready and able to override automated operation if necessary.; and
- automated vehicles under test should be fitted with a data recording device. The data should be able to be used to determine who or what was controlling the vehicle in the event of any incident

The driver (or operator) is responsible for ensuring the safe operation of the vehicle at all times whether it is in a manual or automated mode. Therefore, the Code sets out that the test driver or test operator should hold the appropriate driving licence and be trained to perform this role by the organisation responsible for conducting the testing. In addition, testing organisations should have robust risk management procedures in place.

France

France has also started activities in Automation very early. Already in the end of 1990s the French research centres were studying the issues of the introduction of automation in road transport. The focus was very much on the introduction of more and more ADAS which at this time did not require changes of legislation. Also, French activities on Cybercars attracted media attention but were not mature enough to start regulatory actions.

In Sept 2013, the French government announced a strategic review to define France's industrial policy priorities or "Nouvelle France Industrielle" framed into 34 industrial renewal (or "reconquête industrielle") initiatives (Gouvernement.fr, 2017). Their aim is to focus economic and industrial stakeholders around common goals, to align government means more effectively to these goals, and to harness local ecosystems to build a new, competitive French industrial offering that is able to win market share in France and internationally, thereby creating jobs.

Among the 34 priorities, "driverless vehicles" or "Véhicule à pilotage automatique" has attracted a lot of media attention. The aim of this initiative is to make the French automotive sector a pioneer in vehicle automation, notably by removing regulatory barriers to growth.

The action plan for this action was made public in July 2014. One of the five actions for the driverless vehicles is to “change the regulatory and normative framework for experimentation and the placing on the market of autonomous vehicle”, especially the “Changes in the regulatory and normative framework for experimentation and the placing on the market” and “Establishment of an insurance scheme”.

In spring 2016, the Public Authorities released a provisional administrative procedure that any company that would like to conduct real-world experiments on open roads for automated driving should comply with (RT, 2016). The procedure consists of filling out a form and drafting two reports (one describing the objectives and the design of the experiment and the second one describing the technology used in the experimental vehicles). All documents have to be sent to 3 ministries for they can collectively decide whether or not they officially authorize the experiments, essentially based on the safety aspects of the experiment. Since the administrative procedure has been released, a few companies or research institutes have applied and experiments are currently going on French roads

The French Government announced in 2015 the start of the procedure of the adoption of the necessary legal framework to enable the testing of driverless cars on public roads, and to replace the provisional procedure. The full regulatory framework entered in force in 2017. The adoption of the legal framework is expected end of 2018 / beginning of 2019 and will allow large-scale experiments for first use cases of automated driving, but only for M1 & N1 vehicles on highways or separated 2-way roads (Autovista, 2018).

For 2018, the same action plans the establishment of an insurance scheme in the form of an “Autonomous vehicle special insurance fund.” Finally, the French safety agency La Sécurité Routière (2018) has proposed that autonomous vehicles (AVs) should be made to pass a standard driving test before deployment on roads. Through the proposed test, AVs would be set to autopilot mode and be required to participate in a driving examination. Manoeuvres, different driving speeds, parking and navigation would all be under scrutiny.

The Netherlands

The high-quality infrastructure of the Netherlands combined with the positive cooperation between the automotive industry, researchers and the government make the Netherlands an extremely suitable country for the intended innovation, development and use of self-driving cars. As early as 2014, the Dutch Minister of Infrastructure and Environment announced its intention related to the promotion of automated driving in the Netherlands. The Netherlands is also among the frontrunners when it comes to the combination of autonomous driving and vehicle-to-vehicle communication, aimed at creating high (societal) added value with initiatives like the public-private Connecting Mobility action programme and the Dutch Automated Vehicle Initiative (DAVI, 2018).

In July 2015, the Ministry of Infrastructure and the Environment (I&M) opened the public roads to large-scale tests with self-driving passenger cars and lorries. The Dutch rules and regulations have been amended to allow large-scale road tests. In collaboration with Rijkswaterstaat and the RDW (Dutch Vehicle Authority), the Ministry of I&M have been exploring safe ways to conduct tests on the public roads. The RDW is responsible for the admission of vehicles to the public roads, including self-driving passenger cars and self-driving trucks.

Under the amended legislation, the RDW (2018) (Dutch Vehicle Authority) has the option of issuing an exemption for self-driving vehicles. Companies that wish to test self-driving vehicles must first demonstrate that the tests will be conducted in a safe manner. To that end, they need to submit an application for admission. The Dutch approach to enable large-scale testing includes the following innovation-promoting legislation:

1. To enable self-driving cars (and tests with them) on the public highway from a legal point of view, the existing Order in Council (the decree allowing exemption for exceptional transport movements) under which RDW grants exemptions has been amended in July 2015.

2. The Netherlands will additionally strive for national/international legislation that enables the market introduction of self-driving vehicle technology. For this purpose the Netherlands will take the initiative in international consultative bodies (EU and UN) and will support relevant proposals.

Furthermore, the Dutch EU Presidency (2016) produced the Declaration of Amsterdam "Cooperation in the field of connected and automated driving".

Germany

The German Federal Ministry of Transport and Digital Infrastructure established already in 2013 a Round Table "Automated Driving". This Round Table (BMVI, 2018) can be considered as a national platform where all relevant stakeholder groups (Federal Ministries, public authorities, industry, insurance companies, user associations, technical inspection, research institutes) are represented. The operational work is done by the Working Groups one of which is "Legal Issues". The objectives are building a consensus with respect to core issues of automated driving thereby creating basic precondition for the implementation of highly automated driving in Germany. This national platform also acts as an advisory board of the Federal Ministry of Transport and Digital Infrastructure.

The Working group has been studying the legal aspects of vehicle automation systems to determine what legal changes may be needed and how these relate to different levels of vehicle automation. A joint work of the Working Group and the German Federal Highway Research Institute (BASt) made an extensive legal assessment with respect to regulatory law and liability law, and, offered a classification of the degrees of automation from a policy perspective.

The assessment suggested that the current legislation would allow partial automation levels on public roads i.e. "The system takes over longitudinal and lateral control, the driver shall permanently monitor the system and shall be prepared to take over control at any time." Germany anticipates that deployment of highly automated vehicles will start from 2020 and, the focus will be first on the motorway and multi-storey car park environments. In order to facilitate the research, large-scale testing and deployment, the BMVI (2018) published in 2015 its "**Strategy for automated and networked driving** in which Germany wants to "establish a legal framework in which an automated and networked vehicle can autonomously take over driving tasks, without the driver having to constantly monitor the system."

The strategic paper focusses on the "Legal Certainty" needed for deployment of automated vehicles which includes work on:

1. International Legal Framework: extension of the definition of driver,
2. National Legal Framework: allow use of automated and networked vehicles, consider situations where the system performs the driving
3. Driver Training: handover and takeover of the driving task,
4. Technical Approval and Inspection: adoption of Code of Practice, PTI

Finland

Finland has announced that it wants to be the leading country in the development, deployment and use of automated transport (air, road, rail and maritime) and in highly automated vehicles. The Ministry of Transport and Communications (MINTC), together with the Finnish Transport Safety Agency TRAFI, has closely examined all legislation and regulations related to automated driving in Finland. The Ministry has come to a conclusion that current Finnish legislation (including adherence to international conventions) allows for the use and testing of self-driving vehicles on public roads given that each vehicle has a specified driver and that the driver is, at all times, able to take control of his vehicle. The Ministry has found that there is no legislative or regulative requirement for the driver to be inside the vehicle physically, which allows, in principle, for solutions that use remote control (similar to remotely piloted aircraft).

This means that current legislation and regulations in Finland allow for the testing of very high-level automated driving and that no additional regulations or amendments are currently needed. The Ministry of Transport and Communications will work together with other authorities, cities and commercial actors to enable and support testing of automated vehicles in different test environments around Finland (e.g. Aurora Arctic Challenge, FTA (2018)).

Finland has established a single contact point for automated vehicle trials that is operated by the Finnish Transport Safety Agency TRAFI. The contact point provides support and information to anyone planning automated vehicle trials in Finland. Organisations can use it to apply for a test plate certificate that allows for the use of automated vehicles on Finnish public roads. In the case of type approved vehicles that have already been registered in another EU country, no test plate certificate is required.

The Ministry has developed a plan for promoting intelligent automation in transport services. It was published in 2015 and calls for creating a strong shared determination for Finland to become one of the world's foremost actors in the field of intelligent automation of transport and to create and maintain an enabling regulatory framework that will make this development possible, publication "Robots on land, in water and in the air. Promoting intelligent automation in transport services - Robotit maalla, merellä ja ilmassa. Liikenteen älykkään automaation edistämissuunnitelma" (Pilli-Sihvola et al., 2015).

To promote automated driving, the Ministry and other road and transport authorities have developed a roadmap for automated driving. The roadmap "A roadmap for developing automation and robotics in transport sector 2017-2019 - Liikenteen automaation ja robotiikan kehittämistoimenpiteiden tiekartta 2017-2019 (Arola et al., 2017) was published in 2017 and describes the most important activities to be undertaken in order to facilitate automated driving trials and to prepare for increasing vehicle automation.

Furthermore, the Ministry has given contract to Infotripla for a study called “Analysis of the data and development needs of automated driving - Selvitys automaattiajamisen edellyttämistä tiedoista ja kehittämistarpeista”. The study will be published in 2018.

At the international level, Finland is actively working towards updating the UNECE Conventions on Road Traffic so that, in the future, they would allow for large-scale testing and use of self-driving vehicles and vehicle fleets.

Sweden

Sweden has been very active in the area of automated vehicles, and wants that its automotive industry is a forerunner in Automation. In September 2014, the Swedish Transport Authority (Transportstyrelsen, 2014) unveiled its feasibility study on the need to modify the Swedish traffic and vehicle regulations in view of the increased automation in the transportation system.

The study concluded that there is currently no need for major changes as the partially automated driving systems require that a driver is behind the wheel ready to take over operating control. This means that the responsibility remains with the driver. Driving tests do not need to change because of the new technology.

The pre-study noted that the Transport Agency needs to be more proactive and be active in the development of automated vehicles, and that the law should not stand in the way of technological developments that contribute to better safety, environment and accessibility.

The pre-study lists a number of areas that the Authority intends to work with the future including:

- Participate in or follow the relevant test activities (eg, Drive-Me project and KTH’s automated public transport (bus) project)
- Continue to investigate opportunities to experiment with fully self-driving vehicles on public roads in limited areas.
- Continue to monitor and participate in the work on the EU-level legislation in the field of automated vehicles, cooperative road systems and intelligent Increasing knowledge of the safety of complex and safety-critical systems may be requested.
- Investigate the impact of such systems on the community planning.
- Deepen cooperation with the Ministry of Industry, other government agencies, industry and academia to contribute to a national consensus.

Echoing the Swedish industry, the Transport Agency emphasises the importance of automated vehicles provide new opportunities for example for people who get their license revoked because of illness or age.

Lindholmen Science Park is leading the development of the Automated Transport System in Sweden in which the Drive Me project, initiated by Volvo Cars, plays key role. On the infrastructure side Sweden has ASTAZero (2018) proving ground for active safety and autonomous drive.

Legal and regulatory issues are clearly a very important dimension concerning automation of the transport system. Lindholmen, as a partner in the Drive Me project will engage the Swedish Transport Agency and other relevant organisations, in order to secure the necessary development needed (Sweden, 2017).

2.5 The strategies and plans of the cities and regions

It does not come as a surprise that many cities and regions want to be in the forefront in the development of automated road transport. In Finland for example Helsinki, Espoo, Vantaa, Tampere and Turku have all strategic plans.

The cities promote automation because it is believed to bring a solution to exiting or future transport problems, i.e.- increase safety, alleviate environmental effects and congestion, to increase the use of public transport, and also to reduce costs in offering mobility services (such as MaaS and Last Mile – On Demand transport). Automation is also seen as a way to combat the shift from public transport to the use of private vehicles offered by companies like Uber or Lyft.

There are no local regulations preventing testing of automated vehicles, but typically cities and regions have their own rules e.g. for ride sharing and they maintain the road/street network in their jurisdiction.

In the following we highlight some issues which might be interesting from the point of view of this study, in cities Tampere (Finland), Berlin (Germany) and Stockholm (Sweden), and the following regions MRDH -(Netherlands) and Saclay (France).

2.5.1 Tampere

Overall mobility challenge: Tampere city centre is located on a narrow land area between two lakes and the city centre is easily congested. To decrease congestion and other negative impacts of traffic and to attract more users to public transport a new tramline will be built by 2021. Automated bus transport services will extend the reach and will be fully integrated with the tram and the existing bus lines and will offer effective on-demand feeder transport (first/last mile) for the public transport user, with lower operating costs.

Motivation to operate automated services: Tampere aims to be a sustainable smart city attractive for business and citizens. Development of automated public transport services is one of the spearhead initiatives. Tampere has studied automated bus services, tested automated buses and now wants to deploy automated feeder services as an integral part of the existing public transport system. Automated services are seen as the future complementary alternative for the City.

Existing national/local regulatory framework to operate demonstration of automated services: The existing legislation and regulations allows remotely supervised automation on public roads in Finland.

2.5.2 Berlin

Overall mobility challenge: Developing public transport into a more demand oriented MaaS. Creating an environmentally friendly, efficient, and intelligently integrated transport system

Motivation to operate automated services: Implementation of a real-life public transport system capable of using fully automated vehicles to transport citizens from and to the demo site as well as a seamless integration with existing PT. Generating user acceptance for an autonomous transport systems

Existing national/local regulatory framework to operate demonstration of automated services: Current national regulatory framework is not yet designed for fully automated vehicles on public roads. However, the Berlin Senate is keen to solve potential barriers and approve automated services at the demo site.

2.5.3 Stockholm

Overall mobility challenge: Support Barkaby residents with mobility: transport within the area, to and from high capacity public transport, and with a new link to and from the business area in Kista. (Barkaby is a town north of Stockholm. In Barkaby 18000 homes and 1 000 office spaces will be built within the next ten years).

Motivation to operate automated services: Operating automated services in Barkaby is important to provide residents with sustainable mobility and minimize their need for private cars. Learnings from Barkaby will be transformed to other sites and implementations.

Existing national/local regulatory framework to operate demonstration of automated services: Legislation for operating self-driving vehicles on public streets was adopted in June 2017. Shuttles will be operated on public streets during 2017. This will confirm the legal processes.

2.5.4 MRDH

Overall mobility challenge: MRDH (Metropoolregio Rotterdam Den Haag) covers two important regions in the Netherlands, Rotterdam and The Haag. MRDH plans to test automation in two locations addressing the full scope of automated urban shuttle transport in Capelle and in Delft.

Motivation to operate automated services: To meet the technical challenges to operate automated shuttles in mixed traffic, handling urban traffic scenarios with a variety of other road users. To study the interaction of other road users with automated shuttles and evaluating the ride experience of passengers. To deploy automated shuttle systems within the other MRDH municipalities (23 cities).

Existing national/local regulatory framework to operate demonstration of automated services: Full legislative framework for public roads, including piloting empty driving vehicles. Active Government support and cooperation. 3 years of experience.

2.5.5 Saclay

Overall mobility challenge: Saclay is a commune in the southwestern suburb of Paris, located 19 km from the centre. The local student population will be doubled during the next three years up to 20.000 and the public transport offer has to be able to support the students’ needs in terms of mobility, especially during night period. The main challenge is to go beyond piloting activities and implement a real mobility service using automated vehicles and involving end-users.

Motivation to operate automated services: This academic excellence zone attracts more and more students which demonstrate the strong influence of the area.

The growth of the local mobility need represents the perfect circumstances to test new ways to move through short/medium distances while guaranteeing a high rate of acceptance due to the local population (mostly students).

Existing national/local regulatory framework to operate demonstration of automated services: The French national regulation about the automated vehicles is currently and surely evolving towards full automation.

3 Fleet penetration of automated vehicles

3.1 Timetable for the commercial introductions by manufacturers

Today, the timetable for commercial introduction of level 3-5 automated vehicles needs to for researchers to be based on announcements by industry, market analysis predictions, or expert group judgements. The year of commercial introduction denotes the year when vehicles equipped with the automation use case are brought out openly for sale so that they can be utilised and deployed for commercial or private use. Table 3 shows collective highlights of news release or announcements from a number of major companies that are involved in CAD, regarding the projected timeline to have market-ready highly automated driving (Chan 2017). Most companies are advertising the introduction of Level 3-4 vehicles by 2020 or sooner, while some also claim that by 2021 they will be ready to mass produce Level 3-4 vehicles. However, it is apparent that the level of automation and exact capabilities of the products can differ considerably from one to another. It is important for observers to distinguish the type and level of automation features.

Table 1. Predicted market introduction of automated driving systems (Chan 2017)

Organization	Confirmed and predicted product introduction	Predictions of readiness for autonomous vehicles
Audi/VW	2016 - Piloted Driving	Full AV by 2021
BMW	2014 – traffic jam assist 2014 – automated parking	Available by 2021
Bosch	2017 – Integrated Highway Assist 2020 – Highway Pilot Auto Pilot	by 2025
Continental		Available by 2020
Daimler Benz	2014 – Intelligent Drive	Available by 2020
Ford	2015 – fully assisted parking	To mass produce AV in 2021
GM	2017 – Super cruise	
Google	2015 – Driverless Pod prototype	Available by 2018
Honda		Available by 2020
Hyundai		Available by 2030
Mobile Eye	2016 – technology ready for OEMs	
Nissan	2016 – traffic jam pilot 2018 – multiple lane control	Available by 2020
Tesla	2015 – Lane Assist + ACC	highly autonomous Self-driving 2020–2025
Toyota		Mid 2010s – highly autonomous
Volvo	2015 – traffic jam assist 2017 – Drive Me FOT in Sweden	Zero fatality cars by 2020

From the perspectives of introducing varying levels of driving automation to the market, there are two opposing views about how introduction of CAD products will turn out in terms of technical viability and market acceptance.

One camp advocates an evolutionary path, in which an increasing level of automation will be added into future vehicles, as the maturity of technologies gradually makes it feasible to be incorporated into the products. This path will evolve from lower levels of automation such as advanced driver assistance systems (ADAS) that are currently available in the market, and then onto higher levels of CAD. It is a belief of this camp that automation can assist drivers with driving tasks that demand high precision, fast reaction, and complex calculations. This camp also takes the view that human drivers have abilities to do well in many driving tasks and thus they ought to stay in the loop. For example, human drivers may exchange visual glances or body gestures with other drivers to communicate intentions that are still difficult to be comprehended by a machine. Furthermore, many users will still favour the choice of being able to take control of the vehicle even if automation is available. This type of deployment is often said to be ‟Something Everywhere,” meaning that the deployed vehicles are automated to some degree but they will be available in markets everywhere.

The other camp, however, argues that it is virtually impossible to guarantee that drivers can be called back to resume control especially after the vehicle has been in automated modes for an extended period. For example, in SAE Level-3 systems, the driver is supposed to be receptive to alert and be ready in a few seconds to serve as a fall back to perform the dynamic driving tasks (DDT). This may prove to be a daunting challenge, as drivers may become inattentive or even incapable of performing the required tasks after being relieved of driving tasks for a long time. Some improper user behaviours have in fact even been witnessed in some commercialized Level-2 systems, where drivers are supposed to be still in charge of the object and event detection and response (OEDR) task but they intentionally misuse the system and thus putting themselves and others in risks. Thus, to avoid the difficulty of relying on user vigilance, this camp suggests that ADS must leap straight to full automation and remove the control away from the drivers completely. This view is best exemplified by the concept of Google driverless cars, for example, in which no steering wheel or pedals are present. This type of deployment is often referred to as ‟Everything Somewhere,” meaning that the vehicles are fully capable of doing everything but they only operate in some limited ODDs.

It is highly likely that the introduction of driving automation systems will comprise both of the two trajectories. As the evolutionary approach advances and continues to overcome challenges to robustly realize the highly-automated systems with drivers in the loop, the introduction of fully CAD will also take place in selective venues. Learning from the deployment experience in both approaches and leveraging improvements in technical capabilities, highly automated hybrid systems (HAHS), in which both drivers and automation systems co-exist, will come into the market when technologies, consumers, and market are ready.

ERTRAC (2017), involving many automotive industry players published its road map for the development and roll-out of automated vehicles. Their forecasts on market introduction of automated vehicles are shown in Figure 1, Figure 2, and Figure 4.

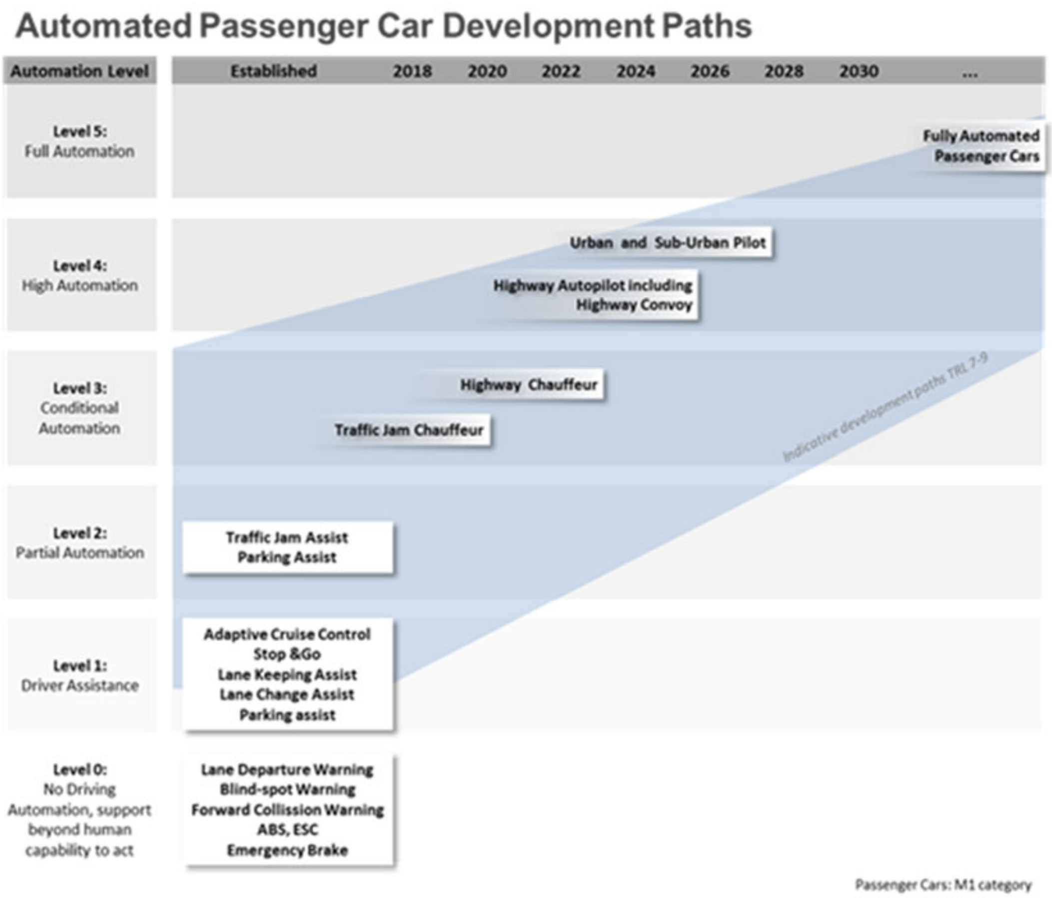

Figure 1. Market introduction of passenger car automation use cases (ERTRAC 2017)

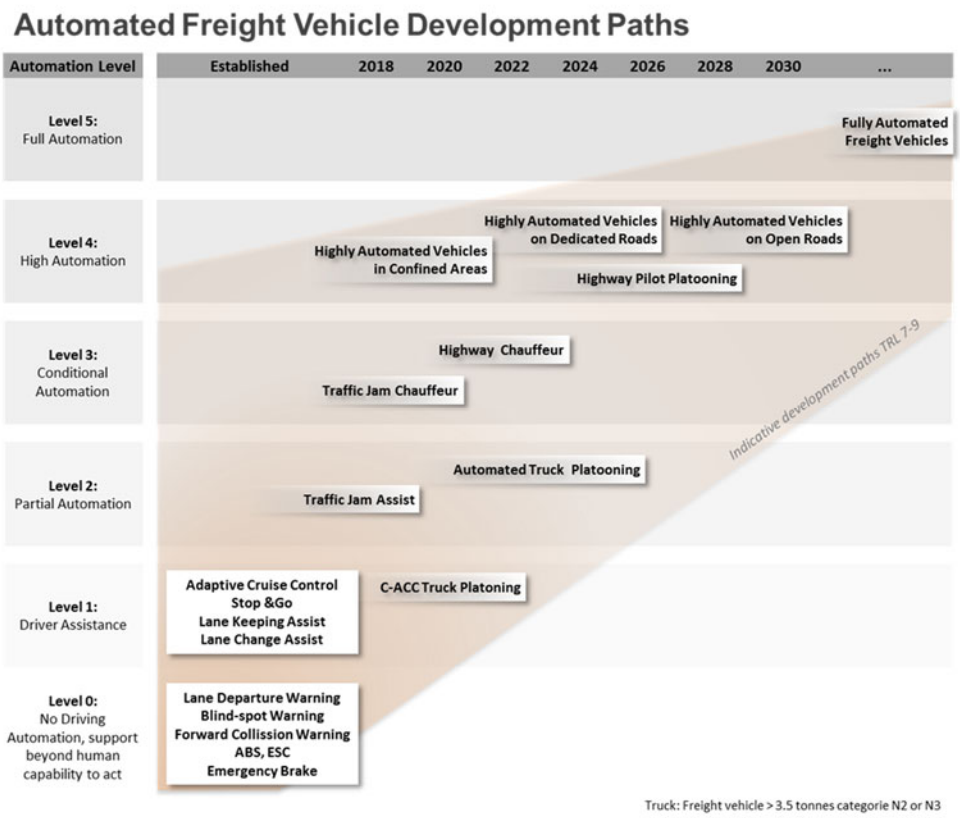

Figure 2. Market introduction of freight vehicle automation use cases (ERTRAC 2017)

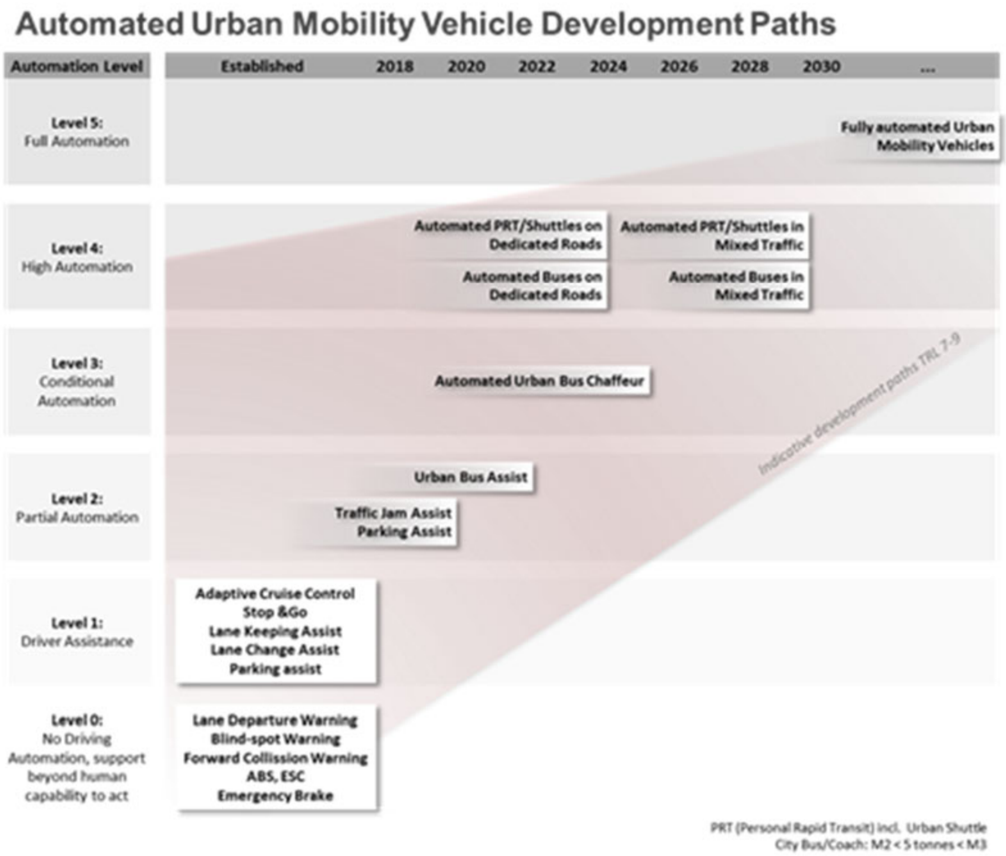

Figure 3. Market introduction of urban mobility vehicle automation use cases (ERTRAC 2017)

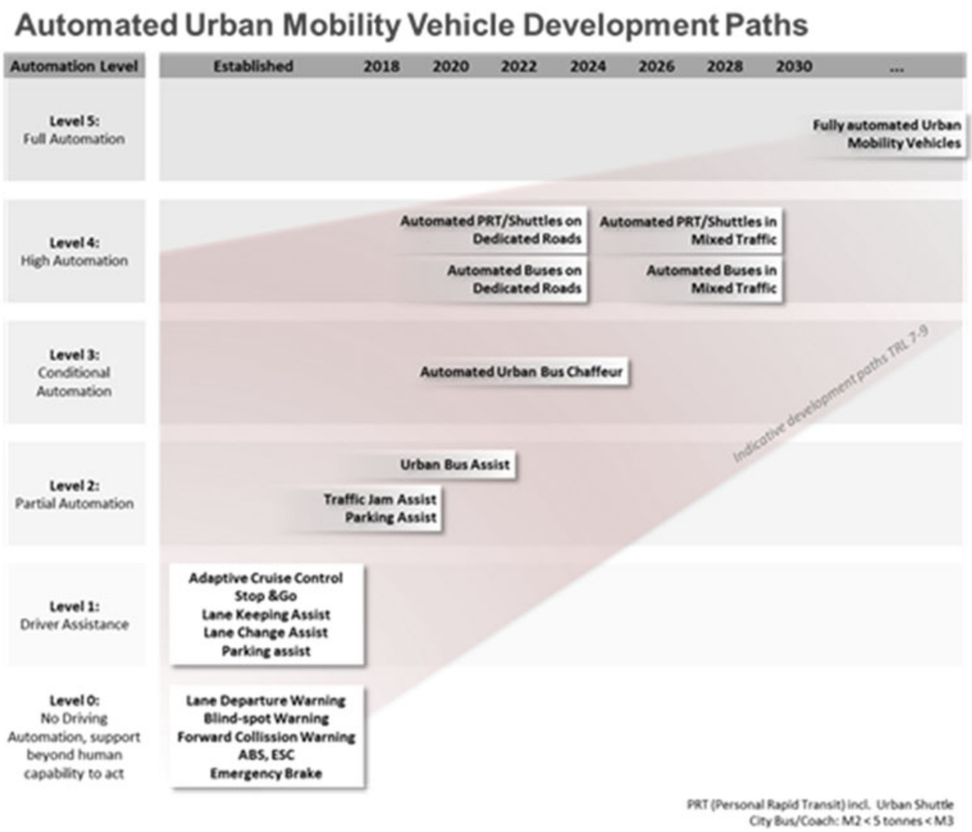

Figure 4. Market introduction of urban mobility vehicle automation use cases (ERTRAC 2017).

On the basis of the ERTRAC road map and the tendencies of optimistic forecasts even by experts, and the views of the project workshop participants, the likely year of market introduction in Europe for the five selected use cases could be :

- Highway autopilot including highway convoy (L4) : **2023**
- Highly automated (freight) vehicles on dedicated roads (L4) : **2025**
- Automated PRT/shuttles in mixed traffic (L4) : **2027**

With regard to the driverless taxis, the industry has during the past years indicated introduction in 2018-2020 (Digital Trends 2016, Johnson & Fitzsimmons 2018, Ohnsman 2018, TechRepublic 2017), but the Uber accident in March 2018 has likely postponed the introduction by a few years. The driverless maintenance and road works vehicles could follow approximately the same timeline as automated freight vehicles on dedicated roads. Thereby, the likely year of European market introduction of the last two use cases could be :

- Commercial driverless vehicles (L4) as taxi services : 2025
- Driverless maintenance and road works vehicles (L4) : 2024

3.2 Estimation of percentage of new vehicles 2019-2040

Market analysis companies have made some forecasts on the market penetration of new vehicles such as Grand View Research (2018), see Figure 5. They estimated the global self-driving cars and trucks (likely Level 4) market size is expected to be approximately 6.7 thousand units in 2020 and is anticipated to expand at a compound annual growth rate of 63.1% from 2021 to 2030.

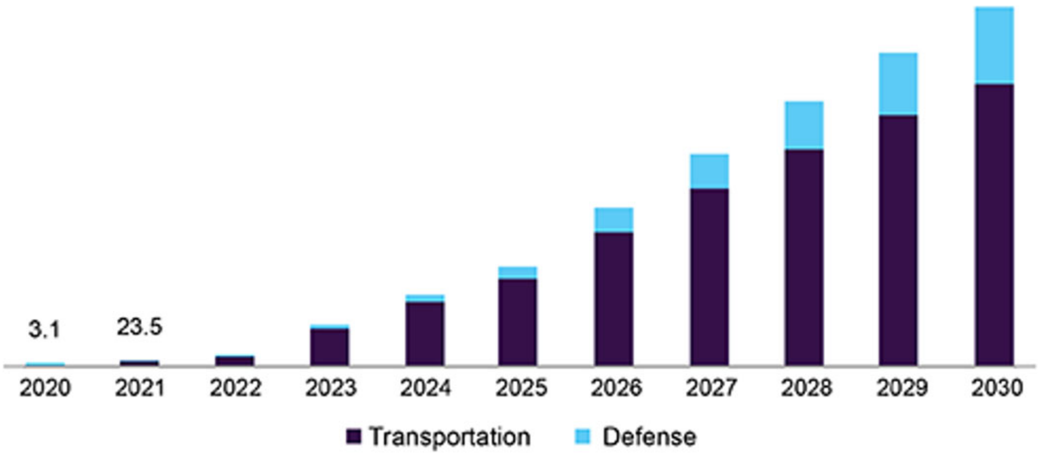

Figure 5. North American self driving cars and trucks market size by application in 2020-30 in thousand units (Grand View Research 2018).

The speed will depend on the automation use case. TrendForce (2018) estimated the global annual growth rate of self-driving taxis to reach 81% from 2018 to 2023.

3.3 Estimation of split between privately or collectively owned or used vehicle

Basically, both automated shuttles and robot taxis will be fully in shared use, although the same vehicles used as robot taxis will likely be sold to private persons as well for urban vehicles, perhaps with minor changes.

All other use cases are likely used for private use of a person or a company. Even in these cases, there may be more than one driver using the vehicle but the vehicle will not be shared openly by any willing person.

3.4 Estimated percentage of the total vehicle fleet and driven kilometers

The project workshop produced market penetration estimates (percentage of new vehicles equipped with the automation use case) for both 2030 and 2040, as well as verified the year of market introduction. The market penetration estimates were given for two scenarios: 1) business as usual or low scenario, and 2) high scenario including implementation support such as mandatory regulation. The resulting market penetration figures for the five use cases are shown in Figures 6-11.

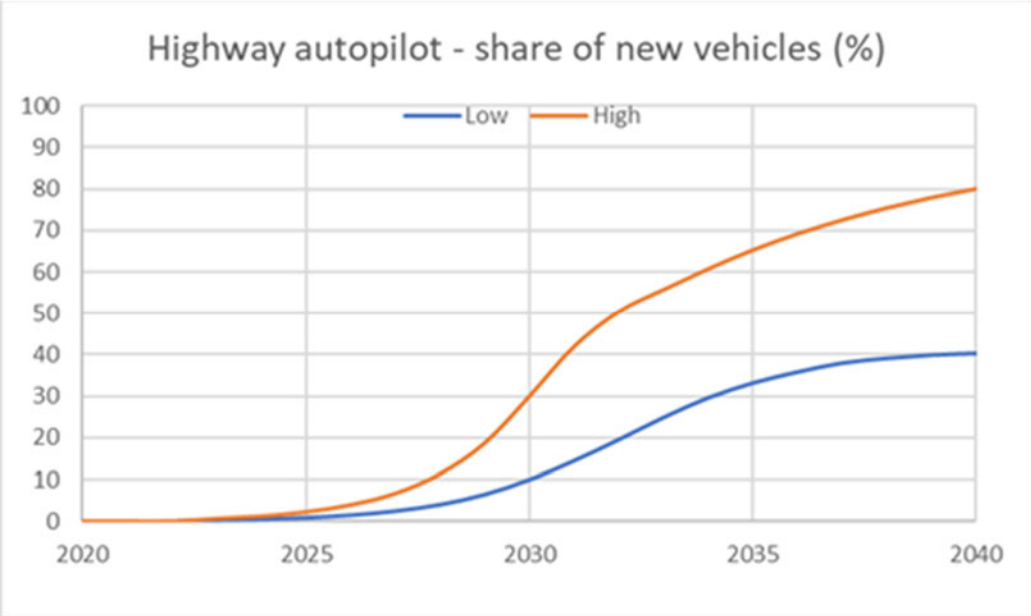

Figure 6. Market penetration of highway autopilot (L4) in new cars in low and high roll-out scenarios in Finland.

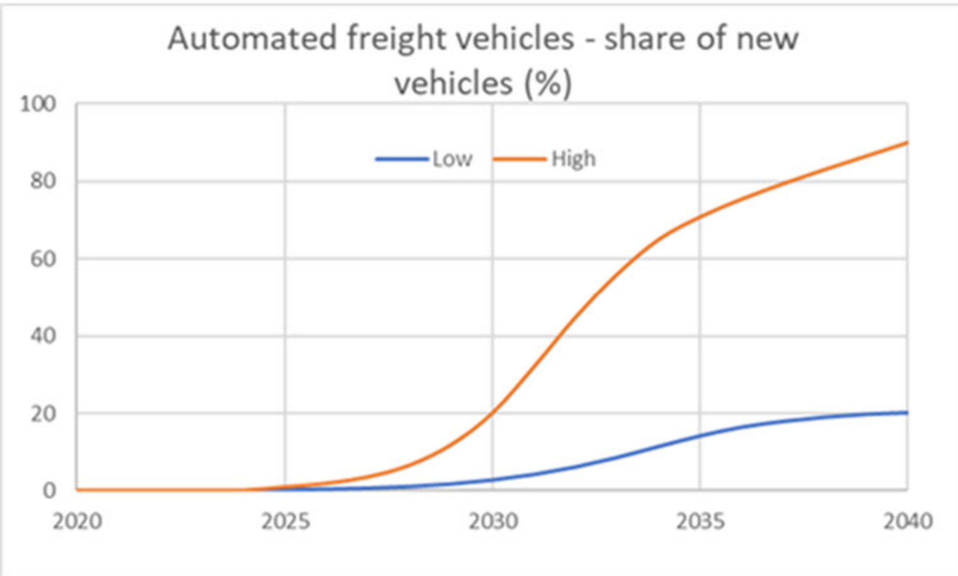

Figure 7. Market penetration of automated (L4) freight vehicles in new trucks in low and high roll-out scenarios in Finland.

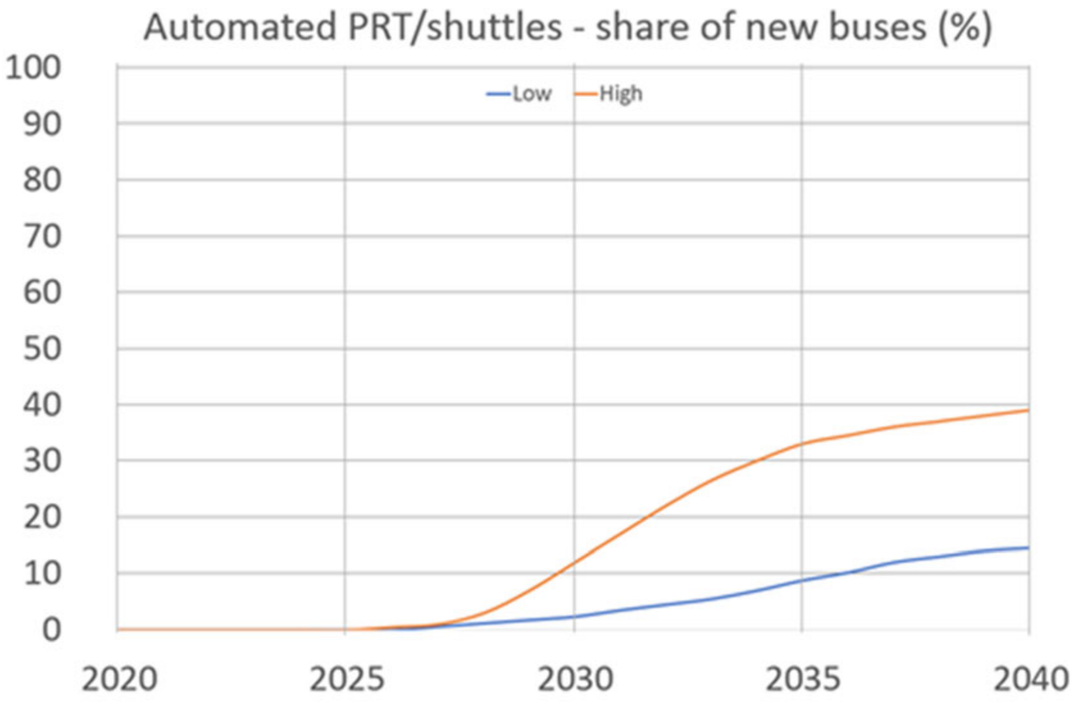

Figure 8. Market penetration of automated PRT/shuttles (L4) among new buses in low and high roll-out scenarios in Finland.

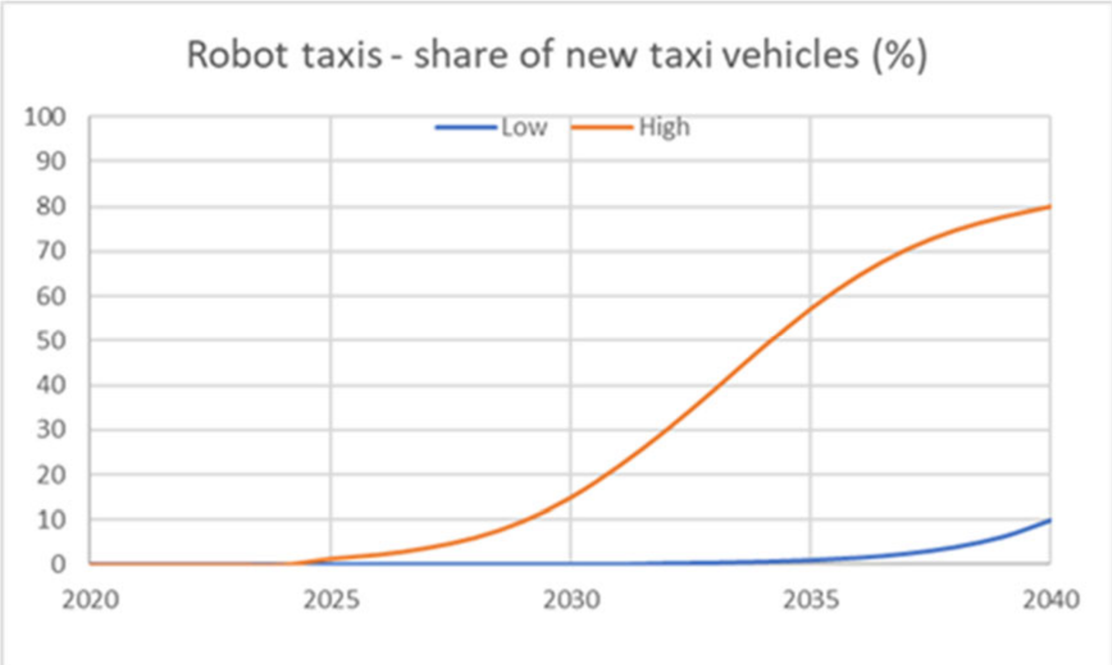

Figure 9. Market penetration of commercial driverless vehicles (L4) as taxi services among new taxis in low and high roll-out scenarios in Finland.

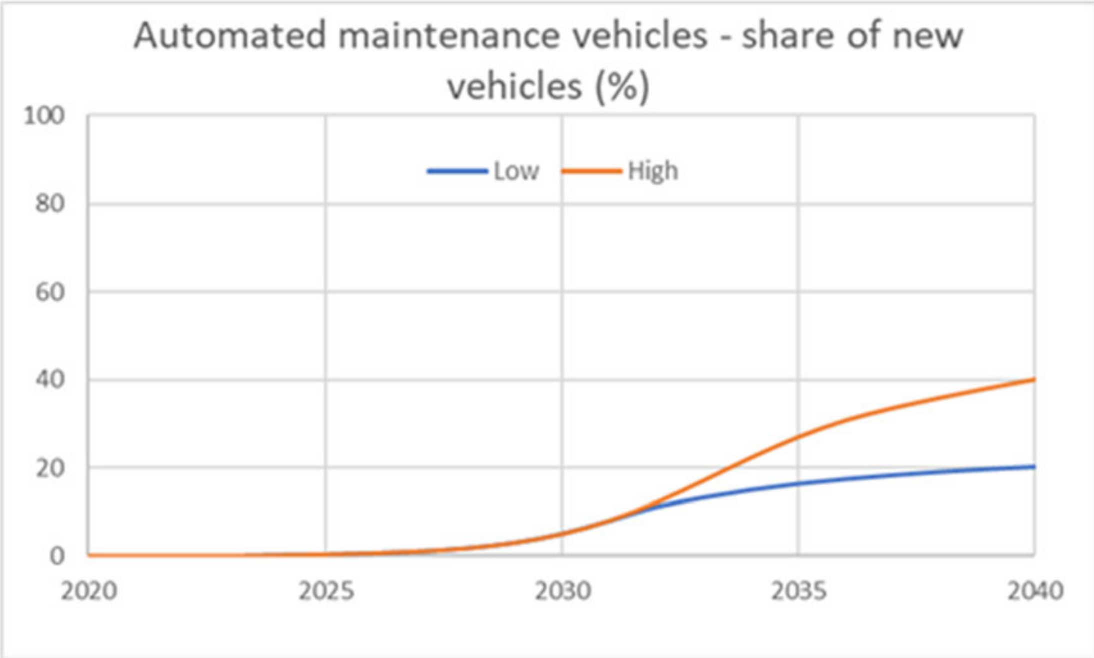

Figure 10. Market penetration of driverless maintenance vehicles (L4) among new trucks used as maintenance vehicles in low and high roll-out scenarios in Finland.

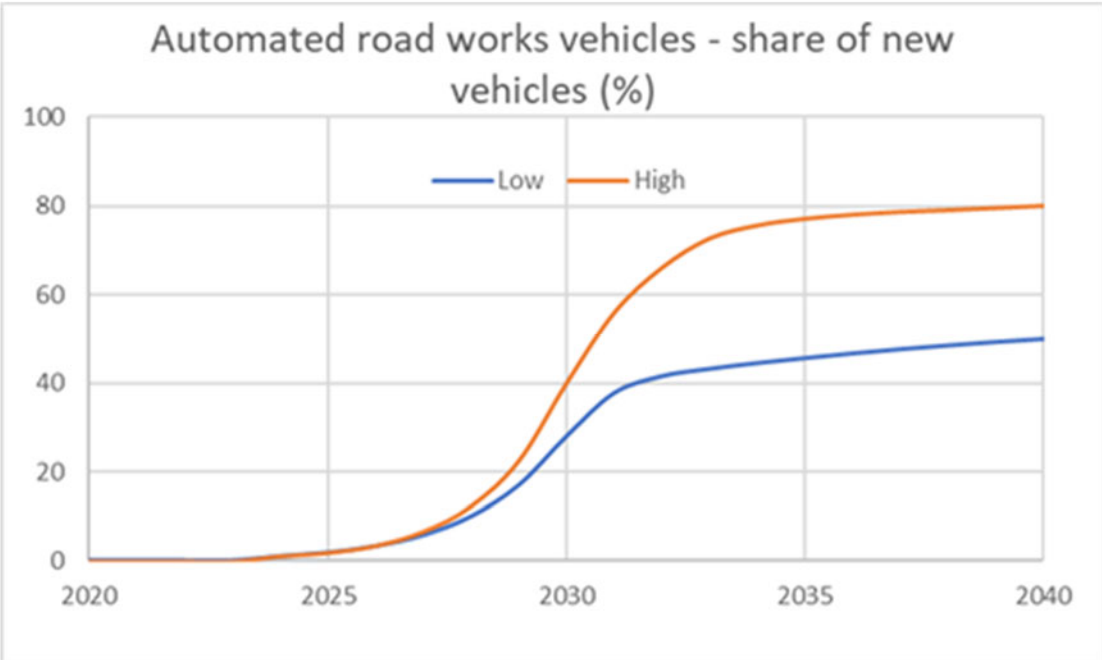

Figure 11. Market penetration of driverless road works vehicles (L4) among new road works vehicles in low and high roll-out scenarios in Finland.

On the basis of vehicle fleet's age distributions and the average annual kms driven be vehicles of different age, we calculated the estimates for vehicle fleet and vehicle km penetration for the different use cases. The results are shown in Table 4 and Table 5.

Table 4. Vehicle fleet penetration (%) of the automation use cases studied in Finland in 2030 and 2040 in both low and high scenarios.

Automation use case	Fleet penetration (%)				Vehicle type
	2030		2040		
	Low	High	Low	High	
Highway autopilot	1.2	3.5	16	34	Car
Automated freight vehicles on dedicated roads	0.4	2.8	8.1	40	Truck
Automated PRT/shuttles in mixed traffic	0.4	1.7	7.0	24	Bus
Commercial driverless vehicles as taxi services	0.0	8.2	5.4	71	Taxi
Automated maintenance vehicles	0.8	0.8	9.3	16	Maint.truck
Automated road works vehicles	4.2	5.6	28	45	RW vehicle

Table 5. Vehicle km penetration (%) of the automation use cases studied in Finland in 2030 and 2040 in both low and high scenarios.

Automation use case	Vehicle km penetration (%)				Vehicle type
	2030		2040		
	Low	High	Low	High	
Highway autopilot	1.7	4.8	20	43	Car
Automated freight vehicles on dedicated roads	0.6	3.9	9.6	47	Truck
Automated PRT/shuttles in mixed traffic	0.2	0.9	3.9	13	Bus
Commercial driverless vehicles as taxi services	0.0	8.4	5.6	72	Taxi
Automated maintenance vehicles	1.0	1.0	11	19	Maint.truck
Automated road works vehicles	5.8	7.7	31	49	RW vehicle

The vehicle fleet and km penetrations are so low in 2030 that the impacts of highly automated vehicles will likely mostly be negligible, although in the taxi or road works vehicle segments the penetrations approach 10% in the high scenario indicating some influence already on their business domain. In 2040, however, the high scenario penetrations are on a level, where the impacts on the transport system will be considerable.

4 Operational design domains

4.1 General on operational design domain

Operational design domain (ODD) is a description of the specific operating conditions in which the automated driving system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/night time, etc.), prevailing traffic law and regulations, and other domain constraints. An ODD can be very limited: for instance, a single fixed route on low-speed public streets or private grounds (such as business parks) in temperate weather conditions during daylight hours. (Waymo 2017)

The ODD is relevant to all levels of automation except for 0 and 5 as shown in Table 6. Any automation use case of level 1-4 is usable only in its specific ODD.

Table 6. Relevance of operational design domain for different automation levels (SAE 2016)

Level	Name	Narrative definition	DDT: Sustained lateral and longitudinal vehicle motion control	DDT: OEDR	DDT fallback	ODD
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)**						
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.	*System*	**System**	*Fallback-ready user (becomes the driver during fallback)*	Limited
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**

The automated vehicles are deployed so that they consider the ODD and especially its ending. This is illustrated in Figure 12.

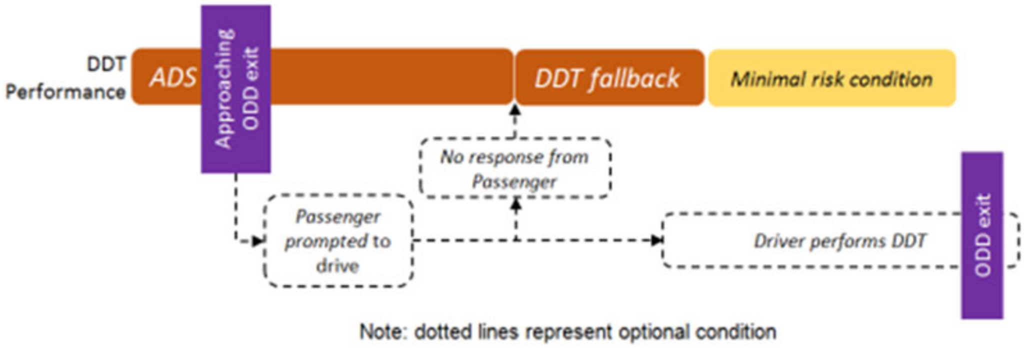

Figure 12. Performance of automated vehicle when approaching ODD exit. ADS = Automated Driving System; DDT = Dynamic Driving Task. (SAE 2016)

The automated driving system becomes aware of the impending exit from the ODD, and may prompt the fall-back ready user to take over the tasks of the driver. If there is no response from the passenger indicating takeover, the system initiates dynamic driving task fallback, and moves to a minimal risk condition. The characteristics of automated achievement of a minimal risk condition at level 4 will vary according to the type and extent of the system failure, the ODD for the automated driving system feature in question, and the specific operating conditions when the ODD exit occurs. It may entail automatically bringing the vehicle to a stop within its current travel path, or it may entail a more extensive manoeuvre designed to remove the vehicle from an active lane of traffic and/or to automatically return the vehicle to a dispatching facility. (SAE 2016)

For the user, it would likely be more comfortable the less often the control of the vehicle needs to be transferred between ADS and the driver. It is also likely that elimination of the transfer situations requires investments from the stakeholders responsible for the existence of the ODD in the specific situation. Hence, the continuity and length of the ODD play an important role for both the user and those responsible for maintaining the ODD.

The attributes of the ODD are directly connected to the way the automated driving system works. Figure 13 shows the example from General Motors.

Figure 13. The building blocks of the automated driving system (General Motors 2018)

Perception, accurate positioning and mapping are evidently the key building blocks in the automated driving systems' architecture. See Figure 14 for the description of the different positioning solutions. The sensors and their range are essential especially with regard to the speed ranges possible (Schoettle 2017). Connectivity/networking to operations centres and real-time information are also important elements. All of these are also related to the vehicle's interaction with its environment, and thereby strongly connected to the ODD.

So far, automated driving use cases have been developed and piloted by various stakeholders without any real coordination. Hence, the stakeholders have made their own decisions concerning the sensor choice, connectivity, positioning options utilised and other factors determining the ODD with only the global, national, and local regulatory frameworks affecting their choices. At the same time, the stakeholders have not published any accurate information about their ODD details as long as the use cases are still not rolled out into the market. There are also proponents calling for more coordinated and interoperable manner to deploy automated driving. Alonso Raponso et al. (2017) recommend Coordinated Automated Road Transport. Their coordinated automated road transport is meant as an extension of the automated driving concept by adding communication capabilities that connect vehicles in between and with the infrastructure and adding a central coordination player to achieve the full potential of automated driving in terms of social, economic and environmental benefits. Such a coordinated approach would require an additional ODD layer, but on the other hand provide more harmonisation of the ODDs between the stakeholders. Shladover (2018b) points out that in the SAE J3016 group, the ODD is specific to each individual driving automation system feature and can only be defined by the manufacturer of the system, based on the specific technological capabilities and limitations of that system.

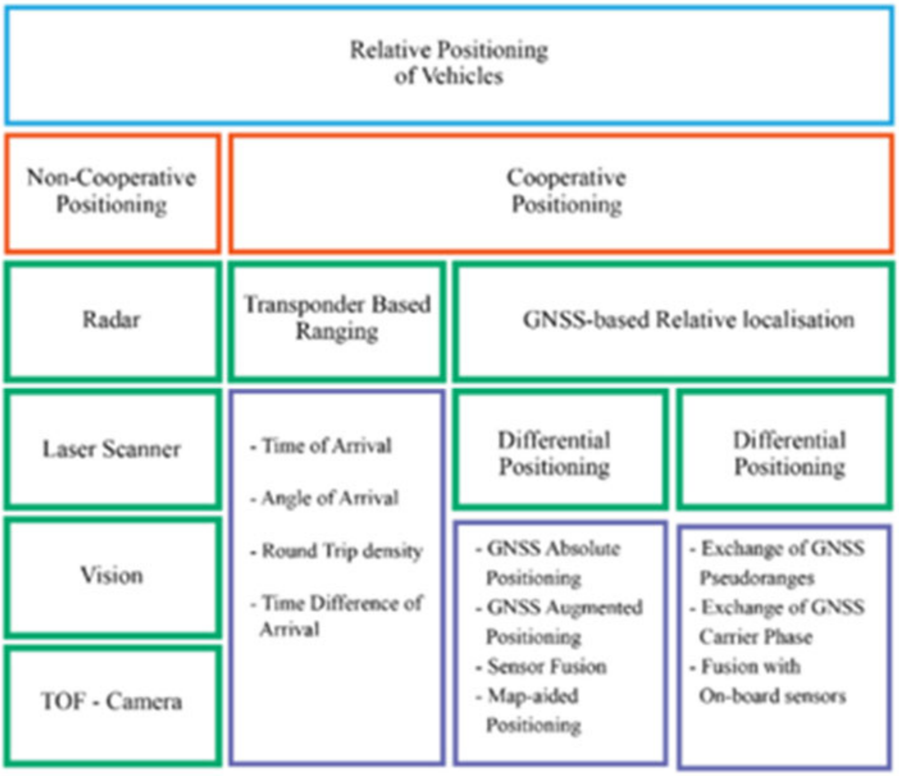

Figure 14. Vehicle positioning technologies. (Johnson & Rowland 2018, on the basis of de Ponte Müller 2017)

So far, the manufacturers and/or designers of automated driving systems have only published ODDs for urban cars in their voluntary safety reports (Ford 2018, General Motors 2018, Waymo 2017). For other use cases, we are forced to make assumptions on the ODD features of the five automated driving functionalities based on pilots, studies and expert views expressed in various working groups, articles or conferences. The assumed specification for the ODD of each chosen functionality (requirements for physical and digital infrastructure) is presented in the following section.

4.2 Possible ODD for each chosen functionality

It is up to the manufacturers of the system to specify the ODD for their automated driving system. For the purposes of this study, the ODD specifications is needed, however. The specifications below have been produced on the basis of available documents, reports and presentations as well as discussions in different fora and working groups. There are no generally accepted specific lists of ODD attributes available, Hence, such a list of attributes was developed during this study (Table 7).

Table 7. ODD attributes proposed.

ODD attribute	Physical / Digital infrastructure	Static / Dynamic
Road	Physical	Static
Speed range	Physical	Static
Shoulder or kerb	Physical	Static
Road markings	Physical	Static
Traffic signs	Physical	Static
Road furniture	Physical	Static
Traffic	-	Dynamic
Time	-	Dynamic
Weather conditions	-	Dynamic
HD map	Digital	Static
Satellite positioning	Digital	Static
Communication	Digital	Static
Information system	Digital	Static

Many attributes are related to infrastructure, mostly the physical infrastructure. Also aspects of the digital infrastructure are relevant for the ODDs.

Concerning the nature of the attributes, most of them are considered as static with regard to the availability of the service behind the attribute. In many cases, the service content itself can be quite dynamic – up-to-date information about a variable message sign from an information service provided in real time via the communications service to a vehicle accurately located just at the moment utilising a newly updated HD map.

4.2.1 Highway autopilot including highway convoy (L4)

According to ERTRAC (2017), the highway autopilot including highway convoy provides automated driving up to 130 km/h on motorways or roads similar to motorway from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system but does not have to monitor the system constantly. The driver can at non-critical times override or switch off the system. There are no requests from the system to the driver to take over when the system is in normal operation area (i.e. on the motorway). Depending on the deployment of cooperative systems, ad-hoc convoys could also be created if V2V communication is available.

The ODD-related requirements were identified for the use case in the C-ITS Platform's Physical and Digital Infrastructure Working Group (Kulmala et al., 2017). The results have been compiled in Table 8.

Table 2. ODD related requirements for highway autopilot (L4) in 2018.

Highway autopilot incl highway convoy	
Road	Motorway or similar, only on line sections not including ramps or intersections, but containing straight driving on weaving sections
Speed range	Up to 130 km/h; some systems do not work below 30-40 km/h; no restrictions 2030-
Shoulder or kerb	Safe stopping for a minimal risk condition requires a wide paved shoulder available for this purpose and not used for, e.g. hard-shoulder running. Safe refuges or shoulder areas similar to bus stops could be made available in case of narrow shoulders at intervals of e.g. 500 m on each carriageway
Road markings	Minimum quality of solid or dotted lines painted on the pavement if accurate lateral positioning is based on a camera detecting the location of the lane borders, and if the lines indicate traffic management information (e.g. no overtaking or lane change)
Traffic signs	Needed for vehicle to react to traffic control indicated by traffic signs along its trajectory to select appropriate speed or to take other required action. The sign content can be accessible via cloud, or tags and/or beacons attached to the sign
Road furniture	Wireless radio beacons or physical landmarks possibly with sensor reflectors to support and increase positioning accuracy for AD vehicles. This is most valuable in tunnels and in totally open areas with no fixed objects nearby, or on sections with high likelihood of poor road weather conditions; or when some objects in the environment interfere with the vehicle's sensors.
Traffic	Not in incident situations with people on roadway, or other safety information cases
Time	No specific requirements
Weather conditions	All conditions except for heavy rain or snowing, or road covered with thick layer of snow or water, or in some cases sun glare, heavy fog, or darkness without lighting, 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD map	HD Map of minimum quality needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations (e.g. RTK) and possibly also by landmarks on problem sections (tunnels, forests, ...) and conditions (weather).
Communi-cation	Needed for end of queue, lane change, and merge situations for negotiations among vehicles and for maintaining a local dynamic map. Short latency V2V communication is a necessity for highway convoy. V2I communication can be used to receive traffic management information in addition to real-time information.
Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances (SRTI) on the road ahead are needed for tactical decisions on route choice, lane selection and safe speed choice. Digital rules and regulations as well as a geofencing database are also needed.

4.2.2 Highly automated (freight) vehicles on dedicated roads (l4)

According to ERTRAC (2017), this means automated freight transport carriers on dedicated and controlled lanes/roads/areas, possibly physically separated from other road users, and for potentially un-manned freight transport. Vehicles can be designed without cab for driver. Operation could be done during night in lower speed for safety and fuel efficiency reasons.

The ODD-related requirements for this functionality are based on the results of the DRAGON project. There the use case specifically contained the automated control of freight movements on a dual carriageway road at night during specified times, without drivers, on a dedicated lane closed to other traffic. (Wilmink, et al. 2017)

This would require use of the innermost lane on each carriageway being dedicated for automated freight transport, with the other lane(s) for other traffic. The use of the inner lane was meant for automated freight only, to be communicated using lane signs on overhead gantries and additional signage explaining about traffic priorities, time of use and method of enforcement or fines (ANPR, CCTV etc.). Automated freight traffic would utilise V2V and V2I communication media to access the dedicated lane. The automated freight traffic would communicate with the installed infrastructure and traffic, whilst progressing to their final destination, so that other traffic is aware (using V2V) and junctions can be closed or opened to allow free passage if required (using V2I). The automated freight movements would require dedicated infrastructure at each end of the corridor to enable a driver to take over the final stage of the journey or automated bays, and transfer of goods from or to the heavy goods vehicle. (Wilmink, et al. 2017)

The ODD requirements adapted to the common format are shown in Table 9.

Table 9. ODD related requirements for highly automated (freight) vehicles on dedicated roads (L4) in 2018.

Highly automated (freight) vehicles on dedicated roads	
Road	More than one lane on carriageway if one or more lanes are left for other vehicles.
Speed range	Up to 80 km/h
Shoulder or kerb	Safe stopping for a minimal risk condition requires a wide paved shoulder to be available for this purpose. Safe refuges or shoulder areas similar to bus stops but long enough for freight vehicles could be made available in case of narrow shoulders at intervals of e.g. 500 m on each carriageway
Road markings	Solid or dotted lines painted on the pavement needed if the accurate lateral positioning solution is based on a camera detecting the location of the lane borders, and if the lines indicate traffic management information (e.g., separation of automated freight vehicle lane from other traffic lanes)
Traffic signs	Needed to indicate the lane use restrictions (automated freight vehicles/other vehicles), either static indicating the times of use or dynamic signs at sufficient intervals. Signs indicating use by automated freight vehicles.
Road furniture	Gantries for overhead lane control signs. Possible gates for entering and exiting the road used for automated freight vehicles, to be opened via V2X. V2X short-range communication beacons at sufficient intervals, and at least at both ends of road and at junctions. Wireless radio beacons or physical landmarks possibly with sensor reflectors can be used to support and increase positioning accuracy for AD vehicles. This is most valuable in tunnels and in totally open areas with no fixed objects nearby, or in poor road weather conditions.
Traffic	Other traffic not present on lane
Time	Likely during night hours only to minimise disturbance to other traffic
Weather conditions	All conditions, except for heavy rain or snowing, or road covered with snow/water. 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD map	Needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations and possibly also by landmarks.
Communi-cation	V2V and V2I communication needed for vehicles to communicate for safety and to access the dedicated lane or road.
Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances on the road for tactical decisions.

4.2.3 *Automated prt/shuttles in mixed traffic (L4)*

According to ERTRAC (2017), this functionality concerns personal rapid transit (PRT) including urban shuttles for smaller urban mobility vehicles primarily for transport of people, for last-mile use, but potentially also for longer distances. The automated PRT/Shuttle drives in mixed traffic in same speed as other traffic in an urban setting. This may be combined with automated functions for enhanced safety, traffic flow and network utilization.

Today's robot buses are equipped with a pretty limited set of sensors. For example, the EasyMile EZ10 bus that was used in the Finnish SOHJOA project in 2016-2018 has one mid-range 3D LiDAR on the roof and four two-dimensional, short-range LiDAR sensors, one in each corner. For precise positioning, satellite positioning is complemented with fixed land stations or network-based reference signal via RTK (real-time kinetics) and VRS (virtual reference station). To calculate the distance, movement, and acceleration of the vehicle an odometer and an inertial measurement unit are used. The exact trajectory for the bus route is pre-recorded, and the objects and shapes of the environment are scanned using the 3D LiDAR sensor. On the run, the bus then compares the observed real-time environment with the pre-scanned map to detect any obstacles. The maximum speed of the EZ10 vehicle is 40 km/h but in the SOHJOA pilot the maximum speed was set to 11 km/h to consider the environment of pedestrians and bicyclists.

Though robot bus manufacturers claim their vehicles as Level 4 autonomous vehicles, their inability of bypassing objects such as parked vehicles on the hard-coded route set major limitations in the ODD definition. Furthermore, without support from other sensors LiDAR scanners cannot that well deal with heavy rain, snow or falling leaves.

Current robot bus model systems do not provide a comprehensive remote control. E.g., in the EasyMile solution the supervisor in the control centre cannot remotely drive the vehicles but only give the onboard operator a permission for manual driving.The ODD-related requirements for current automated PRT/shuttles in dedicated areas but with mixed traffic are based on the ODD description (Nissin 2018) based on their experiences with EZ10 buses in Finnish conditions. The requirements adapted to the common format are shown in Table 10. It is worth noting that more capable vehicles (e,g., including sensor fusion) in future would likely result in a different set of requirements.

Table 10. ODD related requirements for automated PRT/shuttles in mixed traffic (L4) in 2018

Automated PRT/shuttles in mixed traffic	
Road	Urban road with free lane width of 3 m for individual buses or 5.5 m for buses meeting each other; gradient at most 12 %
Speed range	Up to 50 km/h
Shoulder or kerb	Roadside parking space
Road markings	No requirements
Traffic signs	Bus route needs to have marked priority; automatic green at signals
Road furniture	Large enough (2.5 m x 2.5 m) landmarks at min height of 3 m
Traffic	Can not co-exist with high-speed traffic
Time	No specific requirements
Weather conditions	Temperature +2...+40C, Humidity <95%, wind speed <55 km/h, precipitation <5 mm/h, no ice nor snow on road, no fog/steam/smoke/dust hindering vision
HD map	Needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations and possibly also by landmarks.
Communication	At least 3G needed for supporting positioning and at least 4G for remote control of vehicles (and communicating with the onboard operator) when no ODD.
Information system	No requirements

4.2.4 Commercial driverless vehicles (L4) as taxi services

The automated taxi service operates without a human driver transporting passengers from their origin to their destination within the boundaries of a specific geographical area. The ODD specification is based on the Waymo's self-driving car concept as described in their safety report (Waymo 2017).

Waymo's system includes three types of LiDAR developed in-house: a short-range LiDAR giving an uninterrupted view directly around it, a high-resolution mid-range LiDAR, and a long-range LiDAR that can see more than 200 m away. Their vision system also includes colour cameras designed to see the world in context, as a human would, but with a simultaneous 360-degree field of view to spot traffic lights, construction zones, school buses, and the flashing lights of emergency vehicles. The high-resolution cameras are designed to work well at long range, in daylight and low-light conditions. Waymo's radar has a continuous 360-degree view to track the speed of road users in front, behind and to both sides of the vehicle. Waymo vehicles also have a number of additional sensors, including an audio detection system to detect police and emergency vehicle sirens, and GPS to support the accurate positioning of the vehicle. (Waymo 2017)

Positioning is based on a 3D map built during mapping drives with test vehicles equipped with the vision sensors listed above. These maps contain also road types, the distance and dimensions of the road itself, and other topographical features. After that, the map is complemented with automated driving related important information that includes traffic control information such as the lengths of crosswalks, the locations of traffic lights, and relevant signage. The automated driving system can detect when a road has changed by cross-referencing the real-time sensor data with the on-board 3D map. If a change in the roadway (e.g., a collision up ahead that closes an intersection) is detected, the vehicle can re-route itself within the system's ODD and alert the operations centre so that other vehicles in the fleet can avoid the area. In this case, the maps also provide feedback, and the maps can be updated accordingly. (Waymo 2017).

The Waymo ODD covers city streets in good as well as inclement weather, such as light to moderate rain, in both daytime and at night. (Waymo 2017).

The requirements adapted to the common format are shown in Table 11.

Table 11. ODD related requirements for commercial driverless vehicles (L4) as taxi services in 2018.

Commercial driverless vehicles as taxi services	
Road	Urban road with not too complicated junctions; 2030- all urban roads including ring roads and motorways, rural roads
Speed range	Up to 60 km/h; 2030- up to 80 km/h and then 100 km/h
Shoulder or kerb	Roadside parking space on streets, wide shoulders or refuges on other roads with 500 m intervals; Space needed for passenger hop-ons and -offs, likely clearly marked
Road markings	No specific requirements
Traffic signs	No specific requirements
Road furniture	Possible shelters and seats for waiting passengers
Traffic	Separation of pedestrian/bicycle paths
Time	No specific requirements
Weather conditions	Precipitation <5 mm/h, no ice nor snow on road, no fog/steam/smoke/dust hindering vision; 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD Map	Needed as the lane identification and accurate lateral lane positioning solution is based on vision sensors (especially laser scanners) and satellite positioning with 3D HD map matching.
Satellite positioning	Needed to complement the vision sensor system supported by satellite positioning with 3D HD map matching.
Communication	At least 3G needed for V2I communications with operations centre, 4G or higher for remote control of vehicle.
Information system	Digital traffic rules and regulations, geofenced restrictions

4.2.5 Driverless maintenance and road works vehicles (L4)

The driverless maintenance and road works vehicles are to carry out maintenance and road works operations without a human driver in the vehicle. It is, however, assumed that the vehicles are at all times connected to an operations centre, where the on-duty operator can take over remote control of the vehicle when and where needed. The vehicles have flashing yellow lights as usual for maintenance and road works vehicles.

The vehicle is likely equipped with LiDAR, radar and colour camera visual sensing system similar to that of Waymo (2017) to be able to carry out the required operations. The automated driving system is to be used on specific road sections only, and for them the vehicle (or specific mapping vehicles with similar sensors) will first build up a 3D map utilising the same sensors as the automated vehicle, and complement it with an HD map of the road infrastructure in question, provided by the road operator. Then this 3D map is used for vehicle positioning supported by accurate satellite positioning.

In cases where the automated maintenance vehicles are operating among other traffic, they are used at night during low traffic, possibly with reduced speed limit and warning of maintenance conveyed via variable message signs and real-time event information services.

The requirements adapted to the common format are shown in Table 12.

Table 12. ODD related requirements for driverless maintenance and road works vehicles (L4) in 2018.

Driverless maintenance and road works vehicles	
Road	Not in road works areas (maintenance vehicles)
Speed range	Maintenance vehicles up to 80 km/h, road works up to 20 km/h
Shoulder or kerb	No specific requirements
Road markings	No specific requirements
Traffic signs	Possible variable message signs warning other road users of automated maintenance vehicles on road and indicating lower speed limit
Road furniture	Maintenance vehicles: Wireless radio beacons or physical landmarks possibly with sensor reflectors can be used to support and increase positioning accuracy for vehicles. Road works: standard road works furniture, which will include short- and medium-range communication beacons indicating the location and nature of the road works site
Traffic	Other vehicles not allowed onto road works area without permission
TIme	No specific requirements
Weather conditions	For road works precipitation <5 mm/h, no ice nor snow on road, no fog/steam/smoke/dust hindering vision; For winter maintenance vehicles no specific requirements
HD Map	Necessary as accurate positioning solution for both moving and operating is based on vision sensors including laser scanners and satellite positioning with 3D HD map matching.
Satellite positioning	Needed with land station (RTK etc.) support accompanying the vision sensor system with 3D HD map matching.
Communication	4G or higher for remote control of vehicle when and where needed.
Information system	Real-time information of the location and operation of the vehicle to be disseminated to traffic centres and service providers, and finally to other road users; Digital rules and regulations

4.3 The need and potential implementation of remote monitoring and control centres

An operations centre can be used to monitor the vehicles and to supervise their control when and where necessary. The need and potential for such operations centres is presented in Table 13.

Table 3. Need for and potential implementation of operations centres for the selected automated driving use cases

Automated driving functionality	Need for an operations centre to monitor and supervise vehicles	Potential implementation
Highway autopilot & highway convoy (L4)	No real need unless case of a specific fleet	In specific cases only; Not expected very soon.
Highly automated (freight) vehicles on dedicated roads (L4)	The functionality is used for commercial reasons with high economic value but also with safety risks, resulting in need to monitor and supervise.	Ad-hoc centres needed from the start, specific centres set up for normal operations. One operator can manage up to 10 vehicles.
Automated PRT/shuttles in mixed traffic (L4)	Even short stops for ODD termination are disruptive for customer service, thereby remote supervision is necessary. In addition, passenger security requires vehicle interior monitoring, and possible remote intervention at need	Ad-hoc centres needed from the start, specific centres set up for normal operations. One operator can manage up to 20 vehicles.
Commercial driverless vehicles (L4) as taxi services	Even short stops for ODD termination are disruptive for customer service, thereby remote supervision is necessary.	From the start of the service. One operator can manage up to 20 vehicles.
Driverless maintenance and road works vehicles (L4)	Vehicle will likely encounter ODD termination quite often, while the work needs to be carried out in schedule. When among other traffic, control needs to be taken over qucikly, but in road works areas takeover may not be time-critical.	From the start of the service. One operator can manage up to 10 vehicles.

In case of terminating ODD, the Level 4 vehicle is to move to a state of maximum safety, unless a human driver takes over the driving task. In some cases like the robot taxi or automated shuttle, the occupants of the vehicle expect in a problem situation an external supervisor to give guidance to the vehicle about whether a particular manoeuvre can be done safely and to authorize the vehicle to do the manoeuvre (Shladover 2018b). This would be an expected part of the transport service, and thereby the remote operating centre is a key element in the deployment of such services.

In the cases of driverless maintenance and road works vehicles, the vehicles do not have a driver in the vehicle for either business case or safety reasons, and again the remote vehicle operating centre is a must in practice.

For the freight vehicle use case, there likely is a driver in the vehicle in many occasions (e.g. when on road) and he/she could take over when and where a human fall-back is useful. In some situations like loading and other terminal operations, the driver may not be in the vehicle. In any case, the freight transport operator with a sizable vehicle fleet usually has a fleet management centre facility with remote monitoring capabilities of some sort, and this may be extended to provide also remote supervision capabilities.

For highway autopilot, the remote supervision service may by needed in the long-term, if sufficient number of customers would need to have such a support service.

4.4 ODDs provided by the current infrastructure for each functionality

Highway autopilot

The basic requirement is the road type, i.e. the road has to be a motorway or similar type of road with more than one lane in each carriageway so that the carriageways are separated from each other. Only the line sections of the road belong to the ODD, excluding the entry and exit ramps.

Currently there are more than 900 km of such roads. The wide shoulders typically exist on all motorways, and on most of the similar type of roads. The roads tend to belong to the highest maintenance categories, which guarantees the good condition and visibility of the lane markings and traffic signs for most of the time during the year. The accuracy of satellite positioning, availability of HD maps, and need for additional landmarks needs to be investigated. Most of the roads have already fibre optic cables alongside, making it possible to provide short-range communications in the future.

Automated freight vehicles on dedicated roads

The ODD for the use case would likely be implemented on

- sufficiently long parts of motorways or similar types of roads with much freight transport during the night hours, such as :
    - E18 (VT 1 and 7) Turku-Vaalimaa, including Ring III
    - E75 (VT 4) Helsinki-Lusi
    - E12 (VT 3) Helsinki-Tampere
- port connections from the road connections above, e.g. Vuosaari-E18, or from factories and logistic centres
- terminal areas and other logistic areas with restricted access ; this is actually corresponding to a specific use case ”Highly automated freight vehicles in confined areas (Level4)” (ERTRAC 2017)

Currently, only the last mentioned areas have today the ODD required. The actual road connections do not offer the ODD required.

Automated PRT/shuttles in mixed traffic

The basic requirement is that driving should be possible year-round irrespective of the weather conditions. From operational viability point-of-view, the buses should operate on those areas there is enough demand; thus it is not reasonable to define the route only based on road conditions. On the other hand, robot bus routes will be well-defined. At least in the beginning, it is cost-efficient to concentrate on providing LiDAR point maps and making needed improvements specifically on those street sections where robot buses operate before a complete street network is made compatible with automated driving.

Driverless vehicles suit well to the operation during more silent times where it is not economically viable to have a human driver. One example is the parking lot of an airport where transport is needed also at night.

Robot buses have been often piloted in urban environment where it would act as a feeder line to trunk lines. However urban street network is very busy and there are lot of unexcepted events which the vehicle needs to detect and react safely. The sidewalk may need to be separated from the carriageway though this may limit the mobility of pedestrians. On the other hand, the speed of the robot buses is still very low (typically less than 20 km/h) and in that sense they could also run on shared space with pedestrians, bicycles, and with certain limitations, also cars.

The superior financial efficiency of robot buses would suggest that operation in rural areas. There the roads usually have less traffic, less intersections and operation could be started without major investments to the physical or digital infrastructure. The small passenger capacity would not be a problem and therefore robot buses could be even used as longer trunk lines. However, their limited speed is still causing a safety issue because of a considerable speed difference compared with other vehicles. Thus in the beginning the feeder lines operating on smaller roads are more realistic.

The capacity of the communications network maybe a bottleneck, especially concerning the requirements of remote controlling; the quality of service of communications needs to be ensured and for this purpose setting up a private network is a good option.

<u>Commercial driverless vehicles as taxi services</u>

Basically, most cities have areas and street networks without complicated junctions or on-street bicycle facilities. These would be a basis for the ODD. Currently no ODDs exist, however, as these require the availability of detailed LIDAR point maps, and other solutions for accurate positioning throughout the area.

<u>Driverless maintenance and road works vehicles</u>

The accurate positioning and 3D HM map coverage do not exist outside some test sections such as the E8 Aurora test section. In addition, the wireless broadband communications for remote control do not exist so far on the network.

4.5 Estimate of the ODD coverage in 2040

<u>Highway autopilot</u>

In 2040, there are likely about 1 000 km of the roads, where highway autopilot is possible in good weather conditions and incident-free traffic. These roads have also accurate satellite positioning, HD maps, necessary landmarks, and full cellular coverage (5G+) relying on fibre optics alongside all related roads.

<u>Automated freight vehicles on dedicated roads</u>

Likely all major ports and other freight terminals provide the ODD for the use case in 2040. The situation on the road network will likely be restricted to specific connections between a factory or a logistics centre and a terminal (railway station, port, etc.), where a business case exists for the use case. As such roads will not have motorway quality, the use of the roads may not be allowed for other vehicles at the same time as automated freight vehicles. Perhaps around 10 such connections will exist in Finland, mainly for port connections. Typically their length would be between 5 and 30 km.

Automated PRT/shuttles in mixed traffic

By 2030 there may already be tens of urban areas in the five major regions (metropolitan area, Tampere, Turku, Oulu, Jyväskylä) in Finland feasible for robot bus operation. Whereas urban areas may be technically challenging to update the infrastructure to support autonomous vehicles, in rural areas the infrastructure is «less busy». Economical benefits would drive the use of robot buses to rural areas; however, their maximum speed needs to be higher than currently to avoid safety issues with other road users.

Commercial driverless vehicles as taxi services

At the project workshop, the participants estimated that 15 to 30 urban areas would offer the ODD for robot taxis in 2040.These would likely be the largest cities. Although the current versions of the robot taxis would not be able to operate in the central city areas with complicated junctions and high numbers of vulnerable road users, in 2040 they would likely have the whole city area with speed limits of 60 km/h and less as their ODD. They could even have the capability of using the ring roads and arterials in urban areas or rural roads with higher speeds as taxi services are expected to cater for door-to-door transport needs. In this study, the ODD is only limited to lower speed urban streets.

Driverless maintenance and road works vehicles

The positioning accuracy, mapping and communication infrastructure requirements are met at least on motorways and similar roads as well as in the bigger cities for the road works vehicles. It is also likely that these parts of the network will be maintained utilising temporary traffic management solutions and furniture required by automated road works vehicles.

Concerning road maintenance vehicles, the same ODD as for highway autopilot will be applicable. In 2040, it is likely that the weather-related ODD restrictions will be much smaller than when the systems enter to the market. Other main roads with 3D HD maps on road structures, accurate satellite positioning, and wireless broadband (5G+) will likely also provide the ODD for automated maintenance vehicles.

5 Costs

5.1 Preliminary plan for the implementation of the ODDs

As the use cases often set similar requirements with regard to positioning, remote control, and other ODD aspects, this chapter treats the ODDs with regard to ODD type rather than use case. The figures included indicate the likely years of investments with colouring. The colouring differs from one ODD type to another.

Motorways and similar roads

The ODD road map for these roads is shown in Table 14.

Table 14. The road map to 2040 for ODD related measures on motorways and similar roads in Finland. The coloured cells indicate investments related to the measure in question.

Motorways and similar roads																					
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
HD Maps or road areas, infra, equipment																					
HD Maps of road structures for maintenance purposes																					
3D HD maps: road areas & env. (incl. LIDAR point cl.)																					
Satellite posit. enhance-ment with land stations																					
Positioning enhancement with dedicated landmarks																					
Safe "harbours" (shoulders etc.)																					
Superactive snow-removal																					
Low-latency wireless broadband					5G									6G							
High quality real-time situational picture																					
VMS/C-ITS warnings: RW/ARWV/AMV	road works							+ automated road works & maintenance vehicles													

The HD maps are required by highway auto pilot already in 2023-24, stating with maps on road areas, equipment and infrastructure, and then followed by 3D maps including also road structures, and the whole road environment in point clouds produced by e.g. LIDAR sensing. Accurate satellite positioning likely needs also to be provided. All of the above need to be updated regularly. Positioning also likely needs to be supported at specific locations with noted positioning problems with dedicated landmarks.

While these roads tend to have broad shoulders, where automated cars can safely park, the need for providing specific safe harbours on some roads or for trucks and other large vehicles should be investigated, and provided where needed. Quick snow-removal is necessary to maximise the continuity of ODD in time during winter, although this will cause considerable costs (Innamaa et al., 2015). This requirement is expected to vanish after 2035, when technology developments enable driving in snowy and ice conditions as well for most use cases.

Low-latency wireless broadband is a necessity for automated vehicles' local dynamic maps (electronic event horizon provided by real-time situational picture) and their connectivity needs from 2023 onwards. 5G will probably be followed by 6G in 2030s.

Main roads

The ODD road map for other main roads is shown in Table 15.

Table 15. The road map to 2040 for ODD related measures on other main roads than motorways and similar roads in Finland. The coloured cells indicate investments related to the measure in question.

Other main roads																					
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
HD Maps or road areas, infra, equipment	E8			E75				E12			Other roads										
HD Maps of road structures for maintenance purposes	E8					Starting with roads with high traffic volumes															
3D HD maps: road areas & env. (incl. LIDAR point cl.)																					
Satellite posit. enhance-ment with land stations																					
Positioning enhancement with dedicated landmarks																					
Safe "harbours" (shoulders etc.)											Starting with roads with high heavy vehicle volumes										
Superactive snow-removal																					
Low-latency wireless broadband (high vol roads)								5G									6G				
High quality real-time situational picture (hvr)																					
VMS/C-ITS warnings: RW/ARWV/AMV	road works										+ automated roadworks and maintenance vehicles										

The HD maps have been first produced for the Aurora test site on E8 from 2017. Such will be provided also for E75, E12 and other roads starting with those with high traffic and heavy vehicle volumes, where the automated vehicles will also have their highest volumes. Accurate satellite positioning should be available from 2025 onwards, and dedicated landmarks from 2029. The provision of safe harbours should start from the road with high heavy vehicle volumes as stopped (automated) trucks will especially cause disturbance to other traffic.

Super-active snow-removal would likely be needed also on other main roads than motorway, but the costs for deploying this would be likely unacceptably high. The wireless broadband, high quality situational picture and warnings of automated road works and maintenance vehicles on the road will be provided a few years later than on motorways and similar roads.

Terminal connections

The ODD road map for terminal connections is shown in Table 16. Terminal connections here mean the connections between factories, logistics centres etc. and ports, airports, railway depots and other terminals.

Table 16. The road map to 2040 for ODD related measures on terminal connections in.Finland. The coloured cells indicate investments related to the measure in question.

Terminal connections																					
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
HD Maps or road areas, infra, equipment		inside ports and terminals					first connections														
HD Maps of road structures for maintenance purposes					inside ports and terminals					first connections											
3D HD maps: road areas & env. (incl. LIDAR point cl.)								inside ports and terminals													
Satellite posit. enhance-ment with land stations																					
Positioning enhancement with dedicated landmarks		inside ports and terminals																			
Safe "harbours" (shoulders etc.)																					
Superactive snow removal																					
Low-latency wireless broadband								5G									6G				
High quality real-time situational picture																					
Signs and/or barriers for access control																					
VMS/C-ITS warnings: RW/ARWV/AMV							road works + automated road works & maintenance vehicles														

The 2D HD maps are first provided inside the ports and other terminals, and so will also dedicated landmarks providing accurate positioning at spots of load loading and unloading, for instance. For maintenance and other uses, 3D HD maps also going beyond pavement and building surfaces are likely needed. The first actual terminal connections need to be equipped with HD maps, accurate satellite positioning, and low-latency connectivity from 2026 onwards, Safe harbours, fast snow-removal, access control and automated vehicle warnings are needed a few years later when the connections are being taken into routine use.

Urban streets

The ODD road map for urban streets is shown in Table 17. Terminal connections here mean the connections between factories, logistics centres etc. and ports, airports, railway depots and other terminals.

Table 17. The road map to 2040 for ODD related measures on urban streets in Finland. The coloured cells indicate investments related to the measure in question.

Urban streets																					
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
HD Maps or road areas, infra, equipment			dedicated routes					bus routes													
HD Maps of road structures for maintenance purposes																					
3D HD maps: road areas & env. (incl. LIDAR point cl.)	test sites		dedicated routes					bus routes													
Satellite posit. enhance-ment with land stations																					
Positioning enhancement with dedicated landmarks			dedicated r																		
Safe "harbours" (shoulders etc.)																					
Superactive snow-removal																					
Low-latency wireless broadband (high vol roads)								5G									6G				
High quality real-time situational picture (hvr)																					
VMS/C-ITS warnings: RW/ARWV/AMV	road works										+ automated road works & maintenance vehicles										

The mapping via LIDAR point clouds commences at specific test sites, and continues along with 2D HD maps of the road areas, dedicated landmarks and safe harbour locations at kerb on dedicated routes for automated shuttles. This will continue in late 2020s on actual bus routes. At the same time 3D maps of road structures, accurate satellite positioning utilizing land stations, and low-latency wireless broadband in central areas and busy streets at the same time as on motorways. The high-quality situational pictures and warnings of automated maintenance and road works vehicles could be provided on busy streets around 2030. Enhanced 4G or 5G network can be provided as a private network on dedicated shuttle or bus routes before open network deployment.

5.2 Estimated costs for each ODD

The costs have been estimated based on discussions with Finnish Transport Agency and CEDR experts (CEDR 2018) as well as Malmivuo (2010), US DOT (2018), and Karjalainen (2011). The estimated costs are shown in Table 18.

Table 18. Unit deployment costs and annual maintenance cost percentages out of deployment costs for the different ODD features in Finland in 2018.

ODD Feature	Unit cost range estimate (deployment)	Maintenance annually
HD Maps or road areas, infra, equipment	3-4 k€/km	8 %
HD Maps of road structures for maintenance purposes	5-7 k€/km	8 %
3D HD maps: road areas & environment (incl. LIDAR point clouds)	3-6 k€/km/a (paid by the transport operator)	included
Satellite positioning enhance-ment with land stations	RTK station 2-10 k€ (depending on the availability of power); 1 station / 5 km; cost 0.4-2 k€/km	8 %
Positioning enhancement with dedicated landmarks	4-6 k€/km	10 %
Safe "harbours" (broad shoulders, lay-bys etc.)	20-50 k€/safe harbour; or 40-100 k€/km on sections where needed (every 500 m)	8 %
Superactive snow-removal	winter maintenance cost addition: ca 2-2.5 k€/km /a (2-lane roads) and 3-4 k€/km/a (motorways)	included
Low-latency wireless broadband infrastructure	fibre optics 20 - 100 k€/km including outtakes plus 10-15 k€/road side unit	8 %
High quality real-time situational picture	0.4-0.8 k€/km/a incl. digitalisation of rules & regulations, back-office; urban 0.1-0.2 k€/km	included
Signs and/or barriers for access control	30-90 k€/sign; 40-80 k€/gate or barrier; 15-90 k€/km	8 %
VMS/C-ITS warnings: road works, automated road works or maintenance vehicles	0.5-0.9 k€/km /a without new VMS but incl. equipment and marking of road work sites; road works only: 50% of costs	included

5.3 Estimate of the total ODD cost 2019-2040

The total costs can be estimated on the basis of the investment programme and the unit costs from above. It is likely that the unit costs will be greatly reduced due to the technology development improving the capabilities of vehicle sensors and artificial intelligence as well as economies related to mass production of vehicles and their equipment. So far, we have only taken on board one such change: we assume that after 2035, the vehicles can deal with usual snowy and icy road surfaces, and thereby super-active snow removal is not required at all after that year.

Table 19 show the estimates for motorways. All such roads are covered already in 2024, with gradual extensions and investments due to new or upgraded road infrastructures to 1000 km by 2040.

Table 19. The annual sum of investment and maintenance costs for ODD on motorways and similar roads in Finland up to 2040 as well as road km covered in 2040.

Motorways and similar roads																							
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	**Sum M€**	**Road km 2040**
HD Maps or road areas, infra, equipment				1,05	2,18	0,25	0,25	0,25	0,25	0,25	0,96	0,96	0,26	0,26	0,26	0,26	0,26	0,98	0,98	0,28	0,28	**10,3**	**1000**
HD Maps of road structures for maintenance purposes					1,8	1,94	2,09	0,43	0,43	0,43	0,43	0,43	1,66	1,66	0,46	0,46	0,46	0,46	0,46	1,68	1,68	**17,0**	**1000**
3D HD maps: road areas & env. (incl. LIDAR point cl.)					2,03	4,05	4,05	4,05	4,05	4,05	4,19	4,23	4,23	4,23	4,23	4,23	4,23	4,5	4,5	4,5	4,5	**69,8**	**1000**
Satellite posit. enhance-ment with land stations					0,13	0,14	0,02	0,02	0,02	0,15	0,03	0,03	0,03	0,03	0,03	0,16	0,04	0,04	0,04	0,04	0,04	**1,0**	**1000**
Positioning enhancement with dedicated landmarks										1	0,1	0,1	0,1	0,1	0,1	0,6	0,15	0,15	0,15	0,15	0,15	**2,9**	**300**
Safe "harbours" (shoulders etc.)									4,59	0,73	0,73	0,73	0,73	0,73	3,53	0,95	0,95	0,95	0,95	0,95	0,95	**17,5**	**170**
Superactive snow-removal								3,15	3,19	3,22	3,26	3,29	3,33	3,36	3,4	3,43	0	0	0	0	0,00	**29,6**	
Low-latency wireless broadband				1,05	1,13	1,22	0,25	0,25	0,25	0,25	0,25	0,25	0,6	0,63	0,66	0,34	0,34	0,34	0,34	0,34	0,34	**8,8**	**120**
High quality real-time situational picture					0,24	0,54	0,54	0,54	0,55	0,55	0,56	0,56	0,57	0,58	0,58	0,59	0,59	0,6	0,6	0,6	0,6	**9,4**	**1000**
VMS/C-ITS warnings: RW/ARWV/AMV	0,035	0,035	0,07	0,14	0,21	0,42	0,63	0,63	0,64	0,64	0,65	0,66	0,67	0,67	0,68	0,69	0,69	0,7	0,7	0,7	0,7	**11,0**	**1000**
All measures, total	**0,035**	**0,035**	**0,07**	**2,24**	**7,72**	**8,56**	**7,83**	**9,33**	**14**	**11,3**	**11,2**	**11,2**	**12,2**	**12,3**	**13,9**	**11,7**	**7,72**	**8,72**	**8,72**	**9,24**	**9,24**	**177,1**	

Note that the largest cost item of LIDAR point cloud maps is assumed to be covered by the transport operators, and not the road operators.

Table 20-22 show the estimates for other main roads, terminal connections and urban street, respectively.

Table 20. The annual sum of investment and maintenance costs for ODD on other main roads in Finland up to 2040 as well as road km covered in 2040.

ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Sum MC	Road km 2040
HD Maps or road areas, infra, equipment	0,26	0,02	0,02	0,37	0,4	0,08	0,08	0,43	0,45	0,13	0,48	0,51	0,54	0,22	0,22	0,22	0,22	0,57	0,59	0,27	0,27	6,3	970
HD Maps of road structures for maintenance purposes	0,45	0,03	0,03	0,03	0,03	0,33	0,36	0,38	0,41	0,43	0,45	0,48	0,5	0,53	0,55	0,57	0,6	0,62	0,65	0,67	0,69	8,8	820
3D HD maps: road areas & env. (incl. LIDAR point cl.)					0	0,23	0,45	0,45	0,45	0,45	0,45	0,68	0,9	0,9	0,9	0,9	0,9	0,9	1,13	1,35	1,35	12,4	300
Satellite posit. enhance-ment with land stations						0,1	0,11	0,02	0,02	0,02	0,22	0,03	0,03	0,03	0,03	0,03	0,23	0,05	0,05	0,05	0,05	1,1	600
Positioning enhancement with dedicated landmarks										0,2	0,02	0,22	0,04	0,24	0,06	0,26	0,08	0,08	0,08	0,08	0,08	1,4	160
Safe "harbours" (shoulders etc.)											1,4	1,51	1,62	1,74	1,85	1,96	2,07	2,18	2,3	2,41	2,52	21,6	200
Superactive snow-removal																						0,0	
Low-latency wireless broadband (high vol roads)							0,7	0,76	0,81	0,17	0,17	0,17	0,17	0,17	0,17	0,87	0,92	0,98	0,34	0,34	0,34	7,1	120
High quality real-time situational picture (hvr)								0,06	0,09	0,12	0,15	0,18	0,24	0,3	0,36	0,36	0,36	0,36	0,36	0,42	0,42	3,8	700
VMS/C-ITS warnings: RW/ARWV/AMV	0,003	0,003	0,003	0,03	0,05	0,05	0,05	0,08	0,1	0,1	0,13	0,15	0,2	0,25	0,3	0,3	0,3	0,3	0,3	0,35	0,35	3,4	700
All measures, total	**0,721**	**0,056**	**0,056**	**0,43**	**0,48**	**0,78**	**1,74**	**2,16**	**2,33**	**1,62**	**3,46**	**3,92**	**4,24**	**4,37**	**4,43**	**5,47**	**5,68**	**6,04**	**5,78**	**5,93**	**6,07**	62,4	

Table 21. The annual sum of investment and maintenance costs for ODD on terminal connections in Finland up to 2040 as well as road km covered in 2040.

Terminal connections																							
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Sum MC	Road km 2040
HD Maps or road areas, infra, equipment		0,0113	0,01	0,01	0,01	0,01	0,04	0,04	0,05	0,01	0,01	0,01	0,05	0,05	0,02	0,02	0,06	0,06	0,02	0,02	0,06	0,6	95
HD Maps of road structures for maintenance purposes					0,02	0,02	0,02	0,02	0,03	0,07	0,08	0,08	0,09	0,03	0,03	0,03	0,12	0,13	0,04	0,04	0,11	0,9	95
3D HD maps: road areas & env. (incl. LIDAR point cl.)								0,01	0,03	0,04	0,05	0,07	0,07	0,07	0,16	0,25	0,25	0,25	0,25	0,38	0,38	2,3	85
Satellite posit. enhance-ment with land stations							0,01	0,01	0,002	0,002	0,002	0,002	0,01	0,01	0,003	0,003	0,01	0,01	0,005	0,005	0,02	0,1	70
Positioning enhancement with dedicated landmarks		0,0055	0,01	0,01	0,01	0,01	0,003	0,003	0,003	0,003	0,003	0,03	0,01	0,01	0,03	0,01	0,01	0,04	0,01	0,01	0,04	0,2	25
Safe "harbours" (shoulders etc.)										0,38	0,41	0,06	0,06	0,43	0,08	0,08	0,46	0,11	0,11	0,49	0,14	2,8	25
Superactive snow-removal										0,07	0,07	0,07	0,09	0,11	0,11	0,11						0,6	
Low-latency wireless broadband							0,38	0,41	0,43	0,08	0,08	0,08	0,46	0,49	0,14	0,14	0,52	0,55	0,20	0,20	0,57	4,7	80
High quality real-time situational picture							0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,4	50
Signs and/or barriers for access control										1,13	0,65	0,41	0,43	0,17	0,17	0,17	0,45	0,47	0,21	0,21	0,49	5,0	55
VMS/C-ITS warnings: RW/ARWV/AMV							0,00	0,00	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,3	50
All measures, total	**0**	**0,017**	**0,02**	**0,02**	**0,04**	**0,04**	**0,46**	**0,51**	**0,57**	**1,83**	**1,39**	**0,84**	**1,3**	**1,42**	**0,8**	**0,86**	**1,94**	**1,67**	**0,9**	**1,41**	**1,87**	17,9	

Table 22. The annual sum of investment and maintenance costs for ODD on urban streets in Finland up to 2040 as well as road km covered in 2040.

Urban streets																							
ODD related measure	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Sum MC	Road km 2040
HD Maps or road areas, infra, equipment			0,02	0,04	0,06	0,13	0,18	0,23	0,43	0,83	1,27	1,35	1,44	1,52	1,6	1,69	1,77	1,86	1,94	2,02	2,1	20,5	3780
HD Maps of road structures for maintenance purposes					0	0	0,32	0,35	0,05	0,05	0,05	2,64	0,24	0,24	6,72	0,72	0,72	7,2	1,2	1,2	7,7	29,4	3500
3D HD maps: road areas & env. (incl. LIDAR point cl.)	0,0225	0,0225	0,02	0,07	0,14	0,41	0,59	0,81	1,26	2,16	3,51	4,86	6,21	7,56	8,91	10,3	11,6	13	14,3	15,7	17,0	118,4	3780
Satellite posit. enhance-ment with land stations					0	0	0,03	0,03	0,03	0,01	0,01	0,01	0,03	0,03	0,01	0,01	0,04	0,04	0,01	0,01	0,04	0,3	350
Positioning enhancement with dedicated landmarks			0,03	0,05	0,01	0,01	0,06	0,06	0,02	0,02	0,02	0,12	0,13	0,04	0,04	0,04	0,14	0,15	0,06	0,06	0,06	1,1	115
Safe "harbours" (shoulders etc.)			0,35	0,03	0,03	0,03	0,03	1,43	0,14	0,14	0,14	2,24	0,31	0,31	0,31	3,11	0,53	0,53	0,53	4,03	0,8	15,0	145
Superactive snow-removal																						0,0	
Low-latency wireless broadband (high vol roads)							0,7	0,93	1,18	1,44	1,71	1,82	1,93	2,04	2,16	2,27	2,38	2,49	2,6	2,72	2,8	29,2	510
High quality real-time situational picture (hvr)											0,47	0,65	0,83	1,01	1,19	1,37	1,55	1,73	1,91	2,09	2,3	15,0	3780
VMS/C-ITS warnings: RW/ARWV/AMV	0,0018	0,0018	0	0,01	0,01	0,03	0,05	0,06	0,1	0,17	0,55	0,76	0,97	1,18	1,39	1,6	1,81	2,02	2,23	2,44	2,6	18,0	3780
All measures, total	**0,024**	**0,024**	**0,42**	**0,19**	**0,24**	**0,6**	**1,94**	**3,89**	**3,2**	**4,81**	**7,71**	**14,4**	**12,1**	**13,9**	**22,3**	**21,1**	**20,5**	**29**	**24,8**	**30,2**	**35,4**	246,9	

6 Other impacts of automated driving

6.1 Impacts on vehicle ownership and mobility

The impacts of automated driving depend on the way it affects the mobility of people and goods. The impact on mobility in turn is mostly determined by whether the automated vehicles are produced and taken into use as private vehicles or as shared vehicles. If vehicles are shared, either as collective on-demand transport or used individually on a car-share basis, this likely reduces vehicle numbers on the road and avoids the need for local parking. (Urban Circus & Ethos Urban 2018)

A key benefit from highly and fully automated vehicles is that they can provide use of car or another vehicle to those without a car or driving licence, or with physical impairments. These include the elderly and children. Others may simply not want to drive or be concerned about their ability to do so (DfT, 2015). Higher levels of automated driving will provide mobility for those being temporarily or permanently impaired. The impairment may be due to fatigue, illness, medication, alcohol, drugs or other reasons. (Alonso et al., 2018; Carsten & Kulmala 2015)

Kornhauser (2018) states that in the case of private use, self-driving vehicles will by providing comfort and convenience to the drive result in urban sprawl, and vehicle miles travelled going ‘through the roof’. The same will happen with driverless vehicles unless there is substantial ride-sharing like a robot taxi service. A robot taxi service could reduce vehicle miles travelled by 50% while increasing rail transit ridership considerably (Kornhauser 2018).

ITF (2015) estimated that in Lisbon shared transport in form of taxibots could reduce number of vehicles by 90%. The integration of high-capacity public transport with automated car sharing services could result in up to 37.5% average travel time reductions for users choosing to travel by a combination of car sharing and high capacity public transport, in comparison to using a private vehicle. (ITF 2015). A later simulation study indicated similar benefits from shared transport in Helsinki as well (ITS 2017b).

Increased uptake of automated vehicle sharing and ride sharing models, may reduce total vehicle ownership. MaaS is likely to play a key role in encouraging the shared ownership model of automated vehicles (Johnson & Rowland 2018). This is promoted by the lower price of shared mobility for the user. Buckley (2018) estimates that vehicle cost per mile or km will be less than half the current prices of ride-hailing services such as Uber and Lyft.

A study for the Boston area (WEF 2018) predicts a clear shift to mobility-on-demand for both automated and traditional vehicles, which will account for nearly 30% of all trips in the Greater Boston area and 40% of trips within city limits in the future. Driving this shift are the cost-competitive nature of robo-taxis and robo-shuttles – especially on shorter trips – and the added convenience and comfort compared with mass transit. In suburban and other areas outside the city proper, that mobility-on-demand will mainly replace personal-car usage. In urban areas, it will replace the use of both personal cars and mass transit, to equal degrees. Shared automated vehicles will reduce the number of vehicles on the streets by 15% while the total number of miles travelled will increase by 16%. (WEF 2018)

An increase in private vehicle modal share is also possible, as the option of travelling in an automated private vehicle becomes more attractive than using alternative public transport or walking/cycling options (Cavoli et al., 2017, Johnson & Rowland 2018). Automated vehicles even when shared can compete with public transport and active transport modes (walking and bicycling) leading to better individual mobility but less transport system efficiency (UITP 2017).

With automated vehicles, the total Vehicle Kilometres Travelled (VKT) are likely to increase significantly for private travel. Furthermore, induced travel may also increase VKT as it becomes cost-effective and comfortable to travel further distances and make more discretionary trips. This has the potential to affect land use development, as the increased speeds, reduced costs and greater comfort while travelling could promote longer commutes. VKT of heavy vehicles will also increase, because of reduced costs for freight movements (Cavoli et al. 2017, ITF 2017a, Johnson & Rowland 2018). The higher the level of automation, the stronger the effect on vehicle kilometres travelled, mostly as a result of a reduction in driving costs (including changes in the value of travel time) and new users like young people, elderly or disabled. (Alonso et al., 2018)

The likelihood of wishing to utilise an automated vehicle for longer commutes is reflected in the value of travel time. The lower the value, the longer travel times can be accepted. The results of de Looff et al (2017) indicate that the value of travel time is lower in an automated vehicle when compared to a conventional car only when the automated vehicle has an office-like interior design. With a leisure-oriented automated vehicle design, the values of travel time seem to be higher than in a conventional car (van Arem 2018).

A factor affecting the possibility of work or leisure activities in a highly automated vehicle is the proneness of vehicle occupants to motion sickness. Patented measures for motion sickness in automated vehicles have already been developed (Sivak & Schoettle 2018).

Rämä et al. (2018) carried out an assessment of the impacts of involving the expertise of the CARTRE consortium. They used four different scenarios described below in their work.

<u>Scenario 1: Gradual extrapolation of automated services (short-term ca. 2025)</u>

Following the gradual launch of new automated functions, Level 2 automated driving functions for cars and SAE Level 3 functions for trucks have been launched some time ago and are widespread. Overall, there are more SAE Level 3 functions for freight than for cars: traffic jam chauffeur and highway chauffeur are expected to be in general use in trucks. New cars are equipped with cooperative systems to enable connectivity of vehicles and C-ITS. However, as system penetrations are still small, automated functions cannot be built on the assumption of connectivity. There is a high level of interest in shared mobility services among road authorities and private companies. New kinds of mobility services (e.g. private MaaS packages, car or ride sharing) keep on emerging especially in urban areas, and early adaptors are willing to try them. On a large scale, these are growing but still quite marginal. In some cities, and in some urban areas (not yet widely in Europe), automated buses are operating on dedicated roads or areas. The public sector has been supportive towards the development of automated vehicles and testing.

Long-term scenarios 2-4 (ca. 2035)

SAE Level 4 functions in use include highway autopilot, urban and suburban pilot, and automated shuttles and buses in mixed traffic. The freight vehicles path includes highly automated vehicles on dedicated and open roads and highway pilot platooning. Light goods vehicles (vans) for deliveries and services have automated Level 4 functionalities. The vehicle market penetration is not very high; it may be over 50% but seldom close to 90%. SAE Level 4 functions are assumed to be more mature and more in use on highways (and parking) than in urban mixed traffic.

Scenario 2: Disruption through market-driven services

Shared mobility services have broken through and become mainstream, being reliable and convenient in most cases. Fleets of shared and automated vehicles are market operated. Operators are competing against each other for customers, and different levels of service are available. Privately-operated fleets of vehicles have partly replaced traditional public transportation, especially on short distance trips and in densely populated areas. Services are not really multimodal, they are not well integrated with the public transportation service, and connection to and cooperation with mass transport is not well planned. Transport authorities direct market-operated transportation through regulations and subsidies that clarify responsibility issues and encourage private operators towards lower emissions and intelligent use of urban space.

Scenario 3: Authority driven with focus on collective transport

A system of driverless vehicles is providing demand-responsive public transportation for selected routes. There has been a proliferation of commercially explored automated public transportation systems (e.g. pods). The main private operators of public transportation have invested in creating these systems, which have been subsidized by the public sector. Road authorities retain strategic control of the network. The main use of the systems is for access and egress of major public transport hubs and for lower-density areas. Most people have accepted and been used to sharing their trips and car. Travel chains are well functioning and intermodal. Shared and automated mobility is part of the integrated planning process, which is based on public-private collaboration. Privately owned automated vehicles are being quite heavily taxed both centrally and locally through road price charging and parking, for example. Physical and digital infrastructure has been built in (part of) the strategic network.

Scenario 4: Privately operated fleets with authorities focusing on constraints and safety

People do not respond well to sharing automated vehicles with strangers without a driver present. Thus, sharing remains marginal: not many systems have broken the barrier to being commercially explored by private companies, and public companies are not adopting them. Owning automated vehicles is affordable for most people. Governments have not been able to get public acceptance of increasing restrictions to private automated vehicles. Policies focus on reducing emissions, managing urban space effectively, and increasing the safety of automated vehicles.

Utilising these scenarios, Rämä et al. (2018) made an extensive assessment of the mobiity impacts, summarised in Figure 15.

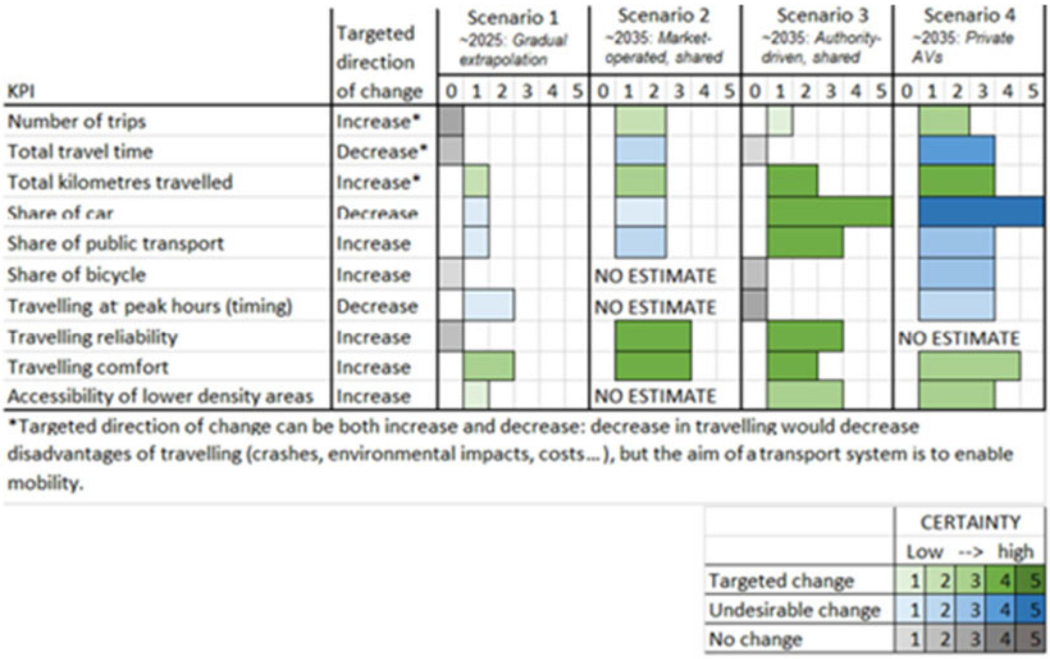

Figure 15. The mobility and travel behaviour impacts for the society. Scale: 0=no change, 5=large change (Rämä et al., 2018).

It was estimated that the usage of different transport modes would change in different scenarios. The amount of travel would increase in all long-term scenarios studied. This estimation is based on the assumption that travelling will become more comfortable along with new automated services. Especially the possibility to focus on other activities than driving while travelling was assumed to increase travelling. At the same time, it was estimated that total travel time would increase along with increased travel in scenarios 2 and 4. (Rämä et al. 2018)

Travelling reliability was assumed to increase in the short-term scenario and in long-term scenarios 2 and 3 (in which mobility is shared). In the case of scenario 4, there was no consensus concerning the travelling reliability estimate: on the one hand new automated services could increase reliability, but one the other congestion due to increased private car usage would weaken reliability. At the same time, a transport system based on private automated vehicles was seen as more comfortable than shared mobility systems. (Rämä et al. 2018)

The most positive long-term impacts were assumed in scenario 3 (automated public transport). The most negative impacts were estimated in scenario 4 (automated private cars), although some positive impacts were assumed in all of the scenarios. It emerged that impacts in scenario 2 (market operated shared mobility) was the most difficult one for experts to estimate. (Rämä et al. 2018)

Total mileage travelled by active modes of transportation, walking and bicycle, was not estimated to increase in any of the given scenarios. In scenarios 1, 2 and 3 there was estimated to be no or a slight change in usage of active modes. It was assumed that the increase in comfort from automation is offset by more shared mobility. In scenario 4, it was assumed that the comfort of automation and private ownership of automated vehicles would lead to a considerable decrease in use of active modes. (Rämä et al. 2018)

The big question is "*How to get from 0.5 % of shared mobility to 50-60%?*" (UITP 2017). Public authorities need to take an active role in the roll out of automated vehicles so that they meet policy objectives, and an effective method is likely road pricing to the advantage of shared high-occupancy vehicles (UITP 2017, UK Parliament 2017). According to WEF (2018), the greatest effects are likely to come from occupancy-based pricing schemes, in which financial incentives discourage single-occupancy rides with a possible citywide travel time improvement by 15%.

All forms of shared mobility, mainly car- and ride-sharing, need to be actively promoted and incentivised as of today. Tax incentives for shared rides or shared ownership of vehicles, shared vehicle zones, promotional campaigns, priority parking places, promotion of pilot projects preparing our citizens for shared autonomous vehicles in the future goes hand in hand with more car- and ride-sharing today. Measures to limit single car occupancy need to be taken as well as measures to avoid having empty private autonomous cars on the roads. (UITP 2017)

6.2 Impacts on the road network and road properties, and possible impacts on road planning

The benefits of highly automated vehicles will be optimal when the roads and road infrastructures are planned to accommodate them. However, there are inherent uncertainties with tailoring roads and road infrastructure for automated vehicles while maintaining a safe and suitable level of non-automated vehicle compatibility. The human factor and the intrinsic variability in how road users interact with the environment around them, means that non-automated vehicle travel on a corridor attuned to automated vehicle travel has risks which need to be considered. (Johnson & Rowland 2018)

Road infrastructure is currently designed so human road-users are able to safely and accurately react. However, road highway standards will require more consistency nationally and globally in roadway design and operations to inform the automated vehicle sensing system. It is also possible that the onset of automated vehicles could lead to a reduction in roadside infrastructure, such as signage, due to the fact that vehicles will have the ability to connect to infrastructure directly instead of relying on visual sensors. (Johnson & Rowland 2018)

Automated vehicles are currently also designed to drive in a much more controlled way compared to human beings. That is why their impact to the pavement structure is also more focused and will most likely cause premature failures and other problems unless the vehicles are not better resembling manually driven vehicles in this regard. The lifespan of transport infrastructure is usually from 20 to 100 years. Thereby any possible changes needed in infrastructure design should be activated as soon as these changes are confirmed in order to avoid wasting the costly infrastructure investments. (Saarenketo 2018c)

6.2.1 Pedestrian and bicyclist crossings and facilities

Although there are potentially significant road safety benefits for pedestrians and cyclists from an automated vehicle future, there is also a real risk that removing the human element (driver eye to pedestrian eye) could create confusion and stress. As highly automated vehicles become a mode of transport with noticeable mode share, they will need to be operated in a manner that aligns with the road priority based on time of day and place value. Highly automated vehicles provide the opportunity via e.g. geofencing to direct ‘traffic’ away from streets with sensitivities to traffic, such as main shopping streets and residential areas. Additional risks to pedestrians, cyclists and motorcyclists may be posed by a significant mix of automated and non-automated vehicles, without appropriate regulation and management. (Johnson & Rowland 2018)

There may be a need for a targeted investment program to improve the automated vehicle interface with pedestrians/cyclists, helping to make their behaviour more predictable for automated vehicles. This could include separated bicycle lanes on strategic cycling corridors and signalisation of crossings and slip lanes along key pedestrian routes. This would be a long-term program that starts in the short-term, to incrementally improve consistency of both user behaviour and infrastructure. (Johnson & Rowland 2018)

Transport Systems Catapult (2017) point out the problems in pedestrian-vehicle interactions, sometimes even with mischievous or malevolent motivations. Infrastructure mounted sensors and V2I communications to connected automated vehicles could assist, but should be developed to deliver robust, mission-critical fail-safe information rather than advisory information. Signal controlled crossings are expected to be easier to handle by connected automated vehicles than other forms of crossing. (Transport Systems Catapult 2017)

In the future, shared space areas where vulnerable road users mingle among slowly moving motor vehicles can be the core ODD for e.g. automated shuttles. Today, in the development phase, the presence of vulnerable road users on carriageways may not fit the ODD of many automated vehicle use cases. The additional risks to vulnerable road users from (often electric) automated vehicles have been listed by Johnson & Rowland (2018) :

- Electric cars, trucks and buses make little to no noise
- Reduced eye contact between pedestrians/cyclists with a human driver
- Automated vehicles may be potentially travelling at the sign posted speed limit significantly faster than human drivers might do in certain circumstances.

There is a direct correlation between the rates of people walking and public health. Walkability can be impacted by several factors, one of which is barriers created by high volume, high speed roads. Automated vehicles - if managed and operated to support walkability - could have significant health, environmental and economic benefits, alternatively widespread use of automated vehicles could see considerable negative outcomes. With the prospect of infrastructure being installed to support the operation of automated and zero emission vehicles, such measures may not be the preferred response for walkers. For instance, the footpath width could be reduced for charging station stations or drop-off/pick-up areas, roundabouts could be selected over traffic signals, potentially causing difficulties for pedestrians and cyclists to cross, and there could be increased separation such as pedestrian fencing and grade separations. (Johnson & Rowland)

6.2.2 Junctions

At signalised junctions, the main concern is being able to detect the signal status both in time to stop for a red signal and also to not pass through a red signal at any time. The means of detection falls into two categories. The first is to use machine vision to see the signal lamps in the same way as human drivers do. The second is to use the more direct method of V2I radio communications. Due to camera performance issues in some conditions and situations, the V2I schemes are preferable. (Transport Systems Catapult 2017)

Making traffic signal phasing available wirelessly to vehicles needs to be developed to be failsafe. The source of the information is already failsafe but how it is propagated may not be and further analysis and development may be needed. In addition, the communication needs to be allowed to fail (be absent when expected) without harmful consequences to the approaching vehicle. For this to be allowed, the vehicle needs to know when to expect a transmission. For this to work the vehicle system need to know where it is against a digital map to realise that it is approaching a signalled junction and needs to have the real-time signal status for the junction so that it can stop the vehicle if this information cannot be obtained for whatever reason. This places a high level of dependence on digital map integrity and on the performance of localisation. (Transport Systems Catapult 2017)

Priority controlled junctions are another significant challenge for which it is difficult to offer a general strategy beyond that of proceeding with caution. A move towards wirelessly managed junctions, possibly signalised junctions would assist with resolving the technical challenge, but may be impractical in practise. Communications equipment may assist connected automated vehicles. Rather than relying solely on the suite of sensors within the vehicle, they could link to mast-mounted cameras around the junction to get a much better view of traffic approaching from various directions. (Transport Systems Catapult 2017)

Modelling studies have found that, particularly at high flows, roundabouts are more efficient for automated vehicles with V2V communications than are traffic signals (Azimi et al., 2013).

6.2.3 Signing and markings

Consistency in sign design and application is key for both road users and automated vehicles. While there are international and national guidelines which advise on sign face design and signage use, the governance structure of road ownership and management sees variances that exist between different assets, roads and networks. This often results in signage inconsistencies potentially causing issues for human drivers, in addition to Traffic Sign Recognition (TSR) systems. (Johnson & Rowland 2018)

Ensuring appropriate signage design and practices for both human drivers and camera vision based TSR systems during the transition phase will require an innovative approach from both industry and government, and highlights the need for strong collaboration within the industry. (Johnson & Rowland 2018)

Potential response for existing infrastructure – review of placement of signs is highly encouraged. Incorporating a camera-based drive by audit into maintenance inspections would allow road authorities to determine whether a sign’s current location is acceptable for TSR systems. (Johnson & Rowland 2018)

A review of signage design guidelines and standards would allow for rationalisation of sign face design. This review should focus on elimination of text heavy designs and investigate the integration of symbols from the Vienna Convention based signs set. (Johnson & Rowland 2018)

It is expected that roll out of most changes is undertaken in a managed and progressive manner which coincides with the replacement life of existing signage. This roll out should also prioritise signage that causes an adverse effect on automated vehicles over those that are not read at all, especially in cases where these signs may compromise road user safety as technology progresses towards TSR controlled vehicle speeds. (Johnson & Rowland 2018)

Line markings may need to be maintained as the default lane use control for the foreseeable future. It is likely that human drivers and camera based driving systems will need to be removed from the road system before line marking is made redundant for automated vehicle operations. It is also important to remember that line marking is a road safety issue, not just a road maintenance issue, and for both automated and non-automated vehicles. (Johnson & Rowland 2018)

Transport Systems Catapult (2017) refers to road marking problems such as old road markings not completely obscured even if blacked out, bitumen lines used to seal cabling or drainage in the roadway, faded indistinct lines on asphalt surfaces, slightly faded lines on concrete road surfaces which present poor contrast, lane markings not in normal use, and discontinuous markings. With road markings forming the 'rails of automated steering systems', the procedures for maintenance of road markings may need to be improved and funding increased. Similarly, with some systems relying on visually detecting and interpreting traffic signs it could be important to ensure that they are maintained to a high standard in terms of cleanliness, clarity, deterioration, non-ambiguous positioning, and obscuration. (Transport Systems Catapult 2017)

6.2.4 Lane widths and pavement

No infrastructure response regarding lane width is considered necessary to facilitate the introduction of automated driving. However, in response to the improved capabilities of a highly automated vehicles, reallocation of road space away from vehicle use through the implementation of narrow lanes, should be considered where the benefits of providing increased pedestrian, cyclist or public transport space or and additional lane in the road corridor would be substantial. (Johnson & Rowland 2018)

During the transition phase, road design practice should tend towards adopting desirable minimum lane widths under current standards (typically 3.0 metres). At the point where the vehicle fleet effectively becomes highly/fully automated, road geometry guidelines around lane widths should be updated to reflect the enhanced sensing and control capabilities of highly automated vehicles. This should see desirable lane widths substantially reduced (likely < 3.0 metres), depending on the traffic mix context and actual vehicle performance (i.e. the need to account for trailer sway in multi-combination heavy vehicles may persist, even when autonomously driven). (Johnson & Rowland 2018) Reducing lane width will, however, lead to more canalized traffic loading patterns that will reduce the lifetime of the pavement structure (Saarenketo 2018c).

The negative impacts of automated driving to the pavement structure can be roughly classified to a) impacts due to reduced tyre wander, and b) impacts of platoon driving. Reduced tyre wander means that vehicles are driving exactly on the same location in the road cross section whereas humans drive with deviation of roughly 40 cm on 3.5 m wide lanes. For passenger vehicles, this will lead to increased rutting do to the wear of studded tyres in Nordic Countries. In other countries, this leads to faster polishing of the pavement surface and problems of low friction. For heavy goods vehicles, the reduced tyre wander will lead to substantially faster pavement fatigue, especially where bound layers are relatively thin (<200 mm), but will also have a long-term effect on thicker pavements. Platoon driving, on the other hand, may lead to pumping problems on roads on weak subgrade and permanent deformations because of increase pore water pressure during the spring thaw period. (Saarenketo 2018c)

Narrower lanes 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 of better wear resistance could be 10-15% more expensive to use. Furthermore, the 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 increase be affected. (Törnqvist 2015)

Automated driving will also reduce the amount of pavement wear caused by studded tyres, because automated vehicles have better control of breaking and acceleration around intersections and traffic lights as well as in congested traffic due to shockwave damping. (Saarenketo 2018c). From concentrated vehicle tracking to a connected system that allows vehicle movements to be dispersed throughout the road cross-section, the planning, design, construction and maintenance of pavements is expected to be different in the future. (Johnson & Rowland 2018 ; Saarenketo 2018a) One possible option could be to have a dynamic lane system, where two lanes used during high traffic volumes could be used as one wide lane in periods of low traffic volumes. Automated vehicles applying the wider road lanes could lead also to major savings of the annual paving costs of the highways.

One possible result of wide-scale AV platooning could be accelerated roughness, cracking, rutting and polishing, requiring a higher frequency of pavement intervention. However, the frequency of intervention is also dependant on the type of asphalt mix, and existing wearing course type. (Johnson & Rowland 2018)

Potential response for existing infrastructure – should concentrated vehicle wheel paths be realised from AVs, existing pavements would likely require more frequent maintenance due to the probable increased wear and loading. To retrofit existing roads, the road network would require pavement strengthening works in single lanes or in sections of lanes. This would involve significant operational disruption and capital cost to excavate to the subgrade level required for reconstruction of the pavement to support concentrated heavy vehicle wheel paths. (Johnson & Rowland 2018 ; Saarenketo 2018a)

Given the significant disruption and cost associated with retrofitting existing assets and designing for an uncertain scenario, it is reasonable to expect that a technology/connected solution would be pursued and developed to maximise the asset life of an existing or future road pavement over an infrastructure solution to upgrade the asset. This technology may include lane positioning of a connected fleet such that vehicle tracking is altered over time to ensure uniform wearing of the pavement and maximise the design life of the existing asset. (Johnson & Rowland 2018; Saarenketo 2018a)

For infrastructure yet to be built or in the planning phase, there is an opportunity to consider concentrated vehicle loads in the design and construction of the new pavements. This may be achieved through use of higher pavement requirements and more polymer modified binders to increase fatigue resistance. However, the level of certainty on what is required and the ultimate operational scenario is currently low, increasing the risk of investment that is not realised during the life of the asset. (Johnson & Rowland 2018)

6.2.5 Road and bridge structures

As with pavement, the future requirements of structures will be a function of the way in which the road network is operated and how technology develops.

Changes to existing infrastructure could be an increased number and change in location of traffic lanes, and loading of the structure for which it had not been designed (such as platooning). This may mean additional structures adjacent to existing road assets or strengthening existing road assets. This type of investment is typically required when a clear need is identified for the works. This is expected to be the case for existing infrastructure in the future. (Johnson & Rowland 2018)

For infrastructure yet to be built or in the planning phase, there is an opportunity to consider how the potential might impact on the structure and how the current design can consider or respond to the potential future requirements. While the ultimate requirements are unlikely to be clear, a design that considers how changes would be made in the future should be developed. The design could consider what type of strengthening works could be easily undertaken in the future, how that would be designed and constructed, and when it would be required within the design life of the asset. (Johnson & Rowland 2018)

Existing structural information could be used to inform vehicles to avoid certain structures or change the way the vehicle is driven. For example, controls could be in place to set a minimum headway on bridges to ensure structure loadings are no different than current heavy vehicle design considerations and standards. (Johnson & Rowland 2018)

Transport Systems Catapult (2017) points out that current loading models used for the design of bridges assume that there will be a "dilution" of heavy vehicles by light vans and cars. Platooning could potentially invalidate these assumptions by creating large blocks consisting only of heavy vehicles. It would be necessary to consider whether the load models used in the design of structures (particularly for long span bridges) would be adequate for this change. If not, it may require an extensive programme of assessment of the long span bridge stock and depending on the results of the assessment, potentially strengthening of bridges.

On motorways and other main roads with thick bound pavement structures, the structural problems due to platooning are minor, whereas on other roads and bridges there could be severe structural problems (Bishop 2018 ; Saarenketo 2018b)

It could become possible in the future to restrict automated heavy vehicles to particular lanes on the freeway. These lanes could then be designed with increased strength to cater for high volumes of heavy vehicles and closer headways. (Johnson

& Rowland 2018) These restrictions could be used also during those seasons, when the pavement structure is at its weakest (Saarenketo 2018c).

Geographical Information Systems (GIS) have improved significantly in recent years in the types and categories of data that can be held. The data on pavements and structures could be used to inform vehicles of which lane to travel in or avoid, resulting in prolonging the life of the pavement. (Johnson & Rowland 2018)

6.2.6 Barriers

Traffic barriers are used to protect vehicle occupants, vulnerable road users and road workers. The barriers include roadside barriers/guardrails to protect traffic from roadside obstacles or hazards, median barriers/guardrails to prevent vehicles from crossing over a median and striking an oncoming vehicle in a head-on crash, bridge barriers/guardrails to restrain vehicles from crashing off the side of a bridge, and concrete, water-filled or other work zone barriers to protect traffic and workers from hazards in work zones. (Wikipedia 2018)

While barriers provide protection to drivers and pedestrians, they also impose a physical constraint on the road corridor, particularly if they are installed within the carriageway such as a centreline to provide separation between two directions of traffic. The removal of barriers such as these in the future may provide opportunities to increase the trafficable operational cross section of a road corridor, increasing capacity and allowing dynamic operation arrangements such as contraflow. Alternatively, the removal of road side furniture and barriers could allow for more landscaping and urban design treatments which reduce the amenity impacts of the carriageway. (Johnson & Rowland 2018) In Finnish conditions, an important effect of the removal of median barriers would be the enhancement of winter maintenance operations.

The need to install and maintain barriers is likely to remain until a point where the probability of errant vehicles is very low and human drivers are no longer involved in the driving task. While the need for barriers for new infrastructure is likely to remain in place for some time, the easy removal of those barriers in the future is something that could be considered in the design of future infrastructure. The design should consider decommissioning the barriers, the opportunities for the entire road corridor once those barriers are removed, and how the design of the current road corridor could consider those changes. For example, drainage or utilities that might typically be constructed adjacent to the barriers, outside of the interim running lanes, could be located elsewhere to allow for that area to become a future lane in the ultimate arrangement. (Johnson & Rowland 2018)

6.2.7 Shoulders

As mentioned earlier, shoulders or emergency parking bays are needed for situations when the ODD is ending, and there is a need for 'minimum risk condition'. Johnson & Rowland (2018) remark that the minimum risk condition greatly differs between manufacturers. Automated vehicles coming to a stop in the vehicle lane, driving at a low speed or weaving across to a shoulder, may all cause significant issues for operations and safety. It should also be noted that emergency shoulders are not safe havens; there quite a few crashes and even severe ones happening on emergency lanes/shoulders of motorways. (Johnson & Rowland 2018)

The situation is even more critical on sections, where hard shoulder running is allowed, and thereby the emergency lane can not be used as an emergency parking space.

When and if automated vehicles are used on high speed roads, the road authority may need to be proactive in instructing vehicles on what to do in minimum risk condition mode and/or understanding what provisions may need to be designed into the road network. Future road projects will need to consider, on a case by case basis, the requirements to ensure minimum risk condition. (Johnson & Rowland 2018)

Catapult Transport Systems (2017) suggest that safe harbours need to be appropriately designed, contain enough space for an appropriate number of vehicles to stop, and to have such safe harbours frequently enough (every 2.5 km on motorways) so automated vehicles can access them when required. It is suggested that vehicles not in 'fallback' position should be restricted from these areas. (Catapult Transport Systems 2017)

6.2.8 Increasing public transport mode share

Achieving a greater public transport mode share is a key priority for many cities. The ability to carry out seamless multi-modal journeys is an enabler to achieving this goal. However, some of the existing multi-modal infrastructure, such as 'Park and Ride' facilities, are currently impacting on the multi-modal customer experience. Automated vehicles, and the potential car share models that could be enabled through automated and zero emission vehicles, have been identified as having the potential to address 'first and last mile' requirements to make public transport more attractive. (Johnson & Rowland 2018)

There are opportunities to improve the integration of automated car sharing fleet services with public transport stations and hubs. Examples may include re-purposing sections of 'Park and Ride' facilities, where they are close to stations, to allow quick and easy pick-up and drop-off of passengers. Current road planning should begin to consider how roads could be easily changed in the future to carry more shared and public transport vehicles. (Johnson & Rowland 2018)

6.2.9 Lane allocation

In order to enable and encourage the safe and efficient operation of highly or fully automated vehicles, segregation to some degree may be required. To clarify, there are four broad types for how a lane(s) could be potentially managed for automated vehicles (Johnson & Rowland 2018) :

- Separated: human drivers would be physically separated from automated vehicles
- Dedicated: human drivers would be banned from operating in a particular lane(s) allocated to vehicles operating in automated mode
- Designated: a lane(s) would be set up to encourage automated vehicles, however they would not be restricted from other lanes, unlike a dedicated lane, human drivers could choose to travel in that lane as well (preferably in a connected vehicle)
- Shared: automated vehicles and human drivers freely mix in whatever lane.

There are already a significant number of vehicles that operate successfully on the road network with limited automation, including steering assistance. The use of advanced driver aids such as cruise control, adaptive cruise control and lane keep assist are already widespread without the need for segregation on our major trunk roads and motorways. Currently, the information available suggests there is no reason why segregated lanes will be necessary. Segregated lanes could potentially impact the efficiency of the road network, by taking away road space. It could be prohibitively expensive to implement segregated lanes across the network. (Johnson & Rowland 2018)

During the transition, a dedicated lane seems unfeasible as a high rate of Level 4 and Level 5 penetration would need to be achieved, and even at that point, automated vehicles are likely to choose to travel in other lanes, especially during peak times and short motorway trips. Issues could arise when there are low numbers of automated vehicles travelling on a particular road but a high number of human drivers, and also less efficient and poor public perception. Implementing a high occupancy lane (three or more people in a vehicle) could potentially deliver the same benefits. Noting that HOV lanes are difficult to police, therefore it is possible that designated lanes would need high levels of connectivity to be policed. Under a shared scenario with higher occupancy levels, (three or more people) a dedicated AV-HOV lane could be a possible long-term outcome, this could be managed dynamically to optimise people and goods throughput. Another possible need long-term for a designated lane(s), could be to prioritise people and goods over vehicles travelling around empty, this could be managed through dynamic lane management. (Johnson & Rowland 2018)

During the transition period, to encourage uptake and help the travelling public to become comfortable with highly automated vehicles on the road, a designated lane could be implemented on motorways and some major arterials. This would allow people to choose to travel with automated vehicles, and this assumes that for Level 4 vehicles and below, automated vehicle mode would only be selected in that lane. (Johnson & Rowland 2018)

6.2.10 Kerbside Management

In addition to on-road lane management, road authorities and local councils will need to begin turning their attention to kerbside management. An Australian and UK cooperation initiative called FlexKerbs is looking at how connected automated vehicles can co-exist with all road users, and the future management of the kerbside lane through the introduction of flexible kerb space. Driven by real-time data and local policy, FlexKerbs will intelligently adjust permitted kerbside uses throughout the day and week to ensure that space both meets demand and achieves local transport goals. Over the course of a day, for instance, a single FlexKerb segment can function as an automated vehicle rank at rush hour, a cycle path at lunchtime, a pedestrian plaza in the evening and a loading zone overnight. (Johnson & Rowland 2018)

6.2.11 Parking

Parking demand

The key dimension of change affecting the level of residential parking demand in the future is likely to be the level of uptake of shared ownership and operation via a MaaS offering. Automation of transport is likely to have lesser effects. Any significant decrease in residential parking demand will be correlated with near-full or full uptake of MaaS and may be relatively independent of vehicle automation. (Jonson & Rowland 2018) Vehicle automation would likely make the provision of MaaS-like services easier by more efficient vehicle provision to customer origin location and fleet balancing ensuring efficient location of vehicles not in use.

Low levels of MaaS will not necessarily lead to meaningful reductions in residential parking demands if mobility services are used occasionally, and while people retain private vehicles to fulfil other travel demands. Nevertheless, effects on parking are likely to vary significantly depending on urban geography, with research showing that today's more frequent mobility service users – especially those who relinquish private vehicle ownership owing to access to shared services - tend to be located in city centres and other major activity centres. (Johnson & Rowland 2018)

The key dimension of change affecting the level of commuter parking demand in the future is likely also to be the level of uptake of MaaS. Automation of transport is likely to have an important, albeit less significant effect. Similar effects are anticipated for other types of longer-stay parking, including student parking at educational institutions and 'Park and Ride' at public transport stations. (Johnson & Rowland 2018)

Demand for Stabling Facilities

Stabling requirements will rise as uptake of shared services increases and vehicles become automated. As services emerge and capture passengers, the demand for stabling facilities will likely grow at a faster rate. At higher market shares of travel, stabling requirements are likely to plateau. (Johnson & Rowland 2018)

At low levels of deployment, passenger trip density will create inefficiencies in fleet operation and high numbers of vehicles (relative to travel demands) to maintain the levels of service expected by customers. Significant vehicle down-time is anticipated, especially during the inter-peak. Fleet operators may opt to geo-fence their services while supply and demand remain low, in order to mitigate inefficiencies and limit fleet size and stabling needs.

At high levels of deployment, greater operating efficiencies are possible and stabling needs (for example bays per fleet vehicle) should reduce. Fleet size may be 9-10% of current light passenger vehicle supply. Stabling facilities may be used both temporarily during daylight operating hours while vehicles wait to be assigned to their next trip and overnight when off-peak travel demands (which may be about 5% of the peak) require a much smaller available shared automated vehicle fleet. Nevertheless, the size and distribution of stabling facilities will depend on a range of factors, including (Johnson & Rowland 2018):

- The number of fleet operators in the market
- Land use regulations
- Any regulation of shared automated vehicle operations and potential stabling sites
- Target levels of service (for example average delays for passengers when mobility is demanded)
- Any government charges/taxes/etc. on empty-running
- The geographic distribution of travel demands.

Studies (ITF 2015, Rämä et al. 2018, WEF 2018) have presumed significant parking space savings associated with shared automated vehicle operations. These estimates may be overstated assuming inefficiencies occur. (Johnson & Rowland 2018)

In contrast, if all vehicles on the network are privately owned and operated automated vehicles, there may be some demand for stabling facilities if parking is not provided at destinations. However, these needs are likely to be much less than in the shared automated vehicle scenario although it will depend on location (availability of stabling hubs), household travel demands (including whether vehicles are shared between family members) and pricing variables (stabling charges, empty-running charges).

Kerbside Access Demand

Increased kerbside access demand is one of the more significant and likely implications of automation of passenger transport. An increase in demand is anticipated whether automated vehicles are owned and used privately or are shared in a shared service fleet. Demand for kerbside space will inevitably increase as the deployment and use of automated vehicles increases.

If all vehicles on the network are privately owned and operated automated vehicles (Johnson & Rowland 2018):

- Kerbside PU/DO (Pick-Up/Drop-Off) is expected to become the prevalent arrival/departure facility for every non-residential land use
- Passengers are likely to opt to be dropped off at PU/DO as close to their destination as possible
- Short-term on-street parking demand is also likely to increase, primarily serving shorter trips. These bays will be popular for vehicles to assign to after drop-off, and for convenient access when called for pick-up
- Private passenger vehicles will compete with service vehicles and surface running public transport for limited kerbside space. This issue will be more acute in major activity centres and city centres.

If all vehicles on the network are automated vehicles operating as part of a MaaS fleet (Johnson & Rowland 2018):

- Kerbside PU/DO becomes the prevalent arrival/departure facility for vehicle trips associated with all land uses
- Passengers are likely to opt to be dropped off at PU/DO as close to their destination as possible
- Private passenger vehicles will compete with service vehicles and surface running public transport for limited kerbside space. This issue will be more acute in major activity centres and city centres
- A significant increase in kerbside access demand is anticipated for all trips with residential ends compared to the privately owned scenario.

Integration of refuelling infrastructure with parking

Should the vehicles of the future run on conventional petrol/diesel, no significant changes to refuelling infrastructure are anticipated. In particular, refuelling stations are not anticipated to become integrated with parking facilities. In contrast, if electric or hydrogen powered vehicles become the norm, step changes to refuelling infrastructure will occur and this will include implications for parking facility design, at least for electrical recharging. (Johnson & Rowland 2018)

The level of uptake of shared services will also affect demands on recharging infrastructure and by implication, design standards for parking facilities in an 'electric' future. If all vehicles within the mobility system are privately owned and operated automated vehicles, aggregate VKT is likely to be significantly higher than if all vehicles on the network are automated vehicles operating as part of a shared on-demand fleet due to the higher number of passenger vehicles and proportion of zero occupancy vehicle trips anticipated. The relatively higher VKT will contribute to greater supply and distribution of refuelling stations. (Johnson & Rowland 2018)

<u>On-street parking</u>

Sweeping changes are required to the current supply and management of kerbside access, given the increase in demand and level of competition for space which is likely to arise from the automation of transport. Some impacts are already being seen – more so in city centres and activity centres – owing to growth in availability and use of mobility services. (Johnson & Rowland 2018)

Similar levels of demand may yield 90-95% savings space set aside for vehicle storage at or near to destinations. While some of the assumptions may be adjusted, the spatial efficiency benefits will remain significant. Critically, any remote stabling space needs are in addition to PU/DO. However, these may be located in less valuable areas where there is a lower opportunity cost. (Johnson & Rowland 2018)

The dimensions and physical requirements of on-street parking bays may not change significantly from current infrastructure. The size and manoeuvring capabilities of automated vehicles may not differ markedly from today's fleet: different vendors can be anticipated to offer different mobility products from prestige to basic. Occupant comfort and kerbside efficiency requirements will be factors limiting the ability for automated vehicles to manoeuvre sharply and repeatedly before accessing bays. The widespread uptake of electric vehicles could require a proportion of on-street parking bays to integrate electric charging infrastructure to meet a range of consumer needs. (Johnson & Rowland 2018)

Conventional kerbside management involves the allocation of spaces based on adjacent land use and relatively limited understanding of both overall and temporal demands. Meters and time limits are used to create turnover in business areas. The role of the local authority is generally to update regulations periodically, based on changes to land use or in response to specific requests (for example for loading zones at supermarkets). The meaningful use of data for planning and management is relatively uncommon, and there is a lack of real-time kerb availability data. This is changing with invention and uptake of apps that track bay availability using in-bay monitoring technology platforms. (Johnson & Rowland 2018)

The considerable added demand for kerbside access - envisaged as an implication of the automation of light vehicle passenger transport (and to a lesser extent uptake of mobility services) - will drastically increase competition for limited spaces. This necessitates that governments manage kerbside space dynamically and define restrictions using appropriate pricing tools.

Critically, management measures need to be adjustable so changes in demand can be responded to. It is therefore important that broader urban data policies include capture of demand and usage statistics and this information is analysed to enable dynamic management. There are opportunities to define PU/DO nodes at block or sub-precinct levels as a means of managing kerbside access across centres in lieu of a more disaggregated policy of supply and management. (Johnson & Rowland 2018)

Off-street parking

The expected decrease in parking demand enables a decrease in parking supply, which should be reflected and embodied in policy, via techniques including the removal of minimum requirements, and the decrease in parking maximums. It may even be appropriate in some cases to not allow any parking to be provided. The decrease in non-residential parking demand (and therefore locations for decreased supply) will vary by location. The largest decrease is likely to occur in high-density urban areas, with high-value land. It is likely to become increasingly feasible for parking to be relocated to the fringes of these areas – although there may be social implications of relocating parking to low-value areas. (Johnson & Rowland 2018)

The decrease in off-street parking demand means that many parking structures may become surplus to the needs of the network or fewer parking provisions will be required. This presents both opportunities and challenges associated with adaptive reuse. There are many potential alternative uses for spaces devoted presently to parking, and opportunities depend on location (for example land in a city centre area is generally more valuable than land in the suburbs). These uses include the following, depending on the needs of the city and precinct: Town square/public space, park/green space/urban farm, playground, residential, commercial/office space, retail, culture and arts. (Johnson & Rowland 2018)

Automation of light vehicle passenger transport will create a range of opportunities to increase the efficiency of the layout of parking structures. Some gains relate to the application of automated valet functionality. When passengers can be dropped at a remote PU/DO facility, parking layouts can be altered and a higher bay yield is possible. This can be due to reduced bay dimension, aisles and ramps becoming one-way, tandem parking arrangements, and the precise manoeuvrability assumed of automated vehicles. (Johnson & Rowland 2018)

This could lead to an increase in capacity of up to 20% is possible due solely to adjustments to parking bay dimensions. Increases in efficiencies for AV tandem parking arrangements varying from 60% to 250% depending on operational tolerances and the types of vehicles assumed, for example ubiquitously smaller vehicles. (Johnson & Rowland 2018, Transport Systems Catapult 2017)

Importantly, no efficiency gains are likely to be possible for parking modules required to cater for mixed parking (both human driven and autonomous vehicles), as these must be able to cater for human drivers according to current parking specifications (unless structures are created which segregate human driven vehicles from their autonomous counterparts) (Johnson & Rowland 2018; Rämä et al. 2018). Furthermore, the layouts represent high efficiency without impacts associated with structural columns, plant and other obstructions, which would manifest in decks and basements. Irregular footprints will also affect the efficiency gains possible. (Johnson & Rowland 2018)

The decrease in off-street parking demand, expected to occur as a result of increasing AV uptake, means much of the parking infrastructure currently being planned, designed and built may no longer be needed in future. It is therefore crucial to not only minimise the amount of parking supplied relative to current demands, but also to make sure new infrastructure that is built is resilient and able to be removed or adapted as needs change. (Johnson & Rowland 2018)

6.3 Impact on traffic management

6.3.1 Cooperative and interactive traffic management

In order for automated vehicles to act and comply accordingly, traffic regulations (static or dynamic; mandatory or advised) need to be digitalised and become 'electronic regulations', able to be coded into the vehicles. The development of advanced automated driving functions depends upon them. (EC 2017b)

To better manage traffic, the road manager needs to be able to translate its mobility options into a digitalised standardised language, so that it can be exchanged with the other road sector stakeholders. The split between the governance and the management levels is important to establish, because the definition of the mobility options precedes its operational implementation. (EC 2017b)

Deploying circulation or traffic management plans, along major corridors or urban networks provides the perfect background to realise the potential of cooperative, connected and automated mobility and to understand the impacts on the roles and borders of the road authorities, traffic managers, service providers, vehicle manufactures, and the physical and digital Infrastructure stakeholders. (EC 2017b)

The basis assumption is that automated vehicles are also connected vehicles capable of communication with traffic management. Cooperative traffic management has the following basic requirements: (EC 2017b)

- Communication – for the purposes of awareness or compliance, the exchange of the appropriate traffic management related data, will be bi-directional.
- Performance – traffic flow conditions will be commonly understood and assessed.
- Collaboration – the actions, from both the public and private sectors, will be complementary, decentralized, and put in place according to pre-arranged agreements.

Cooperative traffic management services will need to be well-orchestrated, as they depend on combined efforts from those involved in the service value-chain, both from the public or private sector. There is a need for scalable and replicable tools to be used across the entire European road network. These tools should provide enough flexibility for city authorities, regardless of their size or mobility policy, and also for traffic managers and road operators, to deploy the services under every possible scenario. (EC 2017b)

To help public authorities play the role of the orchestra conductor and translate their mobility plans into 'standardized exchangeable data', the Enhanced Traffic Management Working Group of the C-ITS Platform conceptualized a specific set of important tools that need to be developed for digital traffic management plans: (EC 2017b)

1. The first building block consists on a classification of roads to be done accordingly to network flow hierarchy; Not always the shortest path will be

fastest, nor the safest. This tool will help public authorities and road managers to conveniently present their views of the main road network hierarchy and the preferred alternatives. These may be useful for re-routing traffic over an area that is becoming saturated, using green light optimized speed advisory (GLOSA), or for tailoring profiles, targeted to specific road user groups, e.g. freight, electric vehicles or passenger transport.

2. The second building block is a geo-fencing mechanism. This will specially help cities to translate their zoning urban planning into traffic management related data, preventing routing through residential areas or close to hospitals and schools. Service providers can relate to these zones and apply virtual delays on top, so that the routing algorithm proposes an alternative way, more in line with the public's authority expectations.

3. In order to manage traffic, its flow efficiency needs to be monitored and assessed. Establishing a network performance Level of Service (LoS) is therefore the third required building block. LoS will depend of the road classification or type of incident, but it will be assessed under a combination of two more evident key performance indicators; speed and volume. These may be collected by road side units, loops, e.g. or provided, by specific probe vehicle data.

4. The fourth and last building block is the trigger and it is the point in which the acknowledgment of data turns into action. After this point the need to engage a cooperative traffic management service becomes decisive, to restore adequate safe and flow efficient traffic conditions. The triggering conditions need to be commonly agreed upon, as cooperative traffic management services are the result of a combination of orchestrated actions, from specific actors.

Finally, in order to make the orchestration of cooperative traffic management services possible, there is a need to develop a Common Operational Picture (COP) to provide the involved actors with a standard overview and regional context of a traffic situation. The COP will provide a visual interface, on top of a map, enabling the display of the appropriate traffic management related data, in accordance with the described building blocks layers. The COP can play a major role for re-routing services, e.g., for identifying the need of any additional measures or, for facilitating extra traffic on alternative routes.

The concept of cooperative or Traffic Management 2.0 has been developed by the ERTICO -hosted TM2.0 initiative (TM2.0 2018). An EU research project SOCRATES 2.0 (2018) is developing the interactive traffic management of connected and automated vehicles further based on the same principles. The aim is a win-win-win situation for all actors in the traffic management eco-system: (SOCRATES 2.0 2018)

- Win for the road user – Effective traffic management depends on the acceptance by an individual traveller. A traveller will only follow traffic management rules well-aligned between the various parties setting up the rules, and also efficiently communicated towards him/her ideally via a “one-stop-shop” of traffic information.,The traveller will be able to communicate back to the traffic management operators, giving feedback on current traffic flows and the efficiency of services.

- Win for public traffic management centres - Traffic management centres will be able to substantially optimise traffic management operations addressing a wide range of road users with tailor-made, precise information, utilising new communication channels and sensor/feedback techniques.
- Win for private service providers - The information services will expand to seamless door-to-door traveller assistance.. The services will be aligned with public, collective traffic management strategies. However, the specific set-up of services towards the travellers (being their costumers) will remain in the service provider's freedom in a competitive market.

To reach the win-win-win situation above, some base concepts and common agreements need to be elaborated among the afore-mentioned actors. This was done around three themes: (SOCRATES 2.0 2018)

1. Smart routing
2. Actual speed and lane advices
3. Local information and hazardous warnings

In order to assess how the stakeholders can cooperate to provide the use cases, a theoretical framework was created, describing options for cooperation. The concept of the intermediary was explored, based on the use cases and cooperation models. An intermediary is expected to have a role in data exchange coordination, aggregation, fusion, quality control and common picture. A set of typical options for the intermediary role has been defined and described. (SOCRATES 2.0 2018)

The role of the intermediary is presented also in Figure 16 (Amelink 2018).

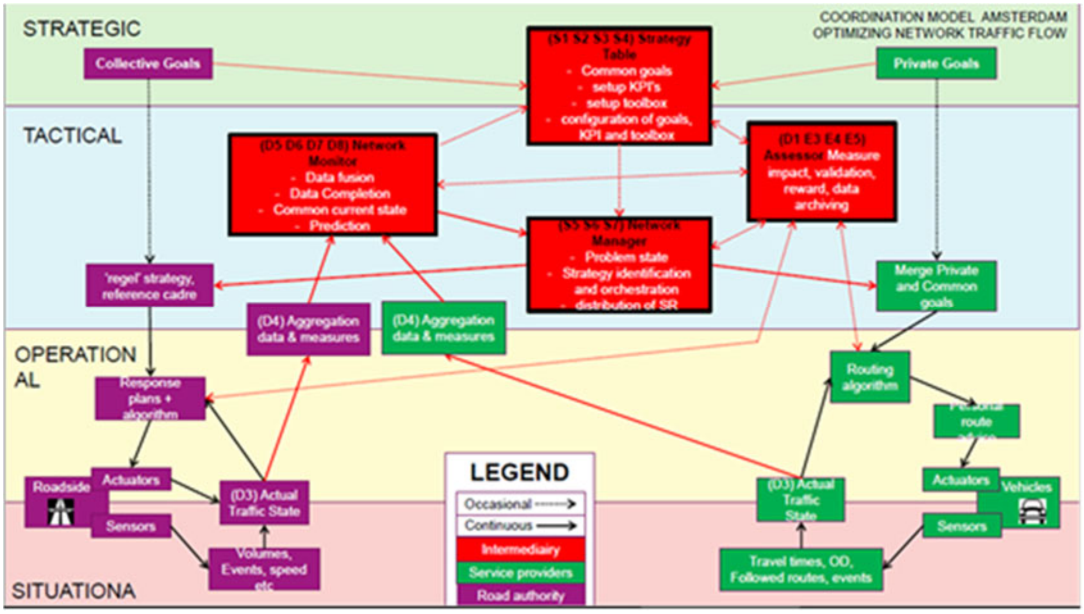

Figure 16. The coordination model for the Amsterdam site of SOCRATES 2.0 (Amelink 2018)

6.3.2 Road works management

Most highly automated vehicles are expected to rely on detailed mapping of the road network, and compare the information received from sensors with the historical information within the maps to perform such tasks as localisation and determining which lane to use. Road works may alter the road layout, changing where the vehicles are expected to travel. For human drivers, intuition and ability to interpret road signs allows them to navigate these areas. However, highly automated vehicles may not have the intelligence to interpret a new environment correctly, and as such may have difficulty navigating through these areas. Due to these difficulties, consideration needs to be given to future, design, implementation, and operations of traffic management measures for roadworks. (Transport Systems Catapult 2017)

Road works can generally be divided into two categories; planned and emergency: (Transport Systems Catapult)

- Planned road works might be scheduled weeks or months in advance.
- Emergency roadworks, which might also include disabled vehicles in the carriageway, occur on an ad-hoc basis and cones are placed on the carriageway by the first responders to the scene.

There is also a need to differentiate between road works that occur on high speed highways and those that occur on other roads. Road works can include a wide range of traffic management measures and alterations to the road. Some road works, for example, can include traffic control measures such as traffic signals or stop-go signs. Occasionally authorised persons or members of the public might direct traffic through an incident. There might be a need to merge in turn as two lanes turn into one. Traffic might be expected to use oncoming vehicle lanes under controlled or uncontrolled conditions. (Transport Systems Catapult 2017)

Consequently, unless vehicle sensors and systems have the ability to detect and interpret traffic management measures of road works with an extremely high degree of reliability and in a wide range of environmental conditions, then there will be a need to communicate details of temporary traffic management measures to the automated vehicles. The details should include time of operation and the road layout. Receiving real-time updates when sites have started and finished their work would be valuable. (Transort Systems Catapult 2017)

The mechanism for achieving this would require further investigation. It might involve geo-locating cones or barriers on a site, or setting up a virtual geofence so that the automated vehicle knows exactly where it can and can not drive. Consideration should be given to an Infrastructure to Vehicle (I2V) communications method to communicate areas of the highway that are closed for road works. (Transport Systems Catapult 2017)

6.3.3 ODD management

In addition to traffic management changes, automated driving may need specific ODD management systems to be developed, deployed and operated. The objective of ODD management is to provide equal services to all vehicles and users on roads, including both automated vehicles, non-automated vehicles, and vulnerable road users. ODD management focuses on the improvement of traffic management under mixed traffic conditions. Furthermore, mobility management is needed to be considered since the details of ODD management will change according to the penetration rate of automated vehicles and the innovative developments of related technologies. (Kawashima 2018)

Figure 17 presents the basic architecture for ODD management systems according to Kawashima (2018).

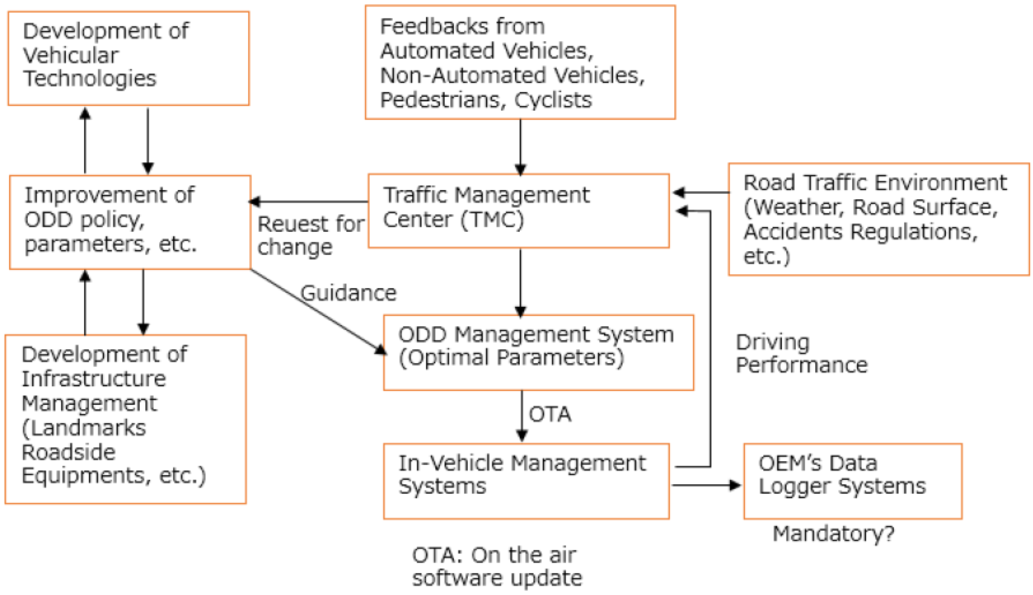

Figure 4. Basic architecture of ODD management systems (Kawashima 2018).

ODD management will influence design of vehicles, system design of traffic management, infrastructure development and operations of road operators. Therefore, at current stage, the concept of ODD management should be established and shared by many players involved in the mixed traffic conditions. This also implies that international collaboration is necessary among automobile manufacturers, network manufacturers and operators, communication industry, governments and various international organizations. (Kawashima 2018)

6.4 Impact on the transport policy goals safety, efficiency and the environment

6.4.1 Safety

Highly automated vehicles will be equipped with an array of sensors and crash avoidance systems. Those technologies will also be available to provide driver support and crash avoidance in manual driving and in driving at lower levels of automation (1 and 2). Therefore, it can be expected that these vehicles will be safer in general operation. (Geissler et al., 2016)

It could also be expected that the automation aspects provide only a small additional benefit. The general safety effects of driver support systems have been estimated in a number of studies. eIMPACT looked at 12 different driver support systems (ESC, full speed range ACC (FSR-ACC), emergency braking, pre-crash protection of vulnerable road users, lane change assistant (warning), lane-keeping support, NightVisionWarn, driver drowsiness monitoring and warning, eCall, intersection safety, wireless local danger warning and SpeedAlert (i.e. advisory ISA) and estimated their fatality reduction potential to range from 1.4% to 16.6% (Wilmink et al., 2008). It was estimated that combining all 12 driver support systems together could produce a fatality reduction of about 50%. The overall safety impact of these vehicles would naturally depend on their penetration into the vehicle fleet and their relative usage (Carsten & Kulmala 2015).

The impacts on road safety are expected to increase with higher levels of automation. Hayden et al. (2018) estimate highly automated driving to reduce road crashes by 50% and fully automated driving by 90%.

There are significant challenges in being able to interact safely with drivers of non-automated vehicles and with vulnerable road users (pedestrians, cyclists and riders of two-wheeled motor vehicles) (Geissler at al., 2016). There is also significant challenge in delivering systems with very low failure rates (Carsten & Kulmala 2015), and in addressing the design challenges in achieving safe cooperation between human operators and automated systems (Geissler et al., 2016).

In motorway driving, automated vehicles have the advantage of maintaining full attention at all times (they do not get distracted, fatigued or impaired by alcohol and drugs) and of faster reaction times than human drivers. Under automation, vehicles will comply with regulations such as static and dynamic speed limits, and both, car following and lane-keeping will be enhanced because of control that is superior to human performance. Sensor limitations may, however, preclude automatic operation in challenging conditions such as snow. (Carsten & Kulmala 2015, Geissler et al., 2016) Sensors may also be distracted and provide false detections as well as related alarms, increasing crash risks.

Safety can be further enhanced by: (Carsten & Kulmala 2015)

- Vehicle-to-vehicle communication to deliver cooperative ACC and smart platooning. This will help to eliminate shockwaves and secondary crashes and could help to eliminate crashes in poor visibility conditions such as fog, where currently there are still significant multi-vehicle collisions often resulting in serious injuries and fatalities.
- Assisted lane-changing to overcome failure to detect vehicles in the blind spot. Again, this would be enhanced by cooperative V2V capability to deliver negotiated lane changes.
- Infrastructure to vehicle communication to notify vehicles of downstream events beyond the visible horizon.

Passengers of automated buses assess their traffic safety to have increased due to automation. However, personal safety is one of issues of concern for passengers for automated buses, especially during night-time services (CityMobil2 2015).

However, there also very real design challenges in automotive human–machine interface (HMI) to be overcome. Similar design challenges have been significant even in the highly regulated and professional operating environment of civil aviation. For car driving, they will be harder to overcome. HMI needs to be well-designed, providing appropriate levels of information when needed, and suppressing superfluous information. Operator monitoring by the vehicle is likely to be required, to ascertain driver availability in take-over situations. Mode errors, in which drivers misinterpret the level of automation or misunderstand the functionality or capabilities of the currently engaged system(s) are likely to occur. Confusion may arise when drivers switch vehicles and encounter capabilities and HMIs with which they are unfamiliar. These problems are likely to be aggravated by the insistence of vehicle manufacturers on having brand-specific design themes. Whereas in civil aviation there are only two major manufacturers, in road vehicle production there are dozens and each will want its own idiosyncratic design, thus making learning more difficult and most likely compounding problems. (Geissler et al., 2016)

Rämä et al. (2018) estimated the impacts of selected automated driving use cases on safety-relevant behaviour. Their results are shown in Figure 18.

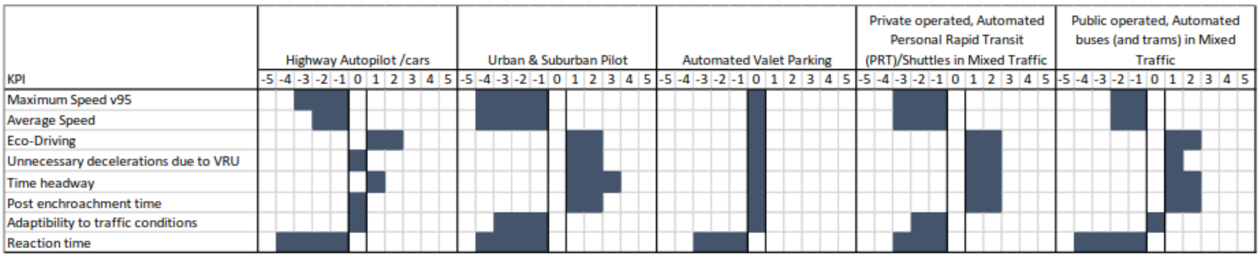

Figure 5. Service based impact estimated for driver behaviour. Scale : -5=large decrease, 0=no change, 5=large increase. (Rämä et al. 2018)

Positive safety impacts are expected due to considerable speed and reaction time reductions.

Concerning the unnecessary decelerations due to VRUs, defensive/conservative driving styles may require unnecessary decelerations when there are many VRUs present. VRU behaviour changes may also strongly affect the interaction and number of unnecessary decelerations. If, for example, pedestrians and cyclists in urban environments learn that automated vehicles will stop if they enter the roadway, and trust that they will, many VRUs may take advantage of this feature to cross roads etc. in a way they would not do with manual drivers (which they may not trust to stop in time). (Rämä et al., 2018)

Time headway settings will likely be higher than the average headway of manual drivers in most of Europe, increasing the headways overall. It is uncertain what the automated vehicles' time headway settings of the future will be, both in terms of technological achievements and the willingness of OEMs/legislators to take risks. The number of cut-ins ahead of automated vehicles (both rural and urban), and driver acceptance of such, are likely to be a driving factor for time headway setting strategies. V2X connectivity will also affect the headway changes for automated vehicles with and without connectivity. Long term (well beyond 2035), when the penetration rate is very high and systems are very reliable, the time headways may again be significantly smaller, with good V2X. (Rämä et al. 2018)

A number of numerical estimates of safety impacts have been produced via modelling and simulation. Zlocki et. al. (2018) assess that urban robot taxis or ”chauffeur” type of automated cars to be able to avoid circa 70% of crashes involving cars. Uchida (2018) estimates the relative accident rate of highly automated driving to be around 15-20% of that in manual driving.

Blanco et al. (2016) explored the available data from the tests of automated vehicles on open roads in the USA in a naturalistic driving study. On the basis of their analyses, self-driving cars seem to have lower rates of more severe crashes than those of manually driven vehicles. The lower crash rates seem to apply also to less severe crashes, although the differences are not statistically significant due to low accident numbers. Furthermore, none of the vehicles operating in automated mode were deemed at fault. (Blanco et al., 2018)

Eventually, the safety impacts are the product of the changes in exposure, crash risk and crash consequences. It is expected that both crash risk and consequences will be reduced considerably, especially after the transition period. Exposure, unless most automated vehicles will be in shared use, can drastically increase, compensating to a meaningful extent the safety gains from reduced crash risk and consequence.

6.4.2 Efficiency

With a reduction in shockwaves and crashes as an accompaniment to increased driving under vehicle control, there should be an enhancement to capacity and efficiency. This is one of the major likely benefits of cooperation. However, there are also factors that could mitigate against this. Long vehicle platoons in the inner or a middle lane could act as an obstacle to lane changing and therefore inhibit overtaking. Long vehicle platoons in the outer lanes could make merging in from an entrance ramp more difficult and could also inhibit access to exit ramps. Dedicated lanes for automated vehicles could reduce capacity for vehicles with only manual driving capability. In urban areas, any dedicated space for automated vehicles might be at the expense of other vehicle traffic. If automated vehicles required totally segregated space, then pedestrians and cyclists could also be negatively affected through loss of street space. The provision of vehicle-to-vehicle communication could mitigate against negative impacts on non-platooned vehicles, but that would require (a) high penetration of V2V systems into all vehicles and (b) a consensus or set of regulations about operational rules such that platoons could be broken apart to meet requests for road space from other vehicles. There is a potential need also for more general agreement or regulation concerning limitations on the operation of long platoons in weaving sections and especially around exits and entries to the roadway. Other road sections where limitations might be needed are up gradients and places where the number of lanes reduces or is limited. (Carsten & Kulmala 2015)

Eventually, the effects on efficiency and road capacity are expected to be very high, but dependent on the following headway length settings. The smaller the headways used, the higher road capacity achieved. (Carsten & Kulmala 2015)

Tientrakool et al. (2011) estimated an increase of 43% in capacity with full penetration of ACC enabled vehicles. That study assumed gaps between vehicles of 1.1 seconds. With longer headways, the effects are contrary: ACC without connectivity would reduce capacity by around 10% via longer headways than what tend to used in manual driving (Oshima 2018, Shladover 2018). However, the cooperative variant of ACC (CACC) would increase capacity considerably (Shladover 2018a). Bierstedt et al. (2014) found that lane capacity could be as much as doubled in a scenario with short gaps between vehicles and aggressive accelerating and decelerating. The benefits were found to be marginal until a high proportion (>75%) of the fleet were equipped with technology to allow enhanced following. Arnaout et al. (2011) suggested that penetration of at least 40% of enabled vehicles is required before benefits are seen. (Atkins 2016)

A German study (Hartmann et al., 2018) looked at impacts of automated vehicles on capacity of German motorways using microscopic traffic flow simulation. For this aim, the standard segments of German freeway infrastructure including basic, merge, diverge, and weaving segments were simulated. The resulting capacity increments were assigned to a country-wide traffic flow model of Germany. The results reveal that the conservative driving behaviour of automated vehicles, as foreseen by the current legislation, has a negative impact on the capacity of freeways. On the contrary, automated technologies that allow shorter headways between the vehicles, have the potential to increase the capacity of the freeway network by 30 % and reduce traffic delays significantly. However, small market penetration rates of automated vehicles do not lead to discernible capacity benefits and the potential benefits are likely to be realized at higher penetration into the traffic mix. (Hartmann et al., 2018)

Headway and other choices or automated vehicle settings likely depend on the user. Hence, it should not be assumed that automated vehicles will necessarily offer enhanced behaviour over the existing vehicle fleet. Accounting for user preference, comfort and safety, it is plausible that at least a section of the emerging automated vehicle fleet is more cautious than that currently operating. This results in a potential decrease in effective capacity and a decline in network performance, especially in high-speed, high-flow situations. Substantial benefits may not be achieved until high levels of connectivity and automation There is great potential for substantial improvements in network performance, particularly in high-speed, high-flow situations. However, there is evidence that at low penetrations, any assertive automated vehicles are limited by the behaviour of other vehicles; that vehicles are not able to make use of their enhanced capability. This leads to suggestion of a tipping point – the proportion of enhanced vehicles required before benefits are seen. This may be between 50% and 75% penetration of automated vehicles. Results for the strategic English road network during peak periods indicate improvements in delay of only 7% for a 50% penetration of CAVs, increasing to 17% for 75% penetration and as high as 40% for a fully automated vehicle fleet. (Atkins 2016)

Benefits are much greater in congested networks, illustrated by the "peak" demand scenario. This is expected as changing vehicle behaviour allows higher density traffic. As uncongested networks are not constrained by traffic density, improvements are not seen. Some improvements are evident in uncongested networks, illustrated by the "non-peak" demand scenario. This may be associated with areas of the network that act as "bottlenecks", such as junctions, as the greater throughput of traffic will still yield user benefits. However, this does not have great benefit to network-level measures of performance. (Atkins 2016)

Results from the Boston area indicate that shared automated vehicles will reduce the number of vehicles on the streets and reduce overall travel times across the city. The number of vehicles on the road would decrease by 15% while the total number of miles travelled would increase by 16%. However, travel time will improve by just 4% on average. (WEF 2018)

Introducing shared automated vehicles would worsen congestion in the downtown area, mostly because these vehicles will be chosen as substitutes for short public transportation trips. Travel time would increase by 5.5% in downtown Boston. In Allston, a neighbourhood outside the city's core, mobility-on-demand would mainly replace the use of personal cars rather than mass transit, and travel time would decrease by 12.1%. (WEF 2018)

The efficiency and capacity effects also depend on the mix of vehicles at various levels of automation and on whether the automated vehicles are equipped with V2X or not. With V2X, automated driving carries much less risk of shock waves and shorter headways can be used. Dutch studies (van Arem 2018) estimate that autonomous vehicles could reduce motorway capacity by 4.5%, while cooperative automated vehicles could increase capacity by 9%, assuming 30% penetration rate of automation in cars and 40% in trucks.

U.S. DOT (2015) states, perhaps somewhat optimistically: "*A fully automated automobile fleet can potentially increase highway capacity five-fold*." However, there could be negative effects at lower levels of automation and in interaction with manually driven vehicles. For example, the ability of manually-driven vehicles to change lane (e.g. to overtake slow moving trucks) could be impeded by automated vehicles driving in platoons with short headways. This implies a potential need to "manage" the behaviour of automated control and provide vehicle-to-vehicle communication to enable lane changing by non-automated vehicles. Entrance and exit ramps might have to be managed in a similar manner, so that platoons do not block intended manoeuvres. (Carsten & Kulmala 2015)

Better lane-keeping facilitated by automation would enable the use of narrower lanes for automated vehicles and fitting more lanes on the same carriageway, increasing road capacity. However, this is only achievable with dedicated lanes for automated driving. Interaction with motorcycle riders would have to be considered, since filtering between such narrow lanes would not be possible. (Carsten & Kulmala 2015)

Better efficiency will also result, if the increased use of vehicle sharing results in reductions in vehicle miles/kilometres travelled. That would reduce congestion and help to counteract the effect of population growth on travel demand. There is also a large potential for vehicles to be used more intensively. This point is made by Schoettle and Sivak (2015). They argue that analysis of U.S. travel data indicates reveals that there is a considerable potential for vehicle sharing within households because trips do not overlap in location in time. Thus, if vehicles had a "return-to-home" capability, there would be less need for multiple vehicles within households. They conclude that ownership rates per household could be reduced by 43% and individual vehicle travel (vehicle km per year) be increased by 75%.

Rämä et al. (2018) estimated the impacts of five specific use cases on efficiency (Figure 19). The impacts were rather minor, and mostly negative with increased travel timed – it should be pointed out that the fleet and traffic flow penetrations were quite low. The automated shuttles were estimated to decrease road capacity somewhat.

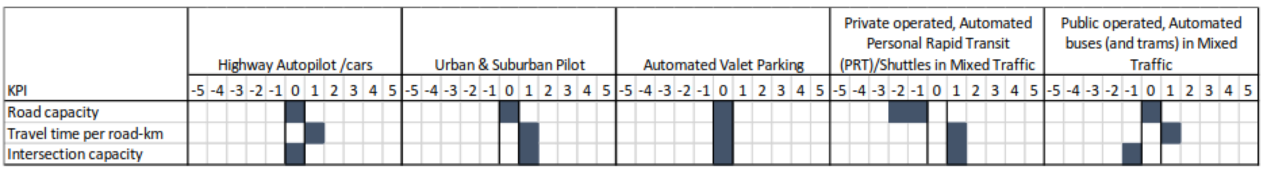

Figure 6. Service based impact estimated for network and efficiency. Scale : -5=large decrease, 0=no change, 5=large increase. (Rämä et al. 2018)

Rämä et al. (2018) discuss intersection capacity in more detail. Intersections are challenging environments for automated vehicles. When signalized, communication of SPAT messages from traffic light installations can assist the connected and automated vehicles. At a signalized intersection, communication and quicker sensing by connected and automated vehicles enables a decrease in the time needed to react to the cycle change from red to green, allowing vehicles to synchronize their acceleration through the intersection. However, the first vehicle to cross the stopping line must first determine whether the intersection is empty of conflicting streams. All vehicles should determine whether the intersection is empty of other road users who may not be observing the traffic rules, like a car turning right when a cyclist is going straight on and has a green or red light. If there are often chaotic situations at intersections (traffic rules not being observed), the connected and automated vehicle might not be able cope with this as well as manually-driven vehicles. (Rämä et al. 2018)

Time headways will likely increase, but in the case of signalized intersections where vehicles accelerate from a stopped position, the headways at lower speeds could be smaller than those of human drivers. (Rämä et al. 2018)

Dedicated lanes for public transport used mostly on roads with signalized intersections mean that there is an additional traffic stream that needs to be included in the signal cycle, which generally leads to a decrease in intersection capacity due to the need for intersection clearance times. Thus, the placement of a dedicated lane at an intersection, which takes space and time, needs to be balanced against the benefits it generates. (Rämä et al. 2018)

The absence of signalling at an intersection will require safety buffers to be introduced. Gap acceptance parameters will change, compared to human drivers (acceptable gaps are likely to be larger than for human drivers). The buffers can include increased distances to other vehicles and reduced speeds when approaching and crossing the intersection. (Rämä et al. 2018)

The more complex the environment, the more uncertain the impacts will be. For instance, if there is a lane drop a few hundred metres after the intersection, the question is how automated vehicles will deal with the lane drop, with potential blocking back effects, e.g. if the merging process is inefficient. (Rämä et al. 2018)

If there is mixed traffic, and the CADs are not suitably improved for identifying gaps etc., then the intersection capacity at unsignalized intersections may decrease. At very high automation levels (nearly 100%), great improvements in intersection capacity are possible. (Rämä et al. 2018)

There is also the potential for operational efficiencies. The use of driverless buses and trams could lower public transport costs and thus act as a counterbalance to the usage of low-occupancy door-to-door vehicles. (Carsten & Kulmala 2015)

6.4.3 Environment

Vehicles operating under automated control can be expected to save energy and emissions because of smoother driving, i.e. fewer harsh accelerations and decelerations and cruising with less flutter in accelerator control than in manual driving. The maximisation of such effects depends on manufacturers’ vehicle control algorithms. Vehicle standards could provide a means to ensure such benefits. (Carsten & Kulmala 2015)

Fuel savings will also be incurred by adherence to the speed limit in motorway driving. According to Carslaw et al. (2010), there would be an overall fuel and CO2 savings of 6% on British motorways with even loose compliance of all cars to the speed limit of 70 mph (112 km/h).

There is also the potential to use I2V communication to actively manage energy consumption and emissions, along the lines of programmes for active emissions management already implemented on Dutch motorways. V2V communication is likely to enhance energy savings. It is also possible for vehicles under automated control to be permanently engaged in eco-driving mode. (Carsten & Kulmala 2015)

Accident reductions would also result in energy savings by reducing network congestion from incidents. (Carsten & Kulmala 2015)

Shared use of vehicles would reduce energy consumption and environmental impacts considerably in urban areas according to studies in Lisbon and Helsinki (ITF 2015 and 2017b).

Vehicle sharing would result in substantial energy savings, by reducing energy consumed in manufacture. However, some of the savings would be cancelled out by the movement of empty vehicles around the network to cater to different demand patterns over the day and the week. (Carsten & Kulmala 2015)

Cavoli et al. (2017) listed the following possible energy consumption improvements to be brought about by automated vehicles:

- energy-saving driving practices (i.e. eco-driving)
- hanges in the design of vehicles, such as lighter vehicles
- optimisation of the transportation system, in particular platooning, synchronised driving and optimised routing
- reduced need to search for parking space
- reduced need for street lighting at night.

Sarkar (2016) looked at the greenhouse gas emission impacts with energy consumption as the surrogate measure – see Figure 20. Automated vehicles reduce energy consumption and thereby emissions via platooning, eco-driving, better performance and right-sizing, improved crash avoidance, and new services. But they might also increase the environmental impacts via higher speeds, increased features and especially more vehicle kilometres travelled due to new user groups and lower travel costs.

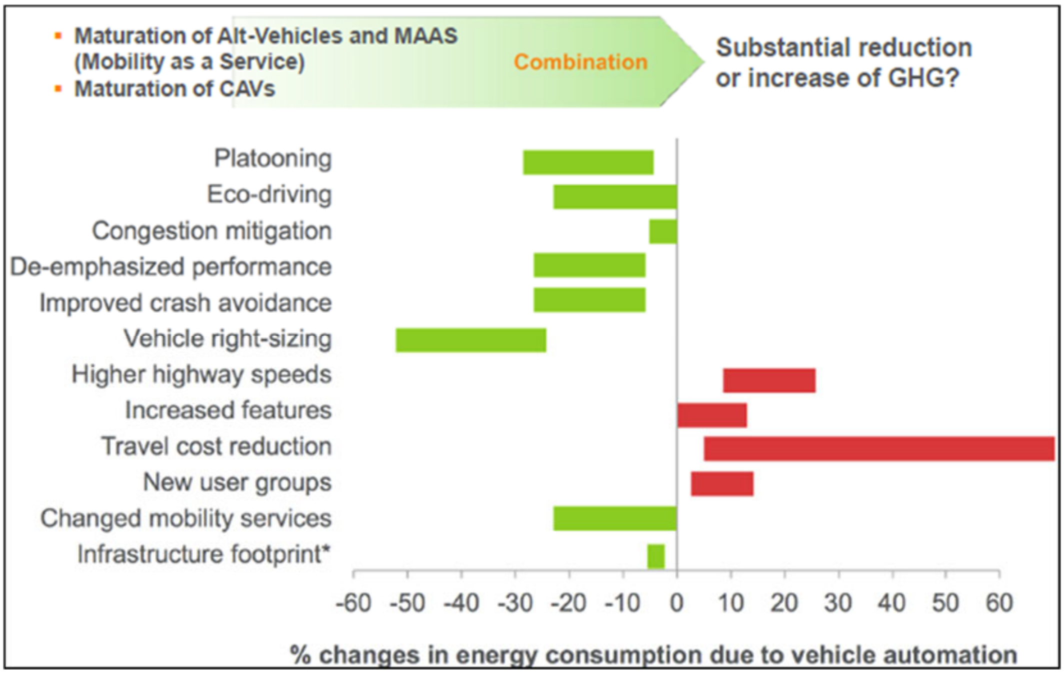

Figure 7. Percentual changes in transport energy consumption due to vehicle automation (Sarkar 2016).

Rämä et al. (2018) investigated the environmental impacts for five different road vehicle automation use cases – see Figure 21. The energy savings due to reduced air resistance would be realised only for highway convoy as a special case of highway autopilot. The result indicate increases in the energy use of in-car IT technologies. They state that energy use of in-car IT cannot be neglected, and that energy consumption for automation of shared vehicles/mass transit comes less into effect than for private cars. For stand-by and low-speed applications, in-car IT needs a significant proportion of energy. In all, the amount of energy needed for in-car IT will increase due to automation. (Rämä et al., 2018).

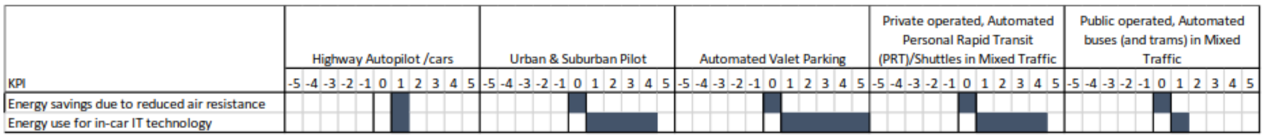

Figure 8. Service based impact estimated for energy and environment. Scale : -5=large decrease, 0=no change, 5=large increase. (Rämä et al. 2018)

All in all, the environmental benefits due to the combined effects of energy savings per vehicle, platooning, individual mobility changes, vehicle sharing and other factors are expected to be positive, according to both Sarkar (2016) and Yagci & Clewlow (2016).

6.5 Impact on economy and employment

6.5.1 Economy

As far as the automotive sector is concerned, connected and automated vehicles may reinforce vehicle sales in line with travel activity increases. The higher the level of automation, the stronger the effect on Vehicle Kilometres Travelled (VKT), mostly as a result of a reduction in driving costs (including changes in the value of travel time) and new users like young people, elderly or disabled. Even though new mobility service models (MaaS) may increase vehicle usage intensity, the resulting decreased vehicle ownership may considerably impact vehicle sales. Scenario estimations provide ranges of passenger vehicle sales increases from 18% to 39% during the period 2015-2025 and from 33% to 51% in the period 2015-2050. (Alonso et al., 2018)

The incremental cost of fully automated trucks to the purchaser is not yet known as it will depend on the balance of supply and demand when the supply breakthrough is made. Stakeholders have argued that the incremental manufacturing costs above the existing new truck technology would be small relative to the overall cost of a truck, perhaps less than 5%. In the short term, any supply constraints might mean that driverless trucks sell at a considerable premium above their production costs. Over the medium to longer term, fully driverless trucks could be cheaper to produce than the traditional “manned” vehicles, for example, because a sleeping unit would not be required for the long-haul vehicles. (ITF 2017a)

Using current average car prices, total revenues from passenger car sales could exceed 550 billion euros by 2050. It is also expected that the sales of heavy commercial vehicles will increase in response to a more intense road travel activity in the future, which could be further reinforced by a more efficient operation of automated trucks. In this case, a growth of 19-29% could be expected in the period 2015-2025 and 38-68% in the 2015-2050 period. Total revenues from commercial vehicle sales could almost reach 150 billion euros in 2050. (Alonso et al., 2018)

The electronics and software sector would clearly benefit from the production and sale of new components and systems needed for automated driving (including hardware and software components). Whereas software will gain a more dominant role (in terms of monetary value proportion) with regard to today, the market for CAVs' hardware components like cameras, lidar, etc. will also grow. With the previously mentioned vehicle sales projections, total revenues from the sector could almost reach 180 billion euros by 2025 for both passenger and freight automated vehicles. (Alonso et al., 2018)

The telecommunication, data services and digital media sectors are also expected to experience significant growth, as in-vehicle connectivity increases and becomes pervasive. 5G networks will support the exchange of massive amounts of data generated by a future connected and automated vehicle. The monetization of car data holds a great potential and users are already demonstrating willingness to pay for services built around this data. (Alonso et al., 2018)

Vehicle automation will act as a transformational technology in the freight transport sector by diminishing operating costs and allowing more efficient logistics (ITF 2017a, Johnson & Rowland 2018).

Operational and transition cost implications for road freight businesses adopting driverless truck technology could be significant. Operationally, there will be a need for additional expenditure of information and communications technology systems and systems maintenance. In transition, there will be some retraining costs for retained staff whose jobs will change, and payment of redundancy entitlements for staff that are not retained. (ITF 2017a)

Other costs of adoption of driverless truck technology are less tangible. Automation of a job generally requires some simplifying and restructuring of tasks to remove elements where computerised systems are inferior to humans. The exact nature of task restructuring for automation truck driving is not yet known since it may depend on the contexts in which driverless trucks are applied. For example, if long-distance motorway operation were possible, while urban operations were not, there would be some costs associated with reorganising supply chains (or driver shifts) around new hubs located at the city limits on motorways. Further reorganisation may be required that would also involve costs, such as consignors and consignees having to upgrade their receipt or shipping systems to interact with a truck's computer systems rather than a human. (ITF 2017a)

Taken together, a reduction in operating cost from adopting driverless trucks is possible in the order of 30% compared with today's costs.(ITF 2017a)

According to Johnson and Rowland (2018) the potential ways in which AVs could alter road freight costs include:

- Reduced direct costs due to removal of driver costs for automated trucks. The extent to which this occurs may vary considerably depending on the requirements for human involvement in delivery functions at trip ends
- Reduced costs due to higher vehicle utilisation – 24-hour operation is likely to be more feasible for automated truck operations, with the removal of driving hours and driver scheduling constraints being a significant factor. Improved information systems may also assist in improving scheduling and reducing

adverse impacts of network unreliability, although such improvements are also likely to be pursued with conventional vehicles
- Better 'self-regulation' capabilities enabling more flexible network access regimes for freight vehicles contributing to higher productivity
- Reduced (or increased) costs due to indirect factors such as changes in road congestion levels driven by private automated vehicles travel.

Cavoli et al. (2017) conclude that connected automated vehicles have the potential to optimise goods delivery and the wider freight network, with the greatest efficiency gains expected to be made through highly connected vehicles. Integrated, connected AV operation throughout the value chain would create opportunities to optimize complex logistics systems, including in urban freight, long haul trucking, and seaport operations. (Cavoli et al. 2017)

The estimates of how automated vehicles may reduce the total cost of ownership of freight vehicles suggest annualised cost reductions of approximately 15%. In the competitive freight industry, such cost reductions are likely to flow onto reducing freight costs for consignors. The extent of the above changes will also be affected by the regulatory and policy settings under which freight operations occur. (Johnson & Rowland 2018)

It is noted that while the focus here is on impacts of automated vehicles, automated operations also have the possibility to change other aspects of freight operations. Port systems for container handling are already highly automated, and with more widespread use, automated operations could potentially lower the current cost penalties associated with double handling of containers where road to rail transfers occur, contributing to improved competitiveness of road/rail intermodal operations. (Johnson & Rowland 2018)

The freight sector benefits would justify the idea that this sector becomes one of the early adopters of automated vehicle technologies. The two most costly elements in commercial vehicles operation are fuel and drivers, both of which can be reduced through truck automation. When it comes to fuel savings, truck platooning could decrease fuel consumption by 2-8% for the leading vehicle and 8-13% for the following vehicle. The role of a professional driver can be radically transformed in the future (starting with early platooning applications), gradually undertaking other duties than driving and possibly turning into a more technical role. (Alonso et al., 2018)

To which extent this will lead to a reduction in the number of drivers needed still remains an unanswered question that deserves careful attention. It is also important to stress that automated vehicle technologies could help to compensate the shortage of long-haul drivers, as e.g. Germany is expecting to lose around 250,000 drivers who will retire in the next 10 to 15 years. (Alonso et al., 2018)

The insurance sector could be disrupted by the expected drastic reduction in the number of road accidents. The improved road safety conditions might imply significant discounts in motor vehicle premiums. On the basis of discounts currently applied to vehicles equipped with collision avoidance systems, estimations indicate potential decreases in insurance premiums of 10-30% in 2025 and 15-40% in 2050 compared to today. These reductions could represent up to 53 billion euros in 2050. (Alonso et al., 2018)

A lower crash rate would also drive a large part of the changes expected in the maintenance and repair sector, with revenues decreasing as a result of a lower demand for crash-related repairs. Although a lower acceleration/deceleration could also lead to reductions in maintenance, this potential decrease could be offset by higher labour and equipment costs of repair. Telematics will enable predictive maintenance applications that would also lead to lowering repair frequency and overall maintenance costs. The Original Equipment Manufacturers' (OEM) privileged access to car sensor data would make them well-positioned in this type of offerings. Competition in car maintenance would be higher, thereby creating downward price pressure and reduced added value in these services. One potential factor leading to a growth in revenues in this sector could be linked to the cleaning and repair activities that could be needed for shared vehicles. (Alonso et al., 2018)

6.5.2 Employment and skills

At the present state of art, automated vehicles cannot perform all the tasks required in most driving-related jobs and there is much uncertainty if they will ever do. However, a partial tasks substitution (e.g. platooning substitutes the tasks that now strictly require a second driver to perform) will increase competition in the lower-skills labour market. Firstly, because the tasks substitution by automated vehicles will make the job appealing for more people that previously had a dislike for driving. Secondly, because lower demand for drivers will make the transport sector less accessible. The competition effect will not only be restricted to the transport sector but to all the other lower-skilled occupations where displaced drivers will apply. (Alonso et al., 2018)

According to the estimations of Alonso et al. (2018), workers endangered of technological substitution (drivers and mobile plant operators) working in land transport amount to approximately 1.5% of total EU-15 employment in 2012 and those who require new training to keep performing the job (metal, machinery and related trades) in wholesale, retail and repair of motor vehicles amount to 0.7% of total EU-15 employment in 2012. It also seems evident that employment effects will not only be restricted to the land transport sector but will impact all sectors that employ drivers such as warehousing and support, wholesale trade or postal and courier activities. The current 3.2 million truck-driving jobs in Europe may decrease to 2.3 or even up to 0.5 million by 2040 according to different scenarios (ITF 2017a). A slow automated vehicle uptake or an informative awareness campaign can lead workers to qualify on time and mitigate the transition costs for them. Retraining or income assistance programs are mechanisms that can support the transition. (Alonso et al., 2018)

It is relevant to note that both occupations under study have low levels of Information and Communication Technologies (ICT) use, whereas ICT skills will be increasingly demanded in the future. Land transport sector will be increasingly dependent on ICT-based and specialized equipment and products. In vehicle repairs, a shortage of ICT professionals has been identified for 2020. (Alonso et al., 2018)

If the demanded skills can be matched in the future, there could be opportunities for reallocation of employees. In the future, some highly qualified mechanics might move over to higher-paying jobs in the information sector. ITF (2017a) also postulates that skilled and experienced drivers could be demanded in the case that remote control rooms are installed for automated vehicle monitoring. (Alonso et al., 2018)

Inequality between low-skilled and high-skilled workers will widen. Automated vehicles can make some sectors more profitable but most of the benefits will be reaped by those highly skilled workers who can either produce and repair the new vehicles or those who get more productive with the additional time previously spent in transport activities. However, another aspect to consider is the easier geographical connectivity facilitated by connected and automated vehicle technologies, which could enable workers to accept jobs from firms previously rejected due to distance to the workplace or because less accessible in general. This effect is likely to be positive on labour market participation and on skills match between employers-employees. (Alonso et al., 2018)

At the level of skills required for driving a connected and automated vehicle, the automation of the driving task will increasingly require supervision and selective intervention skills in opposition to manual control and manoeuvring skills. Understanding the automated driving systems functioning will also be essential for a safe operation of automated vehicles, for which the highly heterogeneous vehicle systems could represent a challenge. As automation is gradually deployed, progressive and continuous training could become more relevant than the current one-off initial training. (Alonso et al., 2018)

The impacts of automated vehicles on employment are largely influenced by the speed of introduction of the new technologies and mobility changes. The more gradual the introduction will be he higher the probability that the negative implications on employment will be absorbed by the economic system of the European society. (Alonso et al., 2018)

7 Impacts on the role and responsibilities of the road operators and authorities

7.1 Road Operators – national road network

7.1.1 The traditional role and responsibilities

In most EU countries, e.g. in Finland the national road network is managed by a transport agency which is responsible for all surface transport (roads, railways and waterways), operating under a ministry of transport or government department for transport.

Transport agencies typically endeavour to optimise the effectiveness of the transport system, maintain the infrastructure, to improve traffic safety and enhance sustainable development, both for passenger and freight. Digitalisation and the transformation of transport with connected automated vehicles are seen as an important avenue to reach the long-term policy goals set by the authorities, and to streamline the internal processes, and to sustain the long-term viability of the agency in the changing environment.

A good example of the tasks of a transport agency is the following list of the tasks of the Finnish Transport Agency (FTA 2016):

- to maintain and develop the transport system in cooperation with other actors
- to be responsible for the state-owned road and railway network and for the waterways administered by us; and to coordinate, guide and monitor waterways management throughout the whole country
- to carry the responsibility for large road projects and for the planning, maintenance and building of railways and waterways
- to manage the operations of the area of responsibility Transport and Infrastructure under the Regional Centres for Economic Development, Transport and the Environment (ELY Centres)
- to participate in the coordination of transport and land use
- to handle and develop traffic management in the state-owned transport infrastructure and in shipping
- to provide the operating framework for winter navigation
- to develop and promote traffic services in addition to a well-functioning market for these services
- to promote productivity improvements in transport infrastructure management
- to develop the operational preconditions for public transport and to grant subsidies aimed at promoting merchant shipping and other transport modes
- to maintain and develop hydrographic services
- to ensure a well-functioning transport system under exceptional circumstances as well as under normal circumstances.

In most of the EU Member States the roads are operated by a similar agency, with similar responsibilities, see Table 23. However, in Germany the Federal Government is responsible for the Autobahn network, but other roads are operated by state (Länder) agencies.

Table 4. Responsibilities of the national road operators in some EU Member States

National road operator	Main responsibilities
United Kingdom: Highways England	Highways England (formerly the Highways Agency) is the government-owned company charged with operating, maintaining and improving England's motorways and major A roads. It operates information services through the provision of on-road signage and its Traffic England website, provides traffic officers to deal with incidents on its network, and manages the delivery of improvement schemes to the network.
France: Ministry of Ecology, Sustainable Development and Energy - Road Section	Mobilities and territories - Planning of infrastructures, urban mobility, logistics, safety, innovation Urban mobility - Collective Transports, active mobility, shared mobility Sustainable and Innovative Mobilities - SCOOP Project, autonomous vehicles, greenhouse gases, adjusting to the climatic change
Netherlands: Rijkswaterstaat	Rijkswaterstaat is responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. This includes the main road network, the main waterway network and water systems. Rijkswaterstaat promotes Smart Mobility in collaboration with the business sector, research institutions and other public authorities, including improving the information provided to travellers. Improving the use of the existing infrastructure and modernising traffic management and information provision and the managing the underlying physical infrastructure.
Germany: Road Construction DG of BMVI	The Road Construction Directorate-General is responsible for maintaining the structural integrity of the road network for which the Federal Government is responsible. This currently comprises around 12,800 km of federal motorways and approximately 40,000 km of federal highways. Another of its tasks is to operate our road network and improve it by upgrading existing roads and constructing new ones. The Road Construction Directorate-General is also responsible for an efficient and appropriate use of public funds. The federal states are responsible for planning and implementing the construction works and carrying out routine maintenance.
Finland: The Finnish Transport Agency (FTA - Liikennevirasto)	The Finnish Transport Agency (FTA) is a Finnish government agency responsible for the maintenance of Finland's road, rail, and waterway systems. The FTA's parent organization is the Ministry of Transport and Communications. The Finnish road network consists of highways, municipal street networks and private roads. In tandem with the fifteen regional ELY centres, the FTA is responsible for the maintenance and development of the state-owned road network. There are 78,000 kilometres of highways maintained by the FTA, of which about 50,000 are paved.
Sweden: The Swedish Transport Administration (Trafikverket)	The Swedish Transport Administration (Swedish: Trafikverket) is a government agency in Sweden, controlled by the Riksdag and the Government of Sweden. Trafikverket is responsible for the long-term planning of the transport system for road, rail, shipping and aviation. Its task is to develop an efficient and sustainable transport system from a perspective that encompasses all modes of transport. The administration works with long-term infrastructure planning in close dialogue with regions and municipalities. It is also responsible for building, operating and maintaining state roads and railways. In addition, the administration is responsible for ensuring that this infrastructure is used effectively and that it promotes safe and environmentally sound transportation.

Finnish Transport Agency to become Finnish Transport Infrastructure Agency

The administration of transport and communications in Finland will undergo a change as of 1 January 2019, at which time the Finnish Transport Agency will become the Finnish Transport Infrastructure Agency (FTIA). The primary name to be used for the agency will be in Finnish “Väylä”.

FTIA will be an expert agency of about 400 people, concentrating on planning, developing, and maintaining road, rail, and maritime transport infrastructure and on the coordination of transport and land-use. In addition, it will also be responsible for arranging traffic control and winter navigation. FTIA will operate in the planning of transport systems as the primary partner of regional councils, municipalities, urban regions, and other players.

The new agency deals with the service level of transport, thus promoting well-being in Finnish society and Finnish business competitiveness. In addition, the new agency will do its part to promote development and responsible construction in the infrastructure field.

The division of labour and the interface with FTIA will be as follows:

- The traffic control tasks for road traffic, rail traffic, and maritime routes will be incorporated as of 1 January 2019 into Traffic Management Finland Group, a state-owned company with a special mission. FTIA will order services for traffic control from the company.
- Regional maintenance of roads will continue to be the responsibility of Finland's ELY Centres. FTIA will deal with the implementation of the national level of service. Daily road maintenance will be handled by contractors based on competitive tenders.
- The new Finnish Transport and Communications Agency (Traficom) will be responsible for transport licences, competences, supervision, and safety. Operations to be transferred to the new agency from the present Finnish Transport Agency will include maritime mapping, transport and land use tasks, and tasks connected with transportation services and public transport services.

7.1.2 Impact of the introduction of connected automated driving

Introduction

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 (EC 2018a).

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. The human factor is an important part of current research on traffic models and one of the reasons 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.

Developing a common roadmap for the introduction of the autonomous functionalities

The developments mentioned imply new challenges, but also new opportunities for national road authorities, road operators and traffic managers and cities. Highly accurate, real-time safety related information via short range and cellular connectivity is already expected to significantly improve road safety in the next few years. Cooperative navigation services will have significant impact on transport efficiency and consequently also reduce the environmental footprint of road traffic as a whole, as will electrification of vehicles.

Different scenarios for implementing Connected and Automated driving are possible, with varying levels of National Road Authority (NRA) involvement (CEDR 2018). Of course, other stakeholders need to be involved as well. On the advice of the their CEDR CAD working group, it is view of CEDR that it is essential for NRAs to recognise the opportunities and challenges brought by CAD development and to act on them because:

It safeguards the NRA interests. NRAs can only affect the developments described by participating in them. Otherwise, NRAs will have no other option than to adapt to or comply with what will be delivered by industry (at the risk of putting things on the road that actually adversely affect road safety, traffic flow and the environment);

NRAs may contribute to drastically improve the effectiveness of new technologies and services. For example, NRAs can extend the vehicle sensor horizon from the current 30…200 m to much longer distance and also around corners by deploying roadside sensors/equipment, and this is specifically relevant in the first years with low penetration rates when there are too few cars in the neighbourhood that can act as sensor;

NRAs are needed to establish a smooth transition from the current situation to the new reality by effectively managing mixed traffic situations without a loss of service for non-connected vehicles and at the same time ensuring safe and smooth driving conditions for all vehicles on the road;

It benefits the competitiveness of Europe. NRAs will act as partners of vehicle manufacturers, service providers, etc. to jointly develop the best solutions, preventing the risk that e.g. a big software supplier dominates the market. This knowledge can be exported to other parts of the world;

Showing the public that NRAs are actively involved in the development, will increase the people's trust in the new technologies and their willingness to use them, thus leading to a quick uptake.

<u>Extensions and improvements of roadside equipment and infrastructure</u>

While NRAs, road operators and traffic managers so far primarily emphasised the roll-out of roadside equipment, in particular for road side signalling, CAD now means that focus will shift towards ensuring availability of a 'digital infrastructure' enabling the use of Information Technology and data for managing roads, which will provide high quality information for drivers using real-time in-vehicle services.

The current infrastructure – physical as well as digital – is not necessarily well prepared to facilitate this change for NRAs to perform their typical roles and tasks. Significant change is expected from the deployment of new technologies like C-ITS or connected automated driving, as well as electric vehicles' demands for re-charging infrastructure. What's new in the current situation is on one hand the magnitude of the needed actions, and on the other hand the significance of the European – if not international – dimension if we consider systems and services where infrastructure directly interacts with in-vehicle systems. This implies that more and more impact of traffic management is generated in a cooperation setup rather than by isolated systems under total control of the road operator.

A high quality digital infrastructure is an essential part for the development and reliability of automated driving systems (EU EIP 2016). The automated driving systems are expected to share data with the infrastructure and other vehicles. Furthermore, connected vehicles may send data back to the manufacturer so they can monitor and improve their software which then gets updated over the wireless connection. The same mechanism will be implemented for digital maps and driving condition use cases. The test currently ongoing on remote supervision/manoeuvring of automated driving systems will provide data on the reliability, latency and bandwidth requirements of that technology, currently believed to be possible only with 5G.

To achieve this the NRAs need to finance at least part of the digital infrastructure. This could mean building the back office infrastructure needed to share information and updates, the single point of access would be a good start. It could also mean taking a 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 to achieve this goal.

Various NRAs already decided to deploy ITS G5 roadside stations or similar equivalents to utilise new technologies (like LTE-V2X). Another open question is what budget implications future cellular technology developments (e.g. 5G) will have. The use of satellite technology (Galileo) could contribute to reaching goals as well, and introduction may have budget consequences.

<u>Extensions and improvements of the back-end system and increasing automation</u>

Equally, substantial improvements in backend systems, services and underlying processes are needed already for SAE Level 2 and 3 systems (Grave 2017). It can be expected that any type of future connected automated driving scenario will require substantial improvements in content delivery from road authority backend systems to feed other service provider back ends (cloud-to-cloud services) but potentially also towards providing data services directly into vehicles (or mobile devices used inside vehicles, like smartphone or in-vehicle Apps) in a hybrid communication scenario. Beyond the functional improvements stated so far, actions required in this sector may also have to cover improved framework conditions, e.g. in terms of IT security and privacy.

Similarly, moving towards automated driving by building up the digital architecture involves open and common standards and interfaces and an efficient, but secure data ecosystem. The Member States have to accelerate the setting up their National Access Points; to facilitate access, easy exchange and reuse of transport related data, in order to help support the provision of EU-wide interoperable travel and traffic services (EC 2018b).

<u>Provision of the C-ITS Day 1 and Day 1.5 services</u>

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, in particular the C-ITS services. Therefore, the C-ITS Day 1, 1.5 and later Day 2 services should be rolled out in the short term by the Road Operators, according to the ITS Action Plan, ITS Directive and the Final Report of the C- ITS Platform.

<u>Public Acceptance and campaigns</u>

General public’s expectations are not well known, although 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 (Shladover 2016).

In Europe, 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 Cetelem 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.

These studies indicate clearly that NRAs have to show to the public that they are actively involved in the development, this will increase the people's trust in the new technologies and their willingness to use them and leading to a quicker uptake. Joint communication campaigns with the industrial partners could be considered.

Budgetary implications to Road Authorities and Operators

The commercial requirements of market introduction of such vehicle systems require pan-European, coherent roll-out on the infrastructure side to provide seamless interoperability across the European road network, which will also inevitably have an impact on budget requirements.

CEDR's CAD working group is currently trying to provide indicative NRA estimates of budgetary implications regarding the presented NRA actions which these requirements may impose, differentiating the presented types of required actions as separate cost categories (CEDR 2018). As said before, different scenarios are possible with different levels of NRA contribution, potentially leading to different levels of NRA investment, but it should be noted that if the described (societal) benefits are to be achieved, investment is needed. Congestion will never fully disappear, but its impact can be substantially mitigated by appropriate NRA actions.

The process is still ongoing, but very first indications show that for the 43,000 km European motorway road network in CEDR countries (including approx. 29,000 km of TEN-T core network), an overall investment in the order of over €10 billion can be expected over the next 10 years. These values will of course significantly vary from country to country. Note that this does not imply the same level of equipment and service everywhere. At this time, the values provided can only be rough estimates with a value range of at least +/- 20%, and it should also be noted that they do include costs that may already be partially covered by current budget plans. Nevertheless, they give a first indication of the overall dimension of transitional change and related investments that NRAs will face in the next ten years.

Since investment comes upfront but benefits – especially societal benefits – may not come immediately at low penetration rates, the NRAs may face problems in securing the required investment. However, continuing with outdated technology will eventually create excessive maintenance cost, whereas innovation will eventually save cost after an initial investment phase.

7.2 Road Operators – street network of cities

Integration of the automated vehicles to general mobility plans and strategy

It does not come as a surprise that many cities want to be in the forefront in the development of automated road transport. Cities promote automation because it is believed to bring a solution to exiting or future transport problems, i.e.- increase safety, alleviate environmental effects and congestion, to increase the use of public transport, and also to reduce costs in offering mobility services (such as MaaS and Last Mile – On Demand transport, Demand Responsive Transport (DRT) (NACTO 2017). Automation is also seen as a way to combat the shift from public transport to the use of private vehicles offered by companies like Uber or Lyft.

Many European and National projects have produced initial results on the use of automated vehicles, typically shuttles or mini-busses, in various cities. Most of the buses and shuttles tested have so far been manufactured by companies Easymile, Navya and Bestmile, but soon there will be a bus manufactured in Finland (Gacha). A number of pilots is ongoing and being planned. The tests are typically run under the exemptions for normal traffic rules set up in National legislation. However, typically cities have their own rules e.g. for ride sharing and they maintain the road/street network in their jurisdiction.

Automation, when taken into use as part of the mobility plan of a city, will have a profound impact on many diverse areas.

<u>The role of networks of cities – EUROCITIES and POLIS</u>

The networks of cities have taken an active role in promoting automation, including pilots. The two most active networks are EUROCITIES (2017) and POLIS (2018).

EUROCITIES is the network of major European cities, founded in 1986 by the mayors of Barcelona, Birmingham, Frankfurt, Lyon, Milan, and Rotterdam. Today, EUROCITIES brings together the local governments of over 130 of Europe's major cities from 35 different countries representing the interests and needs of 130 million citizens.

EUROCITIES is committed to working towards a common vision of a sustainable future in which all citizens can enjoy a good quality of life. EUROCITIES structures its work around five focus areas that to a large extent align with the EU's strategic priorities:

- Cities as drivers of quality jobs and sustainable growth
- Inclusive, diverse and creative cities
- Green, free-flowing and healthy cities
- Smarter cities
- Urban innovation and governance in cities

Regarding connectivity and automation, Eurocities has two working groups active in this area, SMART & CONNECTED MOBILITY Chaired by Vienna and INNOVATION Chaired by Helsinki.

POLIS, established in 1989, is a network of European cities and regions working together to develop innovative technologies and policies for local transport. Polis fosters cooperation and partnerships across Europe with the aim of making research and innovation in transport accessible to cities and regions. The network and its secretariat actively support the participation of Polis members in European projects. Polis participation in European projects allows us to create a framework which facilitates dialogue and exchange between local authorities and the transport research community.

Polis also supports the exchange of experiences and the transfer of knowledge between European local and regional authorities. It also facilitates the dialogue between local and regional authorities and other actors of the sector such as industry, research centres and universities, and NGOs. The activities of Polis are organised around four thematic pillars:

1. Environment and Health in Transport
2. Mobility and Traffic Efficiency
3. Transport Safety and Security

4. Social and Economic Aspects of Transport

The Mobility and Traffic Efficiency pillar addresses issues related to network management and innovative services, in particular those enabled by intelligent transport systems (ITS). Through European projects (notably CIMEC, CODECS and MAVEN) and several European fora (including the Amsterdam Group and C-ITS Deployment Platform), Polis is heavily involved in European discussions on connected and automated transport systems. Its main purpose is to ensure the voice of cities and regions is heard in these developments and to understand where they can bring benefit.

Table 24 lists examples from four cities concerning how the mobility challenges can be addressed with the help of automation.

Table 5. Examples of addressing mobility challenge with automation.

Overall mobility challenge	Motivation to operate automated services
Tampere: Tampere city centre is located on a narrow land area between two lakes and the city centre is easily congested. To decrease congestion and other negative impacts of traffic and to attract more users to public transport a new tramline will be built by 2021. Automated bus transport services will extend the reach and will be fully integrated with the tram and the existing bus lines and will offer effective on-demand feeder transport (first/last mile) for the public transport user, with lower operating costs.	Tampere aims to be a sustainable smart city attractive for business and citizens. Development of automated public transport services is one of the spearhead initiatives. Tampere has studied automated bus services, tested automated buses and now wants to deploy automated feeder services as an integral part of the existing public transport system. Automated services are seen as the future complementary alternative for the City.
Berlin: Developing public transport into a more demand oriented MaaS. Creating an environmentally friendly, efficient, and intelligently integrated transport system	Implementation of a real-life public transport system capable of using fully automated vehicles to transport citizens from and to the demo site as well as a seamless integration with existing PT. Generating user acceptance for an autonomous transport systems
Stockholm: Support Barkaby residents with mobility: transport within the area, to and from high capacity public transport, and with a new link to and from the business area in Kista. (Barkaby is a town north of Stockholm. In Barkaby 18000 homes and 1 000 office spaces will be built within the next ten years).	Operating automated services in Barkaby is important to provide residents with sustainable mobility and minimize their need for private cars. Learnings from Barkaby will be transformed to other sites and implementations
Paris / Saclay: Saclay is a commune in the southwestern suburb of Paris, located 19 km from the centre. The local student population will be doubled during the next three years up to 20.000 and the public transport offer has to be able to support the students' needs in terms of mobility, especially during night period. The main challenge is to go beyond piloting activities and implement a real mobility service using automated vehicles and involving end-users.	This academic excellence zone attracts more and more students which demonstrate the strong influence of the area. The growth of the local mobility need represents the perfect circumstances to test new ways to move through short/medium distances while guaranteeing a high rate of acceptance due to the local population (mostly students).

7.3 Bodies of Traffic Management

Traffic Management for CAD

Traffic management provides guidance to the European traveller and haulier on the condition of the road network. It detects incidents and emergencies, implements response strategies to ensure safe and efficient use of the road network and optimises the existing infrastructure, including across borders. Incidents can be unforeseeable or planned: accidents, road works, adverse weather conditions, strikes, demonstrations, major public events, holiday traffic peaks or other capacity overload (C-ITS 2017).

Traditionally, the road operators perform traffic management providing information to humans who drive vehicles. With the shift towards providing information to software that drives the automated vehicle this will change significantly. These changes and the impact on the role and responsibilities of road operators were discussed recently in EU EIP 4.2 Workshop in Utrecht (EU EIP 2017).

The main conclusion was that a simple translation of the current messages to humans to messages for machines will not be adequate without rethinking the original purposes of the various traffic management measures. As complex as that may seem, traffic management in a mixed environment may be even more complex when road operators have to consider both (partially) automated vehicles and human driven vehicles. So when considering traffic management for automated vehicles there are two main challenges:

- How will the nature of traffic management change when it is directed at automated vehicles?
- What is the transition strategy from the current situation to future situations that include mixed traffic?

Goals of traffic management

Today the over-arching goals are 'no casualties, no congestion and no emissions'. The goals are not likely to change with the introduction of automated driving, but the procedures and methods are likely to change. The roles and responsibilities remain the same, and the road authorities and operators have to set the goals for traffic management.

Traffic Circulation Plans and Traffic Management Plans will need to be deployed differently in the future. Traffic management has to be seen as an integral part of overall mobility management. The automated vehicles should be supported only if they have positive impact on mobility (safety, environment) i.e. by facilitating new services (MaaS, shared mobility, DRT Public Transport). Traffic Management has to be approached from collective perspective, but in best case the collective and individual goals (i.e travel time from origin to destination, length of the trip) can be aligned.

Traffic Management in the transitory phase

The transitory phase or mixed fleet situation is predicted to be very long. Therefore, the road authorities need to prepare their traffic management for a situation where some of the vehicles are automated and some are not. The instruments and processes have to be developed accordingly, to allow for both manual and automated driving.

The foreseen development of Traffic Management processes and methods participants will have the impacts on public acceptance, transportation demand, other road users, interface with other transport modes, congestion and network planning. Bodies of Traffic Management need new systems and new skills, training and new equipment in order to build an efficient Traffic Management system for CAD, even with new business models.

New Opportunities for Traffic Management

With the introduction of automated driving, new possibilities arise for the traffic management.

Before the trip, the driver could choose the parameters for the route from different variables such as duration, length, scenery and environmental impact, and willingness to use longer route due to environmental reasons, or a possible reward. The automated vehicle would be directed to a shortest route or route with low occupation or with lower emissions, accordingly.

It is assumed that for all automated vehicles the origin and destination are known, as this information is present in the vehicle when it commences the trip (the security and privacy issues have to be solved). Knowing the origin and destination is important to facilitate effective routing of the vehicles.

Recommendations for Traffic Management of Automated Vehicles

Opening up the discussion and cooperation between the industry and road authorities and operators is a must for securing the desired development of traffic management in the era of automation. The need for harmonisation of traffic management strategies and practises, both on a local and international level, would be beneficial, as well as the digitalisation of the Traffic Management Plans into a standardized exchangeable data. This way the plans can be well communicated, understood and, when required, timely executed. The C-ITS Platform Phase II Final Report gives the following recommendations. The Traffic Managers should develop additional standards for which:

- enable the local policy for traffic management roles and responsibilities to be accessible on a national level;
- are interoperable and trusted for automated driving on a European level;
- combine with other standards under development such as the Traffic Management set of standards from the CEN WG on Urban ITS, METR (Management for Electronic Traffic Regulations), and LDM (Local Dynamic Map);
- will be investigated (standards and specifications) to become (eventually) mandatory or included within a Delegated Regulation.
- will foster cooperation between the different players and enable coopetition for the development of the common tools and building blocks.

To start piloting digital TMPs, TCPs and the building blocks, in the comprehensive TEN-T Road Network, including urban nodes. Road authorities/operators should be in charge, acting as the 'orchestra conductor', being the only one to have a “global system” view of the road network and its performance, including safety.

The most harmonised traffic management procedures take place in the motorway network, across borders, along the comprehensive TEN-T Corridors. The tools to develop the Cooperative Traffic Management Services will take stock of the TEN-T ITS Policy, its Regulations and the outcomes of the CEF ITS Corridors and the deployment of the C-ITS Pilots of C-Roads.

Traffic management procedures can differ from small-medium sized cities to major urban nodes. They can even differ between two similar cities in the same country, depending of the city's strategic mobility. The complexity to operate and maintain ITS applications has implications on budget and resources. To ensure flexibility, the tools to develop the Cooperative Traffic Management Services should be modular, scalable, replicable and compliant with standards.

7.4 Regulatory Authorities

The evolving role of regulatory authorities

The regulatory authority is in all Member States the government ministry, for example Ministry of Transport and Telecommunications in Finland, which prepares the political and strategic guidelines and legislation within its branch openly and in collaboration with the stakeholders. One of the core goals of transport and communications policy is guidance of the agencies within the Ministry's administrative branch, i.e. the Finnish Transport Agency, the Transport Safety Agency and the Finnish Communications Regulatory Authority. The Ministry guides their operation and makes sure that their performance targets and operations are in line with the Government Programme. The current main responsibilities of the regulatory authorities in some EU Member States are represented in Table 25.

Table 6. Responsibilities of regulatory authorities in some EU Member States

Regulatory Authority	Main responsibilities
United Kingdom: UK Department for Transport (DfT)	The Department for Transport is the government department respon-sible for the English transport network. The responsibilities of DfT include providing policy, guidance, and funding to local authorities to help them run and maintain their road networks, improve passenger and freight travel, maintaining and operating around 4,300 miles of the motorway and trunk road network through Highways England, promot-ing lower carbon transport, encouraging the use of new technologies and maintaining high standards of safety and security in transport.
France: La Sécurité Routière	La Sécurité Routière is responsible for public health and the protection of individuals. The main road safety campaigns, the evolution of regulations and means of control introduced by the government are intended to encourage drivers to comply with the Highway Code, in particular to control their speed, share the route between the different categories of users (motorists, pedestrians, two-wheelers, the weakest often being victims of serious accidents), etc. From 1972, the way of managing this road safety has changed profoundly and the actions carried out began to find an efficiency, with a reduction of the number of killed on the roads. The measures include education, awareness courses and regulatory measures

Netherlands: Ministry of Infrastructure and the Environment (I&M), RDW (Dutch Vehicle Authority)	The Directorate-General for Mobility and Transport focuses on the continued development of the network quality of airways, waterways, railways, the road network, harbours and ports and safeguards their safe and sustainable use by travellers and the transport sector. RDW is the Netherlands Vehicle Authority, its asks include licensing of vehicles and vehicle parts, supervision and enforcement, registration, information provision and issuing documents, in close cooperation with various partners in the mobility chain.
Germany: The German Federal Ministry of Transport and Digital Infrastructure (BMVI)	The Ministry comprises the Directorates and 63 executive agencies. The Road Traffic and Transport Directorate deals with subjects such as obtaining a driving licence, road user behaviour, the registration of vehicles including the technical requirements and commercial passenger and freight transport. At the same time, the Road Safety Programme is constantly updated.
Finland: The Ministry of Transport and Communications (MINTC), the Finnish Transport and Communications Agency	The Ministry prepares the political and strategic guidelines and legislation within its branch. Transport and communications policy aims to ensure, by means of legislation, smoothly running everyday life as well as mobility of information, goods and people.. The Finnish Transport and Communications Agency is responsible for transport licences, competences, supervision, and safety. Finnish Transport Infrastructure Agency (FTIA) is an expert agency concentrating on planning, developing, and maintaining road, rail, and maritime transport infrastructure and on the coordination of transport and land-use. The traffic control tasks for road traffic, rail traffic, and maritime routes are dealt with by the Traffic Management Finland Group, a state-owned company with a special mission. FTIA will order services for traffic control from the company. The regional maintenance of roads will continue to be the responsibility of Finland's ELY Centres. FTIA will deal with the implementation of the national level of service. Daily road maintenance will be handled by contractors based on competitive tenders.
Sweden: Trafikverket, The Swedish Transport Administration	Trafikverket, The Swedish Transport Administration is responsible for long-term planning of the transport system for all types of traffic, as well as for building, operating and maintaining public roads and railways. The Swedish Transport Administration is also responsible for administering the theoretical and driving tests needed to receive a driving licence and taxi driver badge, as well as the theoretical test for the professional know-how needed for a transport licence and certificate of professional competence.

The National Regulatory Frameworks have evolved during the time when automation was only a remote possibility. A large number of Member States have either started or a planning to start regulatory process which will introduce the necessary modifications to the existing regulations, or even introducing new elements. The National Regulations cover typically driver behaviour and driving licence (National traffic rules, civil and criminal law, in particular for ensuring road-safety), and the permissions for testing automated vehicles on open roads including possible derogations to the normal traffic rules. Furthermore, a large number of other areas are impacted through EU and UNECE regulations.

Consequently, introduction of CAD will have an impact on the future key duties and responsibilities of regulatory authorities in all Member States and in all these areas. In the following chapter we focus on the impact on national regulations, and the areas where the ongoing work in the UNECE and other EU and international bodies will have an impact at national level.

Driver training and driving licence

Automated vehicles will blur the traditional distinction between rules applying to drivers (mainly national traffic rules) and rules applying to vehicles (mainly harmonized EU vehicle approval legislation). Driver training is needed in particular to ensure that the driver is not confused or does not misuse the system (e.g. doing secondary tasks, overconfident with vehicle capabilities "Autopilot syndrome"). The national regulators need to identify if there is a need for changing the driver training and driving school programs.

Roadworthiness

It can be expected that the EU Roadworthiness Directive 2014/45 needs to be updated. It may be that the current roadworthiness test format would be insufficiently sophisticated to cater for highly or fully automated vehicles. National Road Authorities have to participate in the work of UNECE and other relevant EU and international bodies in order to bring in their views and to contribute to the decisions on the renewal of the EU Roadworthiness Directive 2014/45.

Testing on open roads

The applicable legislation for testing of highly automated vehicles on open roads is mainly the national traffic law (traffic rules). Derogations to the normal traffic rules are generally possible and issued by the Member State authorities as allowed by the amended 1968 Vienna Convention, as discussed above.

However, it is not possible to test all possible real world scenarios before allowing vehicles on the market. Therefore, more cooperation including sharing of results is needed. The best what can be obtained at this stage would be to establishing an EU-level mechanism to better coordinate open road testing and exchange on lessons learnt and sharing of results.

The 2018 EC Communication on Automated Mobility (EC 2018a) includes an Action to set up such a European Platform, grouping all relevant public and private stakeholders to coordinate open road testing making the link with pre-deployment activities. The ToR will be published still this year (2018). The format could be similar to the C-ITS platform with different Working Groups, and the focus of the platform could be on defining a European testing agenda (priority use cases, corridors for testing) including:

- Definition of common KPIs and methodology for Impact Assessment
- Common strategy and guidelines for sharing data of large-scale testing
- Access and exchange of data (public/private, vehicle/infrastructure)

The Regulatory Authorities of all interested Member States should participate in the work of the European Platform being set up by the EC to coordinate open road testing as an action of the Communication on Automated Mobility.

Type Approval, Testing and homologation

Currently, type homologation can be done once in a European country and still be valid in other countries. It may happen that automated vehicles will be allowed to operate only on specific types of roads and for certain weather conditions (Operational Design Domains, see Chapter 4). The ODDs will be defined separately for each automation use case, and should be defined together by road authorities/road operators with the vehicles manufacturers to ensure safe operating conditions for their systems. This cooperation was already started in a joint EU EIP 4.2 – L3Pilot Workshop which took place in Athens on 25 October 2018 (EU EIP 2018).

Furthermore, UNECE’s Global Forum on Road Traffic Safety (WP.1), has adopted in October 2018 a non-binding legal resolution serving as a guide for the countries which are Contracting Parties to the 1949 and 1968 Conventions on Road Traffic in relation to the safe deployment of highly and fully automated vehicles in road traffic.

The resolution offers recommendations to ensure the safe interaction between automated vehicles, other vehicles and more generally all road users, and stresses the key role of human beings, be they drivers, occupants or other road users.

UNECE’s World Forum for the Harmonization of Vehicle Regulations also established a new Working Party on Automated/Autonomous and Connected Vehicles which had its first meeting on 25-28 September 2018), in which it started to address a variety of technical issues, such as technical requirements; cyber security and software updates; and innovative testing methods, in particular the use of simulations.

Therefore, it is imperative for the regulatory authorities of the Member States to participate in the work of UNECE and other EU and international bodies on the work for the renewal of the UNECE type approval system, in particular the work of the new Working Party on Automated/Autonomous and Connected Vehicles. When there will be, based on this work, updates to the EU Type Approval System, they have to be introduced to the national legislation in order to allow sales and operations of commercial automated vehicles (interoperable within Europe, type approved in any EU country)

8 Conclusions

This report studies the regulatory framework, likely take-up and fleet penetration, Operational Design Domains (ODD) and related deployment costs, mobility, transport policy, economy and other impacts as well as the changes in roles and responsibilities of road operators and authorities in Finland for five different use cases of highly automated (Level 4) driving. The time horizon of the study was up to 2040.

The study does not, however, provide a comprehensive assessment about the impacts on the transport system as a whole.

Concerning the legal frameworks and the strategies of regulatory authorities, the regulatory responsibilities are split amongst Member States and the EU. The challenge facing the authorities is how to develop a coherent legal framework for some vehicles that have not yet been built. The automotive industry is moving on from the testing and piloting stage, which is based on national derogations to type-approved commercially available automated vehicles.

There is already a very extensive regulatory framework at the EU level for the type approval of vehicles and their roadworthiness (Directive 2007/46/EC, the 1968 Vienna Convention on Road Traffic and the Directive 2006/126/EC on driving license). The national regulations typically cover driver training and driving licences. The automated vehicles' tests are normally authorized under experimental licenses with various degrees of responsibilities. There is a lot of uncertainty, however, on up to what SAE level testing of vehicles is allowed. In more and more Member States, remote supervision (driver not in the vehicle) is or will be allowed.

Concerning deployment, this report is based on current knowledge of the actions required from road operators as well as national and local authorities and stakeholders either to provide the ODDs for the automated driving use cases or to cope with the impacts of automated driving. The ODDs are in a crucial position, determining the parts of the road and street network, and the times, when vehicles can be used in the automated mode. The ODDs are dependent on the capabilities of the automated vehicles, and especially on the sensors and artificial intelligence (AI) utilised. It is very likely that the capabilities of the sensors and AI will dramatically increase during the next decades while at the same time their costs and prices will be reduced due to mass production. Hence, it is also likely that the ODDs will also extend a lot for highly automated driving use cases, increasing the coverage of ODDs. An important driver for the development will be the need of the automated vehicle manufacturers to provide continuity for the ODDs – a customer does not want a vehicle, which requires the human vehicle occupant to take control of the vehicle every now and then because the vehicle's ODD suddenly terminates due to an intersection, a roadworks, a wrongly parked vehicle, a rain shower or some other situation easily managed by a human driver. The customer most likely wants a vehicle that can manage a large part of the journey by itself so that the vehicle occupants can utilise the travel to other uses than driving.

This study produced a proposal for a list of attributes of ODDs for highly automated vehicles. This list contains many attributes related to physical road infrastructure, and also quite a few on digital infrastructure. The attributes were also classified according to whether they are static or dynamic in nature.

The industry is reluctant at this phase of fast technological developments and emerging commercial competition to provide details of their vehicles' capabilities and related ODDs in the near and far future. Hence, this report is based on documented knowledge from research projects, automated vehicle trials and pilots, discussions in various international platforms and congresses, and standardisation bodies. Thereby, the background information is not on a fully solid ground. With regard to the situation in 2040, the information is even on a more shaky ground as the future projections have often been based on educated guesses by the authors, supported by the expertise of the steering group and the participants of the two workshops organised during the study project, as well as any relevant literature.

The gaps in knowledge highlight the importance of research and piloting, which will increase our knowledge of the ODDs, technology developments, sensor capabilities, and impacts of highly automated driving.

All results of this study can not be transferred as such to other countries. The results are based on detailed knowledge of the road, street and telecommunications networks, vehicle fleets, regulatory environment, weather and traffic conditions, and the economics in Finland.

According to the estimates of this study, the fleet penetrations of the highly automated vehicles will be very low (from 0.8 to 8.2 % in the optimistic scenario) in 2030, and that the major impacts on mobility, safety, efficiency and environment would materialise by 2040. This is primarily due to the slow updating cycle of the Finnish vehicle fleet, which, however, could be accelerated with the help of incentives and regulations. To support the uptake of automated vehicles among companies and citizens, the ODD coverage needs also to be large enough with regard to road networks and external conditions to attract the customers to buy such vehicles.

Remote supervision of individual highly automated vehicles and fleets of them will be an essential building block in the operation of public transport, taxi, and freight transport services. Much effort is still needed to develop such remote supervision services so that they can safely operate fleets of automated vehicles in cases of sudden termination of ODD for a vast number of vehicles at the same time, for instance in the case of a snow storm.

Unless the automotive and IT industry will extend the ODDs of the vehicles with more capable sensing and AI, the provision of extended ODDs is largely depending on the actions of the network operators. A high cost element will be the provision of 3D HD maps including LIDAR point clouds with continuous updates. These costs are likely covered mostly by service providers and then their customers, although at least road structure related mapping is to be financed by road operators. Provision of safe harbours along the roads and street will also carry high costs especially on roads outside urban areas. Provision of low latency broadband connectivity will also cause high costs on roads and areas without existing fibre optic cabling. With regard to the different road networks, additional high cost elements will likely be the following assuming the current knowledge about the ODDs:

- Motorways and similar roads - enhanced snow removal, provision of safe harbours in addition to existing shoulders
- Terminal connections – signs and barriers for access control
- Urban streets : –provision of VMS or C-ITS warnings, and real time situational picture

It has to be pointed out, however, that the costs needs depend totally on the development of the ODD features for the different highly automated driving use cases in the future. As indicated earlier, this in turn depends on the development of the capabilities and costs/prices of the sensors and software. Thereby, the costs and deployment roadmaps indicated in this report should not be used to steer any major investments.

With regard to the impacts of highly automated driving on mobility, safety, efficiency, environment and more generally the transport system and land use, the impacts hinge on whether the automated vehicles will be primarily used for shared or private use. In private use, the highly automated vehicles will provide high quality mobility for the users, but likely increase urban sprawl, vehicle kilometres driven, congestion, environmental burden and exposure for road crashes. In shared use and good availability, the automated vehicles will likely bring about good mobility, reduced need of parking spaces, better efficiency, and decreased environmental burden. Highly automated driving will reduce crash risks and provide mobility for people without driving license or incapability to drive a vehicle.

Connected and highly automated vehicles will on one hand enhance traffic management via better probe vehicle data and possibilities for tailored traffic management measures, and on the other hand require new development paths to enable dynamic management of large fleets of automated vehicles

The effects on employment and economy will be considerable but difficult to predict with certainty.

Concerning the roles and responsibilities of the road operators and authorities, automation will have profound impact on road operators of national road network, and some impacts as well on the road operators of street network of cities and the bodies of traffic management. The most profound impact will be on the roles and responsibilities of the regulatory authorities, in particular regarding the EU and international type approval, testing and homologation regulations. Currently, type homologation can be done once in a European country and can still be valid in other countries, and this should be the case for automated vehicles, too. The UNECE's World Forum for the Harmonization of Vehicle Regulations established a new working party on automated/autonomous and connected vehicles, which had its first meeting on 25-28 September 2018. It is imperative for the regulatory authorities of the EU member states to participate in this work.

Finally, it is evident that wide cooperation and constructive dialogue are needed between the stakeholders involved. This means on one hand, the discussions between automotive industry, road operators and regulatory bodies. On the other hand, such cooperation and dialogue are also needed between national, regional, and local road operators and authorities. The move into automated transport is a huge step in the development of the transport system, which should be taken in a synchronized and coordinated manner to achieve its full benefits.

9 References

5G Action Plan, 2018. 5G for Europe Action Plan. European Commission. 2018. https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan

5GAA 2016. The Case for Cellular V2X for Safety and Cooperative Driving. 5G Automotive Association. 2016. 8 p. http://5gaa.org/5gaa-in-motion/news/#white-papers

5GAA 2018. 5G Automotive Association website. 5gaa.org/

85/374/EEC 1985. Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products, 1985. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31985L0374

Alonso Raposo, M., Ciuffo, B., Makridis, M. and Thiel, C. 2017. The r-evolution of driving: from Connected Vehicles to Coordinated Automated Road Transport (C-ART), Part I: Framework for a safe & efficient Coordinated Automated Road Transport (C-ART) system, EUR 28575 EN, doi:10.2760/225671.

Alonso Raposo, M., Krause, J.; Després, J.; Mourtzouchou, A.; Ciuffo, B.; Saveyn, B.; Thiel, C.; Krasenbrink, A.; Galassi, C.; Levati, L.; Grosso, M.; Fernández Macías, E., 2018. An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills. 211 p. doi: 10.2760/007773.

Amelink, M. 2018. SOCRATES2.0 Project setup & evaluation. Presentation made at ITS World Congress, Copenhagen, 17-21 September 2018. 14 p.

van Arem, B. 2018. Spatial Impacts of Automated Driving. Presentation at the Strategic Innovation Promotion Program - Innovation of Automated Driving for Universal Services (SIP-adus) workshop, Tokyo, 13-15 November 2018.

Arnaout, G. and Bowling, S. 2011. Towards reducing traffic congestion using cooperative adaptive cruise control on a freeway with a ramp. Journal of industrial Engineering and Management, 4(4), pp. 699-717.

Arola, T.; Antikainen, P. 2017. Liikenteen automaation ja robotiikan kehittämistoimenpiteiden tiekartta 2017-2019. Ministry of Transport and Communications. 2017. https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/79868/10-2017%20Liikenteen%20automaation%20ja%20robotiikan%20kehittamistoimenpiteiden%20tiekartta%202017-2019.pdf?sequence=1&isAllowed=y [Finnish]

ASTAZero 2018. AstaZero AB. 2018. http://www.astazero.com/ [Accessed 7 November 2018]

Atkins 2016. Research on the Impacts of Connected and Autonomous vehicles (CAVs) on Traffic Flow. Summary Report. Department for Transport, May 2016. 57 p.

Autovista 2018. France to amend legislation for autonomous vehicle trials (03 April 2018). Autovista Group. 2018. https://www.autovistagroup.com/news-and-insights/france-amend-legislation-autonomous-vehicle-trials [Accessed 7 November 2018]

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

Bierstedt, J., Gooze, A., Gray, C., Peterman, J., Raykin, L. and Walters, J., 2014. Effects of next-generation vehicles on travel demand and highway capacity. FP Think Working Group, University of Princeton pp.10-11.

Bishop, R. 2018. Statement made at the ITFVHA (International Trask Force on Vehicle-Highway Automation) 22nd Annual Meeting in Copenhagen, 16 September 2018.

Blanco, M.; Atwood, J.; Russell, S.; Trimble, T.; McClafferty, J. & Perez, M. 2016. Automated Vehicle Crash Rate Comparison Using Naturalistic Data. Final Report Delivered by the Virginia Tech Transportation Institute. January 2016. 88 p.

BMVI 2018. Automated and Connected Driving. Federal Ministry of Transport and Digital Infrastructure. https://www.bmvi.de/EN/Topics/Digital-Matters/Automated-Connected-Driving/automated-and-connected-driving.html [Accessed 7 November 2018]

Buckley, S. 2018. Shaping a World of Shared Automated Vehicles. WSP presentation, October 25 2018. 76 p.

BusinessKorea 2017. World's Largest Test Bed for Self-driving Cars to Be Opened in Korea (May 8, 2017). BusinessKorea Co., Ltd. http://www.businesskorea.co.kr/news/articleView.html?idxno=18018 [Accessed 7 November 2018]

C-ITS 2017. C-ITS platform phase II. Cooperative Intelligent Transport Systems towards Cooperative, Connected and Automated Mobility. European Commission. 2017. 127 p. https://ec.europa.eu/transport/sites/transport/files/2017-09-c-its-platform-final-report.pdf

CAR 2 CAR 2007. CAR 2 CAR Communication Consortium Manifesto. V1.1. Car 2 Car Communication Consortium. 2007. 94 p. https://www.car-2-car.org/fileadmin/documents/General_Documents/C2C-CC_Manifesto_Aug_2007.pdf

Carslaw, D.C., Goodman, P.S., Lai, F.C.H and Carsten, O.M.J. (2010). Comprehensive analysis of the carbon impacts of vehicle intelligent speed control. Atmospheric Environment, 44: 2674-2680.

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.

CARTS 2014. Committee on Autonomous Road Transport for Singapore. Government of Singapore. https://www.mot.gov.sg/news-centre/news/Detail/Committee-on-Autonomous-Road-Transport-for-Singapore [Accessed 7 November 2018]

Cavoli, C.; Phillips, B.; Cohen, T. & Jones, P. 2017. Social and behavioural questions associated with Automated Vehicles. A Literature Review. University Transport Institute. London, January 2017.124 p. https://www.ucl.ac.uk/transport-institute/pdfs/social-and-behavioural-literature-review.pdf [Accessed 27 December 2018]

CCAM 2018. An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe, Maintenance and Repair, https://publications.europa.eu/en/publication-detail/-/publication/60258b54-597c-11e8-ab41-01aa75ed71a1/language-en

CEDR 2018. National Road Authority CAD strategy 2018-28. Connected and Automated Driving Working Group, CEDR. 8 p.

http://www.cedr.eu/download/Publications/2018/NRA-CAD-strategy-2018-final-v2.doc [Accessed 7 December 2018]

Chan, C.-Y. 2017. Advancements, prospects, and impacts of automated driving systems. International Journal of Transportation Science and Technology, 2017. www.elsevier.com/locate/ijtstasdasd

China Money Network 2018. China Issues National Autonomous Vehicle Rules In Bid To Catch US (April 13, 2018). China Money Network Limited. 2018. https://www.chinamoneynetwork.com/2018/04/13/china-releases-first-national-guidelines-on-autonomous-vehicle-road-testing [Accessed 7 November 2018]

CIO 2018. China issues nationwide guidelines for road-testing of autonomous vehicles. CIO Network Pte Ltd. 2018. https://www.opengovasia.com/china-issues-nationwide-guidelines-for-road-testing-of-autonomous-vehicles/

Citymobil, 2018. Citymobil Web site, 2018. http://www.citymobil-project.eu/

CityMobil2 2015. Vantaa ex-post evaluation report. CityMobil2 Deliverable D25.3, 2015. 75 p.

CMVSS 2018. Motor Vehicle Safety Regulations (C.R.C., c. 1038). Minister of Justice, Canada. 2018. 288 p. http://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._1038/

CPUC 2018. California Public Utilities Commission. 2018. http://www.cpuc.ca.gov/ [Accessed 7 November 2018]

DAVI 2018. Dutch Automated Vehicle Initiative. davi.connekt.nl/ [Accessed 7 November 2018]

Digital Trends (2016). MIT’s NuTonomy aims to bring self-driving taxis to Singapore by 2018. https://www.digitaltrends.com/cars/nutonomy-driverless-taxi-singapore/ [Accessed 17 Jul. 2018].

Directive 2002/58/EC 2002. Directive 2002/58/EC of the European Parliament and of the Council of 12 July 2002 concerning the processing of personal data and the protection of privacy in the electronic communications sector (Directive on privacy and electronic communications). European Commission. 2002. 11 p. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002L0058

Directive 2006/126/EC 2006. DIRECTIVE 2006/126/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 December 2006 on driving licences (Recast) (Text with EEA relevance). 43 p. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32006L0126

Directive 2007/46/EC 2007. Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) (Text with EEA relevance). 2007. 160 p.
https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32007L0046

Directive 2008/96/EC 2008. Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management. 2008. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32008L0096

Directive 2009/103/EC 2009. Directive 2009/103/EC of the European Parliament and of the Council of 16 September 2009 relating to insurance against civil liability in respect of the use of motor vehicles, and the enforcement of the obligation to insure against such liability (Text with EEA relevance). 2009.

https://publications.europa.eu/en/publication-detail/-/publication/510d4015-9752-4295-8a7f-774575a1396d/language-en

Directive 2014/45/EU 2014. Directive 2014/45/EU of the European Parliament and of the Council of 3 April 2014 on periodic roadworthiness tests for motor vehicles and their trailers and repealing Directive 2009/40/EC Text with EEA relevance. 78 p. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0045

DfT 2015. The Pathway to Driverless Cars: A detailed review of regulations for automated vehicle technologies. Department for Transport. February 2015. 191 p. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401565/pathway-driverless-cars-main.pdf

Dutch EU Presidency 2016. Declaration of Amsterdam on Cooperation in the field of connected and automated driving. 9 p. https://www.regjeringen.no/contentassets/ba7ab6e2a0e14e39baa77f5b76f59d14/2016-04-08-declaration-of-amsterdam---final1400661.pdf

EC 2017a. Communication on "Building a European Data Economy". European Commission. 2018. https://eur-lex.europa.eu/content/news/building_EU_data_-economy.html

EC 2017b. C-ITS Platform Final report Phase II. Cooperative Intelligent Transport Systems Towards Cooperative, Connected and Automated Mobility. European Commission, September 2017. 127 p.

EC 2018a. Commission Communication (2018) On the road to automated mobility: An EU strategy for mobility of the future. European Commission. 2018. https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180283_en.pdf

EC, 2018b. Intelligent transport systems. National Access Points. European Commission, 12.7.2018. https://ec.europa.eu/transport/themes/its/road/action_plan/nap_en [Accessed 7 December 2018]

EC 2018c. Commission Communication (2018) Towards a common European data space. European Commission. 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0232

EC 2018d- Commission Staff Working Document. Guidance on sharing private sector data in the European data economy Accompanying the document Communication from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the Regions "Towards a common European data space". European Commission. 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018SC0125

Edwards, M.; Seidl, M.; Tress, M.; Pressley, A.; Mohan, S. 2017. Final report: Study on the assessment and certification of automated vehicles. Euroepan Commission. 2017. 114 p. https://ec.europa.eu/growth/content/final-report-study-assessment-and-certification-automated-vehicles_en

ERTRAC 2017. Automated Driving Roadmap. Version 7.0, Date: 29/05/2017. ERTRAC Working Group "Connectivity and Automated Driving". 54 p. http://www.ertrac.org/uploads/images/ERTRAC_Automated_Driving_2017.pdf

EU EIP 2016. EU-EIP Activity 4.2 Facilitating automated driving, Task 1: Identification of needs towards network operators. v1.01. EU EIP, 31.12.2016. https://www.its-platform.eu/filedepot_download/1950/5833 [Accessed 7 December 2018]

EU EIP, 2017. Workshop report (15–16 March 2017, Utrecht): Facilitating Connected & Automated Driving – a Road Operator's Perspective. Version: 1.0. 30.6. 2017, EU EIP.

EU EIP, 2018. Joint EU EIP 4.2 & L3Pilot stakeholder workshop - The impacts of automated driving, how to maximize the benefits, 25.10.2018, Athens. https://www.its-platform.eu/calendar/joint-eu-eip-42-l3pilot-stakeholder-workshop-impacts-automated-driving-how-maximize [Accessed 7 December 2018]

EUROCITIES, 2017. EUROCITIES Web site, 2017. http://www.eurocities.eu/eurocities/home

Flament, M. 2015. Regulatory needs and solutions for deployment of Vehicle and Road Automation (Draft2, VRA Project). European Commission. 62 p. https://cordis.europa.eu/docs/projects/cnect/7/610737/080/deliverables/001-D322RegulatoryNeeds1.pdf

FMVSS 1999. Federal Motor Vehicle Safety Standards and Regulations. U.S. Department of Transportation. 1999. https://icsw.nhtsa.gov/cars/rules/import/FMVSS/

Ford 2018. A matter of trust. Ford's approach to developing self-driving vehicles. 44 p. https://media.ford.com/content/dam/fordmedia/pdf/Ford_AV_LLC_FINAL_HR_2.pdf

FTA 2016. Operating philosophy. Finnish Transport Agency, 28.12.2016. https://www.liikennevirasto.fi/web/en/operating-philosophy#.W0SjytUzbX4. [Accessed 7 December 2018]

FTA 2018. Arctic Challenge. Finnish Transport Agency. 2018. Liikenne https://www.liikennevirasto.fi/web/en/e8-aurora/r-d/arctic-challenge#.W0tHt9UzbX4 [Accessed 7 November 2018]

GEAR 2030 (2017). High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union - FINAL REPORT. 74 p. https://ec.europa.eu/growth/content/high-level-group-gear-2030-report-on-automotive-competitiveness-and-sustainability_en

Geissler, T.; Kulmala, R. & Carsten, O. 2016. The evolution towards automated driving – Classification of impacts, review of assessments of automated driving functions, challenges for evaluation. In: Lu, M. (ed.) 2016, Evaluation of Intelligent Road Transport Systems: Methods and Results. IET, The Institution of Engineering and Technology.

General Motors 2018. 2018 Self-driving safety report. 33 p. https://www.gm.com/content/dam/company/docs/us/en/gmcom/gmsafetyreport.pdf

Gouvernement.fr 2017. Innover pour retrouver de la croissance. La nouvelle France industrielle. Gouvernement.fr. https://www.gouvernement.fr/action/la-nouvelle-france-industrielle [Accessed 7 November 2018] [French]

GOV.UK 2013. National Infrastructure Plan 2013. 152 p. Ref: ISBN 978-1-909790-57-5, PU1576. https://www.gov.uk/government/publications/national-infrastructure-plan-2013

GOV.UK 2015. The Pathway to Driverless Cars. Summary report and action plan. Department for Transport. 2015. 40 p. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/401562/pathway-driverless-cars-summary.pdf

GOV.UK (2) 2015. The Pathway to Driverless Cars. Testing automated vehicle technologies in public . https://www.gov.uk/government/publications/automated-vehicle-technologies-testing-code-of-practice [Accessed 7 November 2018]

GOV.UK 2018. Government to review driving laws in preparation for self-driving vehicles. https://www.gov.uk/government/news/government-to-review-driving-laws-in-preparation-for-self-driving-vehicles [Accessed 7 November 2018]

Government Offices of Sweden 2018. Conclusions from the Third High-Level Meeting on Connected and Automated Driving. Gothenburg, 18–19 June 2018. 16 p.

Grand View Research (2018). Self-driving Cars And Trucks Market Size | Industry Report, 2020-2030. https://www.grandviewresearch.com/industry-analysis/driverless-cars-market [Accessed 23 Jul. 2018].

Grave, R., 2017. The vehicle architecture of automated driving level 2/3. OpenSystems Media, 30.6.2017. http://www.embedded-computing.com/embedded-computing-design/the-vehicle-architecture-of-automated-driving-level-2-3 [Accessed 7 December 2018]

Hartmann, M.; Motamedidehkordi, N.; Krause, S.; Hoffmann, S.; Vortisch, P- & Busch, F. 2017. Impact of Automated Vehicles on Capacity of the German Freeway Network. ITS World Congress 2017 Montreal, October 29 – November 2. 13 p.

Hayden, J.; Graham, A.; Castle, J.; Williams, D. & Padden, J. 2018. Impacts of connected and automated vehicles on road safety in the UK. 25th ITS World Congress, Copenhagen, Denmark, 17-21 September 2018.

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.

ITF 2015. Urban Mobility System Upgrade: How shared self-driving cars could change city traffic. OECD, International Transport Forum, Corporate Partnership Board Report.

ITF 2017a. Managing the Transition to Driverless Road Freight Transport. OECD, International Transport Forum, Case-Specific Policy Analysis. 74 p.

ITF 2017b. Shared Mobility Simulations for Helsinki. OECD, International Transport Forum, Case-Specific Policy Analysis. 97 p.

Janssen, R.; Zwijnenberg, H.; Blankers, I. & de Kruijff, J. 2015. Truck platooning – driving the future of transportation. TNO, February 2015. 36 p.

Johnson, B. & Rowland, M. 2018. Automated and Zero Emission Vehicles. Transport Engineering Advice. Infrastructure Victoria & ARUP. REP/261257, Issue 1 July 2018. 209 p.

Johnson, L. and Fitzsimmons, M. (2018). Uber self-driving cars: everything you need to know. TechRadar. https://www.techradar.com/news/uber-self-driving-cars [Accessed 24 Jul. 2018].

Karjalainen, M. 2011. Tien parantamistoimenpiteiden kustannukset [Costs of road improvement actions]. Oulun seudun ammattikorkeakoulu, Rakennustekniikka, Insinöörityö. 65 p. + App. 7 p. [Finnish]

Kawashima, H. 2018. Personal view of ODD management in mixed traffic conditions. Presentation made at the Amsterdam Group and MLIT Meeting, ITS World Congress, Copenhagen, September 2018.

Kornhauser, A. 2018. The SmartDrivingCar R/Evolution. Some Comments/Questions. Presentation made at SAE Automated and Connected Vehicle Systems Testing Symposium, Greenville, SC, USA on June 20-21, 2018. 46 p.

Koskela, A. 2018. Aurora Borealis automated driving & intelligent infrastructure testing area – 1st results. Presentation given at NEXT-ITS3 A4 ICT Infrastructures meeting, Helsinki 22-23 August 2018. 22 p.

Kulmala, R.; Egemalm, Å.; Harrer, M.; Svensk, P.-O. & Rombaut, K. 2017. Highway Autopilot Physical and Digital Infrastructure. C-ITS Platform WG Physical and Digital Road Infrastructure. Brussels, 19 January 2017. 5 p.

KWM 2018. Shanghai Issues Regulations on Self-driving Cars Road Testing (March 2, 2018). King & Wood Mallesons. 2018. https://www.chinalawinsight.com/2018/03/articles/corporate/shanghai-issues-regulations-on-self-driving-cars-road-testing [Accessed 7 November 2018]

L'Observatoire Cetelem, 2016. Voiture autonome: Les automobilistes prêts à lâcher le volant pour la silicon valley. L'Observatoire Cetelem, March 2016. https://observatoirecetelem.com/wp-content/uploads/2013/07/observatoire-cetelem-automobile-2016.pdf [Accessed 7 December 2018]

La Sécurité Routière 2018. Ministére de l'intérieur. 2018. http://www.securite-routiere.gouv.fr/ [Accessed 7 November 2018] [French]

de Looff, E.; Homem de Almeida Correia, G.; Cranenburgh, S.; Snelder, M. & van Arem, B. 2018. Potential changes in value of travel time as a result of vehicle automation: a case-study in the Netherlands. 15 p.

Malmivuo, M. 2010. Maanteiden talvihoidon kokonaisedullisuus Suomessa [Cost-efficiency of winter maintenance on public roads in Finland]. Liikenne- ja viestintäministeriön julkaisuja 34/2010. 54 p. [Finnish]

MLIT 2018. MLIT Moves Towards New Guidelines for Autonomous Driving. Mar. 28, 2018, Nikkan Jidosha Shimbun Inc., Bonuterra Inc. https://www.japanautomotivedaily.com/2018/03/28/mlit-moves-toward-new-guidelines-for-autonomous-driving/ [Accessed 7 November 2018]

Mudge, R.; Kornhauser, A. & Hardison, M. 2018. Market Framework and Outlook for Automated Vehicle Systems. Society of Actuaries. 44 p. + app. 4 p.

NACTO, 2017. Blueprint for Autonomous Urbanism. 60 p. National Association for City Transport Officials (NACTO), Fall 2017. https://nacto.org/publication/bau/blueprint-for-autonomous-urbanism/ [Accessed 7 December 2018]

Nissin, O. 2018. EZ-10-operointiolosuhteet [EZ-10 operational domain]. Excel file via e-mail Nissin-Kulmala 26 July 2018.

NHTSA 2017. Automated Driving Systems, A Vision for Safety. National Highway Traffic Safety Administration. 2017. 36 p. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

NHTSA 2018. National Highway Traffic Safety Administration. https://www.nhtsa.gov/

Ohnsman, A. 2018. Why Waymo Is Worth A Staggering $175 Billion Even Before Launching Its Self-Driving Cars. Forbes 7 August 2018. https://www.forbes.com/sites/ alanohnsman/2018/08/07/why-waymo-is-worth-a-staggering-175-billion-even-before-launching-its-self-driving-cars/#6c7772c5dd3a. [Accessed 13 August 2018].

Oshima, D. 2018. Presentation at Special Interest Session SIS53 impact assessment of automated vehicles on traffic flow and environment. 25th ITS World Congress, Copenhagen, Denmark, 17-21 September 2018.

de Ponte Müller, F. 2017. Survey on Ranging Sensors and Cooperative Techniques for Relative Positioning of Vehicles. Sensors (Basel). 2017;17(2):271. Published 2017 Jan 31. doi:10.3390/s17020271

Pilli-Sihvola, E.; Miettinen, K.; Toivonen, K.; Sarlin, L.; Kiiski, K.; Kulmala, R. et al. 2015. Robots on land, in water and in the air. Ministry of Transport and Communications. 2015. 48 p. https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/78339/Julkaisuja_14-2015.pdf?sequence=1

POLIS, 2018. POLIS Network Web site, 2018. https://www.polisnetwork.eu/

RDW 2018. Self-driving vehicles. https://www.government.nl/topics/mobility-public-transport-and-road-safety/self-driving-vehicles [Accessed 7 November 2018]

Regulation No 79 2008. Regulation No 79 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to steering equipment. 27 p. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A42008X0527%2801%29

Regulation (EC) No 715/2007 2007. Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information (Text with EEA relevance). European Commission. 2007. 16 p. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007R0715

Regulation (EU) 2016/679 2016. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) (Text with EEA relevance). European Parliament. 2016. 88 p. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.119.01.0001.01.ENG

Regulation No. 116 2014. UN Regulation No. 116 and innovative vehicle alarm systems / anti-theft systems. UNECE. 2014. 2 p. https://www.unece.org/fileadmin/DAM/trans/doc/2014/wp29grsg/GRSG-107-08e.pdf

RSC 2017. Mandate to CEPT to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz. Working Document. Radio Spectrum Committee, European Commission. 2017. 7 p. https://cept.org/Documents/ecc/39175/ecc-17-099_cept-mandate-on-its

RT 2016. France greenlights driverless car trials on public roads. Autonomous Nonprofit Organization “TV-Novosti”. 2016. https://www.rt.com/news/354683-france-driverless-car-trials/ [Accessed 7 November 2018]

Rämä, P.; Kuisma, S.; Steger-Vonmetz, C.; Vlk, T.; Page, Y.; Malone, K.; Wilmink, I.; Bärgman, J.; Macbeth, I.; Sumner, G.; Homem de Almeida Correia, G.; Gougeon, P.; Wilsch, B.; Barnard, Y.; Cizkova, T.; Alessandrini, A. & Nikolaou, S.

2018. Societal impacts of automated driving. CARTRE Coordination of Automated Road Transport Deployment for Europe, Deliverable D5.3, 28 September 2018. 86 p.

Saarenketo, T. 2018a. Roads for Intelligent Transport. Presentation at Interactive Symposium on Research & Innovation for Connected and Automated Driving in Europe, Vienna 19-20 April 2018. 8 s.

Saarenketo, T. 2018b. Discussion Saarenketo-Kulmala at ITS World Congress, Copenhagen, 16 September 2018.

Saarenketo, T. 2018c. Comments made to report draft on 17 December 2018.

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/

Sarkar, R. 2016. Transportation-As-A-System (TAAS) Presentation made at the Automated Vehicle Symposium, San Francisco, USA. July 19th 2016. 16 p.

Schoettle, B. 2017. Sensor Fusion: A Comparison of Sensing Capabilities of Human Drivers and Highly Automated Vehicles. The University of Michigan, Sustainable Worldwide Transportation. SWT-2017-12. August 2017. 45 p.

Schoettle, B. & Sivak, M. 2015. Potential Impact of Self-Driving Vehicles on Household Vehicle Demand and Usage. The University of Michigan, Sustainable Worldwide Transportation. SWT-2015-3. February 2015. 16 p.

Shladover, S. 2016. What "Self-Driving" Cars Will Really Look Like. Scientific American, June 2016. https://www.scientificamerican.com/article/what-self-driving-cars-will-really-look-like/ [Accessed 7 December 2018]

Shladover, S. 2018a. Presentation at Special Interest Session SIS53 impact assessment of automated vehicles on traffic flow and environment. 25th ITS World Congress, Copenhagen, Denmark, 17-21 September 2018.

Shladover, S. 2018b. Comments made to report draft on 20 December 2018.

Sivak, M. & Schoettle, B. 2018. Universal motion sickness countermeasure system. U.S. Patent US 9,862,312 B2, Jan.9, 2018. United States Patent and Trademark Office. 10 p. http://pdfpiw.uspto.gov/.piw?PageNum=0&docid=09862312&IDKey=0A36011EF4C5 [Accessed 19 December 2018]

SOCRATES 2.0 2018. Proposed cooperation framework & bottlenecks. Activity 2 – deliverable, June 2018. 116 p. https://socrates2.org/application/files/5415/3077/5353/Report_SOCRATES_Framework_Cooperation.pdf

State of California 2017. Autonomous Vehicle Disengagement Reports 2017. Department of Motor Vehicles. State of California. 2017. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/disengagement_report_2017 [Accessed 7 November 2018]

Sweden 2017. Government paves the way for self-driving vehicles. Government Offices of Sweden. https://www.government.se/articles/2017/05/government-paves-the-way-for-self-driving-vehicles/ [Accessed 7 November 2018]

Technology Review 2018. Beijing is letting its first driverless cars take to the roads (22 March 2018), https://www.technologyreview.com/the-download/610606/beijing-is-letting-its-first-driverless-cars-take-to-the-roads/ [Accessed 7 November 2018]

TechRepublic. (2017). General Motors to roll out fleet of self-driving taxis by 2019, ahead of Ford, Uber, and Waymo. https://www.techrepublic.com/article/general-motors-to-roll-out-fleet-of-self-driving-taxis-by-2019-ahead-of-ford-uber-and-waymo/ [Accessed 17 Jul. 2018].

Tientrakool, P. ; Ho, Y.C. and Maxemchuk, N.F. 2011. Highway capacity benefits from using vehicle-to-vehicle communication and sensors for collision avoidance. In Vehicular Technology Conference (VTC Fall), 2011 IEEE (pp. 1-5).

TM2.0 2018. Platform web site http://tm20.org/

Transport Systems Catapult 2017. Future Proofing Infrastructure for Connected and Automated Vehicles. Technical Report. February 2017. 75 p.

Transportstyrelsen 2014. Swedish Transport Agency. https://www.transportstyrelsen.se/en/road [Accessed 7 November 2018]

TrendForce (2018). Global Self-driving Taxi Market Will Grow at a CAGR of 81% from 2018 to 2023, Says TrendForce. https://press.trendforce.com/press/20180207-3062.html [Accessed 23 Jul. 2018].

Törnqvist, J. (2015). Telephone interview of senior research scientist Jouko Törnqvist, a specialist in road engineering at VTT Technical Research Centre of Finland, 16 February 2015.

Uchida, N. 2018. A Multi-agent Traffic Simulation to Predict the Impact of Automated Driving Systems on Safety. Presentation at the Strategic Innovation Promotion Program - Innovation of Automated Driving for Universal Services (SIP-adus) workshop, Tokyo, 13-15 November 2018.

UITP 2017. Autonomous vehicles: a potential game changer for urban mobility. Policy Brief 16/01/2017. https://www.uitp.org/sites/default/files/cck-focus-papers-files/PolicyBrief_Autonomous_Vehicles_LQ_20160116.pdf

UK Parliament 2017. Connected and autonomous road vehicles. House of commons library, Briefing paper Number CBP 7965, 12 June 2017. 30 p.

UN 1968. Convention on Road Traffic Vienna, 8 November 1968. https://treaties.un.org/Pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XI-B-19&chapter=11&Temp=mtdsg3&clang=_en

UNECE 2012. WP.29-How it Works, How to join It. United Nations Publications. 2012. http://www.unece.org/trans/main/wp29/publications/other_vehicles.html

UNECE 2016. UNECE paves the way for automated driving by updating UN international convention. 2016. https://www.unece.org/info/media/presscurrent-press-h/transport/2016/unece-paves-the-way-for-automated-driving-by-updating-un-international-convention/doc.html [Accessed 7 November 2018]

UNECE 2017. Proposal for the Definitions of Automated Driving under WP.29 and the General Principles for developing a UN Regulation on automated vehicles (2017). 11 p. https://www.unece.org/fileadmin/DAM/trans/doc/2017/wp29/ECE-TRANS-WP29-2017-145e.pdf U.S. DOT 2018. ITS Cost Elements. United States of America, Department of Transportation, Intellogent Transport Systems, Joint Program Office. https://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/Images/Reports/$File/CostElements%202015-02-11.xls [Accessed 23 October 2018]

Urban Circus & Ethos Urban 2018. Automated and Zero Emission Vehicles - How They Might Reshape Our Streets. May 2018.

U.S. DOT 2015. Beyond Traffic: US DOT's 30 Year Framework for the Future. Draft. US Department of Transportation, Washington, D.C.

U.S. DOT 2018. ITS Cost Elements. United States of America, Department of Transportation, Intellogent Transport Systems, Joint Program Office. https://www.itsknowledgeresources.its.dot.gov/ITS/benecost.nsf/Images/Reports/$File/CostElements%202015-02-11.xls

Verge 2018. Self-driving cars continue to face little resistance from the federal government. Vox Media, Inc. 2018. https://www.theverge.com/2018/3/5/17080824/dot-autonomous-vehicle-listening-session-washington [Accessed 7 November 2018]

Voege, T.; Godziejewski, B.; Grand-Perret, S.; Merat, N.; Rødseth, Ø.; van Schijndel-de Nooij, M. 2017. Connected and Automated Transport. Studies and reports. 85 p. https://ec.europa.eu/programmes/horizon2020/en/news/connected-and-automated-transport-expert-group-report

Waymo 2017. On the road to fully self-driving. Waymo Safety Report. 43 p. https://www.mtfchallenge.org/wp-content/uploads/2017/02/waymo-safety-report-2017-10.pdf

Wikipedia 2018. Traffic barrier. https://en.wikipedia.org/wiki/Traffic_barrier [Accessed 19 December 2018]

Wilmink, I., Janssen, W., Jonkers, E., Malone, K., van Noort, M., Klunder, G., Rämä, P., Sihvola, N., Kulmala, R., Schirokoff, A., Lind, G., Benz, T., Peters, H. and Schönebeck, S. 2008. Impact assessment of Intelligent Vehicle Safety Systems. Deliverable D4 of eIMPACT (Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe). http://www.eimpact.info/download/eIMPACT_D4_v2.0.pdf

Wilmink, I.; Calvert, S.; de Kievit, M.; Landen, T.; Zlocki, A. 2017. Exploration of impacts, constraints and enablers of automated vehicles on NRAs. DRAGON: Driving automated vehicle growth on national roads, Deliverable No 2.1, March 2017. 62 p.

World Economic Forum 2018. Reshaping Urban Mobility with Autonomous Vehicles. Lessons from the City of Boston. System Initiative on Shaping the Future of Mobility, in collaboration with The Boston Consulting Group. 34 p.

WP.1 2018. Global Forum for Road Traffic Safety (WP.1). http://www.unece.org/transport/areas-of-work/road-safety-forum/meetings-and-events/working-party-on-road-traffic-safety-wp1.html [Accessed 7 November 2018]

WVTA 2018. Technical harmonisation in the EU. European Commission. 2018. http://ec.europa.eu/growth/sectors/automotive/technical-harmonisation/eu_en [Accessed 7 November 2018]

Yagci, O. and Clewlow, R. 2016. Estimated energy impacts of automated vehicles: implications for policy makers. Presentation given at the Transportation Research Board 95th Annual Meeting, Washington, D.C., 10–14 January, 2016.

Zlocki, A.; Rösener, C. & Eckstein, L. 2018. A Traffic-based Method for Safety Impact Assessment of Road Vehicle Automation. Presentation at the Strategic Innovation Promotion Program - Innovation of Automated Driving for Universal Services (SIP-adus) workshop, Tokyo, 13-15 November 2018.