STUDY

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The impact of emerging technologies on the transport system

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RESEARCH FOR TRAN COMMITTEE

The impact of emerging technologies on the transport system

Abstract

This study provides an overview of the impact of Smart Mobility and their underlying emerging technologies on transport, the transport infrastructure and society. The main challenges for the deployment of Smart Mobility applications are identified and (policy) actions are defined that could be taken to overcome these challenges.

This document was requested by the European Parliament's Committee on Transport and Tourism.

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
ACES	Automation, Connectivity, Electrification, and Sharing
ADAS	Advanced Driver Assistance
AI	Artificial Intelligence
API	Application Programming Interface
ATM	Air Traffic Management
AV	Automated Vehicle
AVP	Automated Valet Parking
B2B	Business-to-Business
C-ACC	Cooperative Adaptive Cruise Control
CCAM	Connected Cooperative Automated Mobility
CEF	Connecting Europe Facility
CEN	Comité Européen de Normalisation
C-ITS	Cooperative Intelligent Transport Systems
CO_2	Carbondioxide
CRL	Certificate Revoke List
CTL	Certificate Trust List
DA	Delegated Act
DINA	Digital Inland Waterway Area
DTLF	Digital Transport and Logistics Forum
EC	European Commission
EFTI	Electronic freight transport information
ERTMS	European Rail Traffic Management System
ETD	European Technology Platform
ETSI	Eurpean Telecommunications Standards Institute
EU	European Union
GHG	Greenhouse Gases
GHz	Giga Herz
GLOSA	Green Light Optimised Speed Advisory
GDP	Gross Domestic Product
H2020	Horizon 2020

HD	High definition
HGV	Heavy Goods Vehicles
HPC	High Performing Computing
I2V	Infrastructure-to-Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISAD	Infrastructure Support levels for Automated Driving
IT	Information Technology
ITS	Intelligent Transport Systems
Lidar	Light Detection and Ranging
LTE	Long Term Evolution
MaaS	Mobility as a Service
MNO	Mobilie Network Operator
NGV	Next Generation Vehicular
NO_x	Nitrogen oxides
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PKI	Public Key Infrastructure
PM	Particulate Matter
PPP	Public-private partnership
RIS	River Information System
SESAR	Single European Sky ATM Research
SME	Small Medium Enterprise
SoL	Self-organising Logistics
STRIA	Strategic Transport Research and Innovation Agenda
TEN-T	Trans European Network of Transport
TJAW	Traffic Jam Ahead Warning
TNC	Transportation Network Companies
TSI	Technical Specifications for Interoperability
UK	United Kingdom
URLLC	Ultra Reliable Low Latency Communication
US	United States

V2I	Vehicle-to-Infrastrucure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Person
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VMS	Variable Message Sign
VRU	Voice response unit
WAVE	Wireless Access in Vehicular Environment

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EXECUTIVE SUMMARY

Mobility is in transition. The combined development of different emerging technologies (e.g. smart sensors, blockchain, artificial intelligence) boost innovations in Smart Mobility. The increasing pressure on achieving societal goals within the transport sector (e.g. decarbonisation, improving traffic safety, reducing congestion) will be another driver for the developments in Smart Mobility.

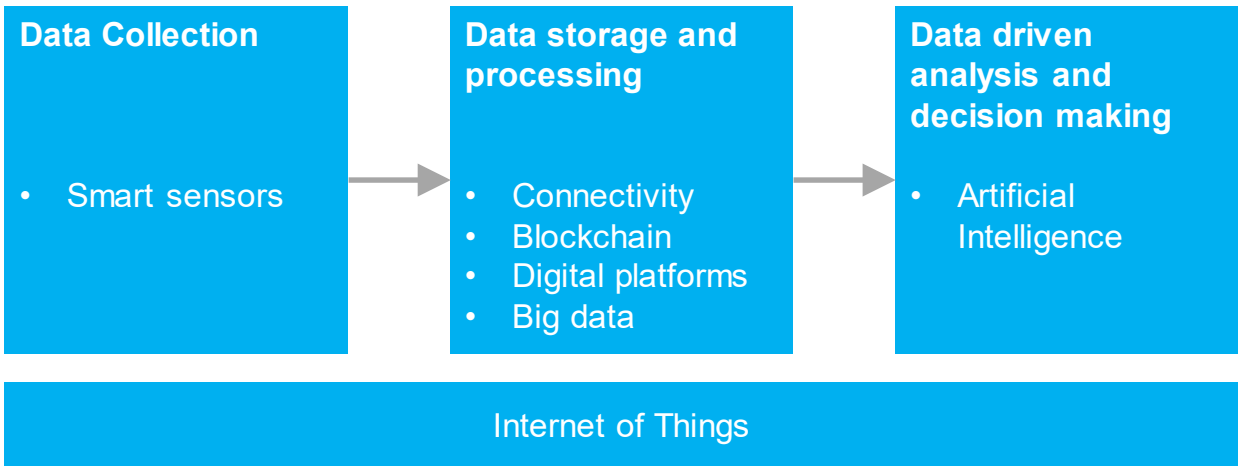
There are, however, still many challenges to implement Smart Mobility applications in a way that maximises the benefits for Europe and at the same time minimises any negative impacts. Lack of harmonisation in national legislation and lack of social acceptance are just two examples of issues that may hamper their large-scale deployment.

This study provides an overview of the most relevant Smart Mobility applications and their underlying emerging technologies for all transport modes (i.e. road, rail, shipping and aviation) for the period up to 2030. Their impacts on the transport system and society are assessed. Additionally, the main challenges for their development and deployment are identified, and actions that could be taken to address these challenges are discussed.

Overview of emerging technologies and their applications in the transport sector

Collection, storage, processing and analysis of data are the main building blocks of Smart Mobility applications. The main emerging technologies supporting these steps in the data supply chain are given by Figure 1.

Figure 1: Overview of key emerging technologies



The level of maturity of the various emerging technologies varies greatly. Some are already widely applied (e.g. smart sensors, connectivity technologies), although further development is expected in the next decade. Other technologies (e.g. Artificial Intelligence) are in potential ground-breaking, but applications are only just starting to use them, discovering what is already possible and what still needs to be developed.

The emerging technologies mentioned above are key drivers of developments in Smart Mobility applications. The most promising applications are:

- **Cooperative Intelligent Transport Systems (C-ITS)** are applications where Intelligent Transport Systems (e.g. vehicles, infrastructure equipment, traffic control centres) communicate and share information in order to improve road safety, traffic efficiency, sustainability, etc.

- **Connected Cooperative Automated Mobility (CCAM)** comprises different levels of assisted and automated driving. It ranges from driver assisting features like automated cruise control to fully automated vehicles.
- **Mobility as a Service (MaaS)** is the integration of various forms of transport services into a single mobility service accessible on demand. It offers transport users access to plan, book and pay for a range of transport services, which can be easily accessed by an app.
- **Self-organising Logistics (SoL)** refers to decentral coordination of logistic chains, meaning that individual agents in the chain (e.g. companies, vehicles, containers) make autonomous decisions based on local intelligence and local data.

Impacts on transport and the society

Smart Mobility applications are expected to provide significant benefits for transport users, particularly by increasing transport efficiency (e.g. more flexibility) and improving travel experience (e.g. higher feeling of comfort). Furthermore, Smart Mobility applications may also have the potential to significantly contribute to the achievement of societal goals, like less CO_2 emissions, improved traffic safety and less congestion. To what extent this potential will be materialised depends on its design and management by public authorities (with actions such as legislation, funding, piloting and public-private cooperation). If not managed well, Smart Mobility applications' contribution to achieving societal goals will be less prominent, and may be even negative (e.g. if the additional transport demand expected to be generated by CCAM is not managed well, it may result in additional emissions which may undo any emission reduction at the vehicle level, ending up with higher total emissions levels).

The full impact of Smart Mobility will only be realised on the long-term. First, because most applications need a critical mass to become fully effective. Secondly, because Smart Mobility applications become more effective in the next decade due to technological improvements.

Finally, the evidence on the impacts of Smart Mobility applications is only available from small-scale pilots, scenario studies and stated preferences studies. Therefore, the uncertainty in these findings is high.

Impacts for transport infrastructure

The deployment of Smart Mobility applications requires a well-developed digital infrastructure. The development, availability, security and governance of the digital infrastructure need to be a key priority in Smart Mobility policies. As the lifetime and user-requirements of the digital infrastructure differs widely from the physical infrastructure and the development of the infrastructures is not congruent, specific (but integrated) strategies for the various levels of transport infrastructure are required. This asks for a close cooperation between different stakeholders, as the various infrastructure levels are managed by different parties, with shared responsibilities.

Challenges for the deployment of Smart Mobility

To facilitate and accelerate the deployment of Smart Mobility applications, many challenges have to be overcome. Although each individual application has its own challenges, some general challenges can be identified. These are technical, as well as economic and social and all seem to be equally important. Improving user and public acceptance, developing viable business cases, guaranteeing data privacy, providing a harmonised and secure data sharing infrastructure and ensuring interoperability between countries/regions and modes are some of the main challenges for the deployment of Smart Mobility applications.

Actions to accommodate the Smart Mobility applications

To overcome the various challenges, actions at different levels are needed. Not only by European policy makers, but also by a range of other stakeholders (e.g. Member States, cities, vehicle manufacturers, infrastructure managers, etc.). Each Smart Mobility application is in a different stage of development and the same is true for the underlying emerging technologies. Therefore, a targeted set of actions is required for each application.

In addition to specific actions, an overarching European strategy towards Smart Mobility is required as well because of the common challenges to the various Smart Mobility applications, the fact that they make use of the same technologies, and the increasing integration of the various applications in the future. The European Commission is currently working on a strategy for a Sustainable and Smart Mobility which could provide such an overarching perspective.

Policy recommendations

Based on the main findings summarised above, the following policy recommendations are formulated.

- *Develop an overarching strategy for Smart Mobility* with the view to coordinate effectively all initiatives on the various types of Smart Mobility applications.
- *Create base conditions for Smart Mobility,* e.g. by further investments in digital infrastructure.
- *Define targeted sets of policy actions for each Smart Mobility application*, stimulating and facilitating actions from all stakeholders. Policies include a consistent legal framework, large-scale pilots, and a good balance between public, public-private and private financing.
- *Ensure that policies are proactive, flexible and adaptive,* such that they can be quickly adapted when new technological concepts become available or user preferences are different than anticipated.
- *Improve the knowledge base on Smart Mobility applications* on issues like technical requirements, expectations and concerns related to these applications, and the impacts these applications can have on the transport sector and society.
- *Organise cooperation between all relevant stakeholders* (including end-users), by promoting and/or prolonging and/or extending cooperation and consultation bodies (like the CCAM Platform).

1. INTRODUCTON

1.1. Background to the study

Our mobility system is changing rapidly. Due to technological developments like artificial intelligence, big data, connectivity technologies (e.g. 5G) and blockchain (see Section 2.2 for more information on these technologies), but also due to changing preferences of travellers and companies getting used to digital services and demanding more and more 'custom–fit' mobility and transport services. Additionally, there is the urgency to realise sustainable and safe mobility, reducing its carbon footprint and aiming for zero casualties, as is clearly noted in the European Green Deal (EC, 2019c) and the EU Road Safety Policy Framework 2021-2030 (EC, 2019b). The COVID-19 crisis has shown us that our mobility choices can change substantially, are highly uncertain and difficult to predict and the crisis has accelerated the need for a digital infrastructure and mobility innovations.

There are a lot of new emerging mobility solutions, like connected and cooperative Automated Mobility (CCAM), Mobility as a service (MaaS) and Self-organising Logistics (SoL). These solutions are possible by — and dependent on — key technologies like data science, 4G/5G/C-V2X connectivity, and artificial intelligence.

These new mobility solutions have the power to fundamentally change the transport sector. For example, concepts like CCAM and MaaS have the potential to realise a shift from vehicle ownership to vehicle use (reducing the number of vehicles), although the likeliness and size of this impact is still uncertain. And concepts like Self-organising logistics have the potential to increase transport efficiency and hence reduce movements. There will probably also be a further integration of the various transport modes, both in passenger transport (e.g. by all kinds of MaaS applications) and in freight transport (by applying smart logistics solutions).

In addition, the new solutions are also claimed to have all kinds of potentially beneficial environmental (GHG emissions, air pollutant emissions), social (less congestion, higher traffic safety levels, better access to mobility for people without cars) and economic (opportunities for the European vehicle and IT industry) impacts (EC, 2019e; 2019c). However, potential unintended and rebound effects should be considered with respect to these beneficial impacts. For example, MaaS services may encourage additional transport movements, which may have adverse environmental and social impacts (Pangbourne, et al., 2020a). The net impacts of these new solutions should therefore be carefully assessed, taking both the intended and unintended impacts into account.

There are still significant challenges to implement the new mobility solutions and underlying emerging technologies in a way that maximises the benefits for Europe and at the same time minimises any disruptions (EC, 2019e). Privacy issues, data security, lack of harmonisation in national legislation, poor cooperation between stakeholders and lack of user acceptance are just some examples of issues that may hamper the wide-scale implementation of these solutions. Also, the current transport infrastructure requires adaptations to accommodate the full-scale implementation of the emerging technologies. The realisation of a well-functioning digital infrastructure meeting the requirements of the various relevant Smart Mobility applications and aligned with its specific context is key.

On behalf of the European Parliament's Committee on Transport and Tourism, CE Delft and TNO have conducted a research project on these emerging technologies, their impact on the transport sector and actions needed to prepare transport infrastructure for these changes. The results of this project are presented in this report.

1.2. Objective and scope

The objective of this study is to provide a comprehensive overview of emerging technologies driving the transformation of the transport system (i.e. transport sector + transport infrastructure). This overview includes a discussion on possible applications of these technologies and their potential impacts on the system. Furthermore, it covers the state of play and future actions required to fully accommodate these technologies and related mobility applications.

The scope of this study is limited to *technologies and applications related to Smart Mobility*. Cooperative Intelligent Transport Systems (C-ITS), Connected Cooperative Automated Mobility (CCAM), Mobility as a Service (MaaS) and Self-organising Logistics (SoL) are the four types of Smart Mobility applications that are specifically considered in this study (see Section 2.3 for an introduction on these applications). Other technological developments are out of scope. This means that also electrification, another major transition taking place in mobility (one of the four major transition, so called also known as ACES: Automation, Connectivity, Electrification and Shared mobility), is out of scope. Electrification is expected to have a major impact on the transport sector, but it is not considered a Smart Mobility application. It is for sure an enabler, as electric vehicles will definitely be using the possibilities CCAM and MaaS will offer, just like "regular" combustion based vehicles will do. And there are also many interlinkages between electrification and Smart Mobility (e.g. C-ITS applications are used in demand management of charging infrastructure). But electrification in itself is no Smart Mobility application. How electrification will (also) transform the transport sector is worth a study in itself.

The study covers all modes of transport, i.e. road, rail, waterborne and air transport. As Smart Mobility applications are more intensively researched (and applied) in road transport than in the non-road modes, more information is available for that mode. For that reason, road transport will be discussed in more detail than the other modes in this report. Geographically, the main focus of this study is on the EU-level, implying that particularly EU-wide developments are considered.

1.3. Methodology

This study is based on literature research, interviews and case studies. The literature study covered academic papers, research reports, position papers, policy documents, etc. In order to validate and supplement the evidence from the literature review, 10 semi-structured stakeholder interviews were carried out, In Annex A, an overview of the interviewees is given. The results of the interviews were used as input for the analyses presented in the next chapters. Finally, four case studies (each covering one of the four Smart Mobility applications considered in this study (see Section 1.2) were executed to illustrate the main findings of this study. A brief introduction of these case studies is given in the text box below. The most relevant findings of the case studies are presented in text boxes throughout the document, while a full description of the case studies is provided in Annexes C-F.

Box 1: Overview case studies

Case 1 - C-ITS use case

In this case study we discuss a C-ITS deployment pilot in the Czech republic. The aim of this pilot is to evaluate the possibilities of C-ITS services to prevent collisions of trains with road vehicles on railway level crossings. Specific attention was paid to the comparison of the functioning of different short- and long-range communication technologies.

Case 2 - Regional impacts of automated driving

This case study explores the mobility impacts of connected and automated driving and shared mobility. In a future oriented study, four (extreme) scenarios were explored in which 100% of the vehicles have high levels of vehicle automation and people have a low or high willingness to share. Using a new transport model, the potential impacts of automated and shared vehicles in the Dutch Province of North-Holland and the larger Amsterdam region were examined.

Case 3 - MaaS in Finland

This case study explores Mobility-as-a-Service in Finland. Finland is often considered as one of the front running countries in Europe in this field. This case study explores the MaaS ecosystem, the policy goals, the roles and responsibilities of stakeholders, the relation between new mobility concepts (e.g. bike sharing, MaaS apps/platforms) and traditional transport options and the policies to manage this development (e.g. laws and regulation, support actions such as changes in transport code and open data rules, support actions such as investments/funding/PPP).

Case 4 - Changing competitiveness of road, rail and inland waterways for freight transport

This case study explores the changing competitiveness of road, rail and inland waterways for freight transport at the EU level. Currently, transport policy for freight transport is often aimed at achieving a modal shift from road to rail and inland navigation, but an analysis of trends shows that road transport will become more attractive as result of emerging technologies. Without policy measures, this could lead to a reversed modal shift from rail and inland navigation back to road transportation. This case study explains the relevance of the interactions between different developments in the freight sector (including the rise of emerging technologies and Smart Mobility applications), explores various policy directions and discusses how to deal with uncertain developments of emerging technologies.

1.4. Overview of the study

The structure of this report is as follows:

- Chapter 2 provides an overview of the main emerging technologies and their applications in the transport sector. As part of this chapter, the four Smart Mobility applications that are central in this study (i.e. C-ITS, CCAM, MaaS and SoL) are discussed.
- Chapter 3 assesses the impacts the four Smart Mobility applications have on the transport sector (e.g. transport demand, modal shift, transport efficiency) and the society in general (e.g. environmental impacts, safety impacts).
- Chapter 4 discusses the impacts the four Smart Mobility applications may have on transport infrastructure, considering both the physical infrastructure as well as the digital and operation infrastructure.
- Chapter 5 shows the role that is foreseen for Smart Mobility in various EU strategies regarding the achievement of societal goals like decarbonising the transport sector and improving traffic safety. Furthermore, the main current EU policies and initiatives with respect to the four Smart Mobility applications are discussed.

- Chapter 6 discusses the main challenges with respect to the four Smart Mobility applications and the actions that could be taken by various types of stakeholders to address these challenges.
- Chapter 7 presents the main conclusions of this study as well as some policy recommendations.

2. EMERGING TECHNOLOGIES AND THEIR APPLICATIONS IN THE TRANSPORT SECTOR

KEY FINDINGS

- There is a variety of emerging technologies, or clusters of technologies, that boost the development of Smart Mobility in multiple ways. The most relevant ones for the period up to 2030 are smart sensors, connectivity, blockchain, digital platforms, big data, artificial intelligence and Internet of Things.
- In understanding the impact of emerging technologies on the transport sector, the applications based on these technologies are key. It will be the applications that will transform transport, the mobility choices of people and the organisation of freight transport, and hence the impacts on the transport sector and society. Cooperative Intelligent Transport Systems (C-ITS), Connected Cooperative Automated Mobility (CCAM), Mobility as a Service (MaaS) and Self-organising Logistics (SoL) are identified as the most promising (clusters of) Smart Mobility applications in the period up to 2030.
- Each Smart Mobility application uses multiple emerging technologies and each emerging technology contributes to several applications. Hence, further developing and seizing Smart Mobility opportunities benefits from an integral approach.
- The level of maturity of the investigated emerging technologies varies greatly. Some are already widely applied. Others, often advocated as very promising, still have to prove their value in practice. 5G, Artificial Intelligence (AI) and blockchain are in potential ground-breaking, but applications are only just starting to use them, discovering what is already possible and what still needs to be developed.
- In the long run, the various Smart Mobility applications may merge into one integrated transport system in which Smart Mobility plays a key role in achieving the societal goals (e.g. accessibility, sustainability and safety). In the mobility transition, the Smart Mobility applications are related. MaaS and SoL require a digital infrastructure that can also be used by C-ITS and CCAM., e.g. starting by using C-ITS services to pave the technological infrastructure and MaaS and SOL to boost the development of the digital infrastructure for autonomous vehicles.

2.1. Introduction

New technologies are currently becoming available, forming the foundation of major transitions in mobility. Connectivity technologies like C-V2X and 5G, environmental perception systems (smart sensors), artificial intelligence, big data and blockchain are examples of these emerging technologies. Some of these technologies are in fact a cluster consisting of several underlying technologies. Big data for instance is not a technology but is referring to the possibilities of having access to (large quantities of) data supply, and being able to analyse large quantities of data. So, it is not a technology but a concept made possible by other technologies (for instance the technological developments in

connectivity)[1]. However, to keep things simple, we will refer to these concepts by using the term 'technology' in this chapter.

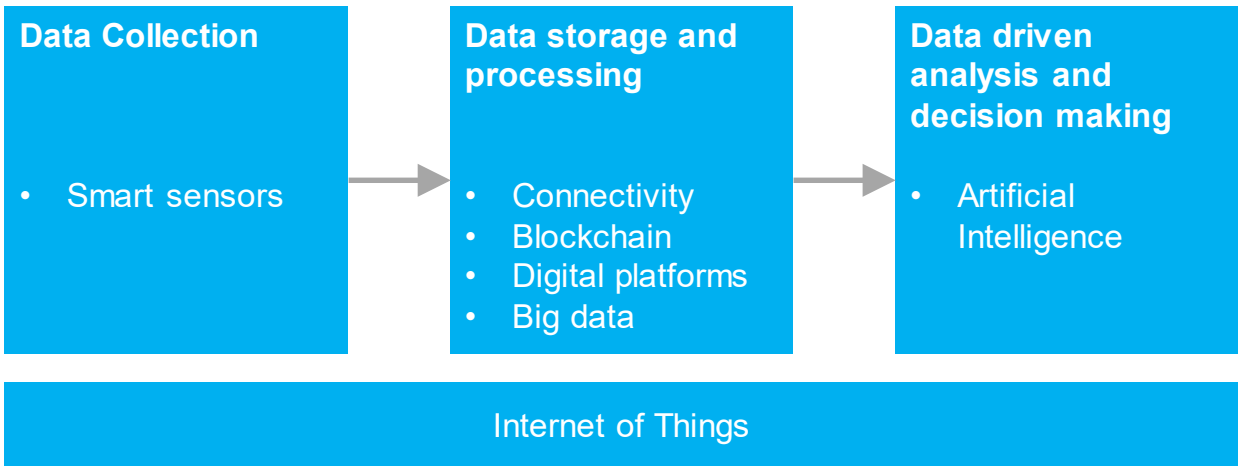
In the remainder of this chapter, some main emerging technologies for the transport sector are discussed (Section 2.2). These are the innovative technologies that are expected to have the most impact on the transport sector in the period up to 2030. These technologies were selected based on an iterative process, using the valuable input of EU officials, stakeholders, interviewees and literature.

In order to get a good understanding of the impact of emerging technologies on the transport sector, transport infrastructure and society, knowledge on how these technologies will be used in specific mobility applications is key. This knowledge is also required to assess the challenges and opportunities laying ahead for these technologies, as well as to understand which policy actions are recommended to support the deployment of these technologies. Therefore, we provide a broad overview of the main types of transport applications using the various emerging technologies in Section 2.3.

2.2. Main emerging technologies applied in the transport system

Collection, storage, processing and analysis of data is the main building block of innovative Smart Mobility applications. Emerging technologies facilitating this data driven processes are therefore key for future mobility options. The main emerging technologies for the next decade are given by Figure 2. They are categorised according to their potential role in the data supply chain.

Figure 2: Overview of key emerging technologies



Above-mentioned technologies are seen – in literature and by the interviewed stakeholders - as the most relevant technologies for the transport sector. The reason for this is threefold: the major technical progress which has been made the last years, the promising expected future developments, and most of all their applicability in some of the promising applications which are transforming the transport sector, making it "smart": C-ITS, CCAM (Connected cooperative and Automated Mobility), MaaS (Mobility As A Service) and Self-organising Logistics. For that reason, these technologies are discussed in more detail below.

[1] This shows how current technological development is strongly driven by advancing technological containerisation and aggregation: whereas in the 70's we would still worry about the analogue design of an electric sensing device, today we consider these as obvious building blocks for any complex application.

2.2.1. Smart sensors

Modern vehicles have been equipped with many internal sensors in the last decades: fuel level, engine temperature, battery level, seat belt reminder, to mention a few. These sensors are mostly meant for monitoring the safe state of the vehicle. With the advent of cooperative, connected and automated mobility (CCAM), external sensors like radars and cameras have been introduced. The purpose of these sensors is to detect the presence and behaviour of other transport users.

Three main categories of sensors are distinguished: radars, cameras and lidar. Radars and cameras are currently most often applied, as costs of applying lidar systems is relatively high. In test vehicles, Lidar systems are often used because of its full-circle field of view (see Figure 3). Each sensor type has its strengths and weaknesses (Table 1). Radars are very good at measuring speed but may create many temporary reflections ('ghost objects'). Cameras, on the other hand, are good at detecting pedestrians and poor at measuring distance and speed at large distance. Both are more or less sensitive to rain and fog. Lidar detects many objects, but at the same time produces many ghost objects.

Table 1: Characterisation of various external automotive sensors

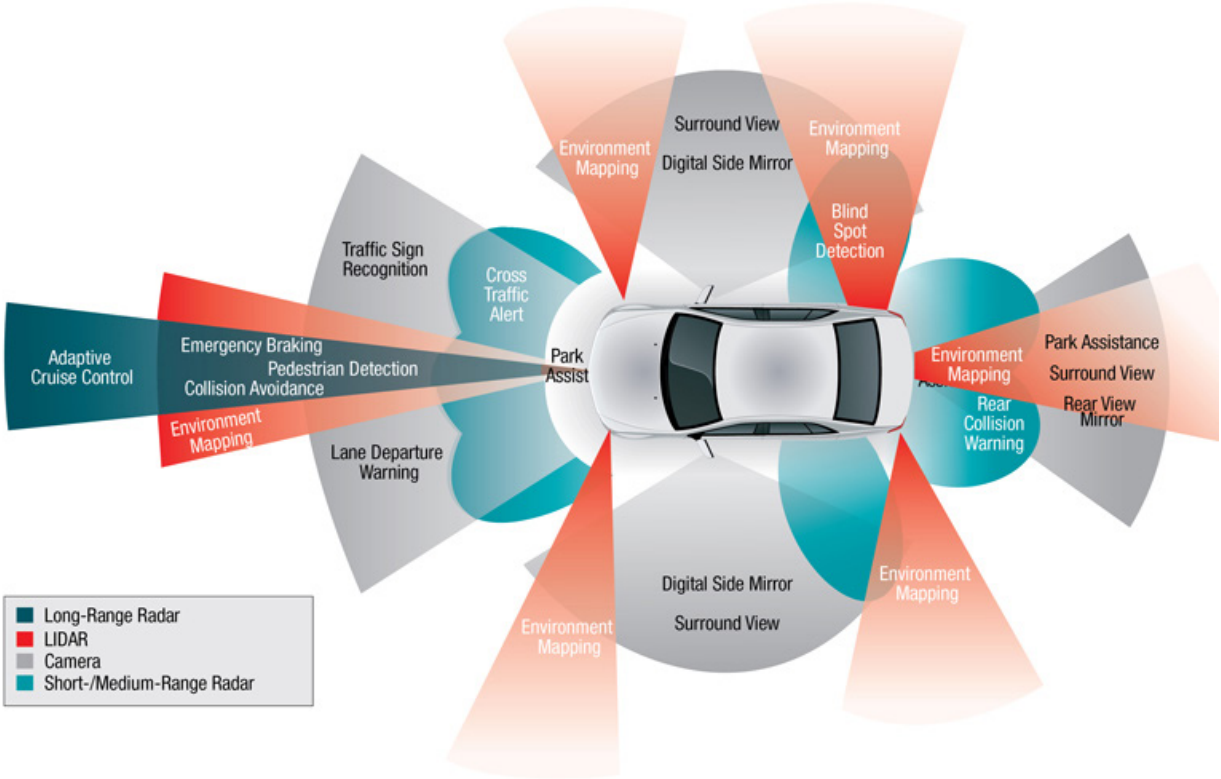
Sensor type	Field of view	Approximate price (at low volume)[2]	Strengths	Weaknesses
Radar	4°-60°	2,000-2500 €	All weather, exterior mounting, speed measurement.	Object classification only recently possible. Poor detection of humans.
Camera	54°-190°	100-200 €	Small, automotive grade, can detect infrastructure. Can detect traffic and brake lights, lane markers.	Powerful and expensive hardware for image process needed. Poor at depth perception (unless stereo camera), poor at speed measurement.
Lidar	90°-360°	2,000-15,000 €	Object classification, high angular resolution, ranges, object size.	Performance level depends on weather conditions.

It should be noted that the field of automotive sensors is innovating rapidly and some of the limitations will be overcome soon. For example, the expected solid state lidars and mobile phone lidars will lower the price considerably.

For safety engineering, redundancy in sensors is important. Combining various sensors helps to be robust in various conditions and even if a sensor fails. In all cases, a combination of sensors will be needed.

[2] The price indications shown are for prototype volumes. For production volumes, OEMs can negotiate much lower prices.

Figure 3: Various sensor types with their applications



Source: Mechlectures.com

Which (combination of) type(s) of sensor(s) should be applied also depends on the context in which it will be applied. For example, road transport applications used on highways often use a forward-looking radar with a narrow field of view (e.g. 17°). In urban situations, a field of view of 150° or much more is necessary: as the speeds of vehicles and pedestrians are closer (both below 30 km/h), the time needed to anticipate a collision course requires a wider field of view

To achieve the smart character in 'smart sensors', several approaches can be adopted:

- Combination of several sensors (sensor array, e.g. stereo camera) or several types of sensors (sensor fusion).
- Object recognition using multiple sensors to a 'world model' (a model of the world around the vehicle including road objects and transport users). Here, neural networks and other AI techniques play a major role.
- Filtering of temporary non-existing objects ('ghost objects' or 'artefacts').
- Handling of static objects, e.g. a vehicle should not brake for trees along the road, but it should brake for objects that create a safety risk, such as temporary road works objects or the middle wall of a tunnel.
- Detection of lane markers and road edge.
- Indication of confidence level: how certain is the sensor about the detection of the physical parameter (e.g. speed).

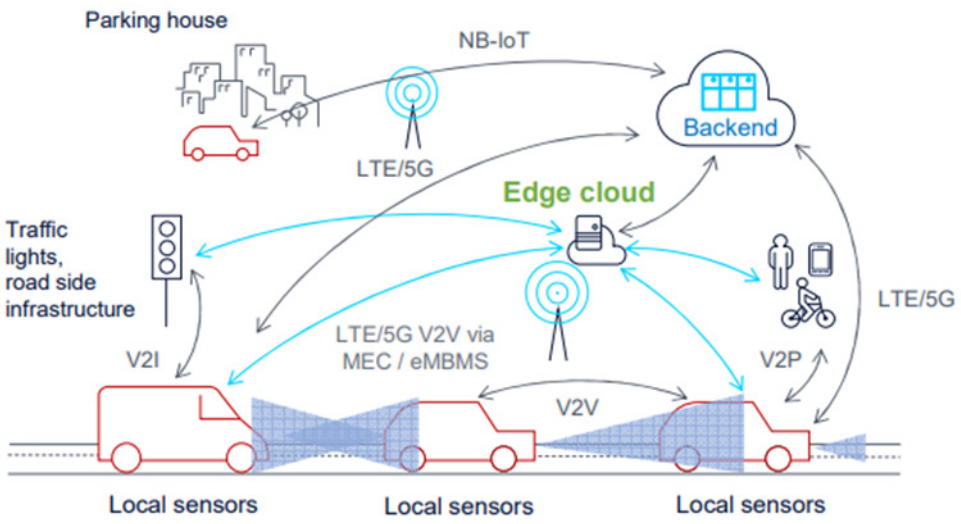
- If camera data is stored: anonymisation of detected transport users (filtering license plates and human facial features).
- Prediction of behaviour of other traffic users in the coming seconds.

Connectivity information is usually handled by vehicle control and not seen as part of sensor fusion. However, through connectivity vehicles might share their world models (view of surrounding objects and traffic users, also known as situational awareness) and create a much extended horizon of awareness, beyond the range of sensors in the vehicle itself. Information beyond the sight of the vehicle, for instance information from the traffic situation on the road more than a couple of 100 metres away or around a corner, can be shared real-time with the vehicle, so it can be taken into account in the decision making of the vehicle. The vehicle sensors (like camera, radar and/or lidar) are "extended" in this way. It is expected that the increasing possibilities of connectivity (higher bandwidth, lower latency) will enable vehicles to use sensor data of other vehicles as if it were their own sensors, as concept names extended sensors. These possibilities will be explored in the coming decade.

2.2.2. Connectivity

Over the past decade, both short- and long-range vehicle communication technologies have been developed and introduced in the transport domain with the primary goal of improving traffic safety and efficiency. Vehicle communication technologies comprise equipment, applications and systems to enable vehicle-to-everything (V2X) communication. Figure 4 gives an overview of the V2X communication architecture, after which the various types of communication are being discussed.

Figure 4: V2X communication architecture overview



Source: 5GAA (2020b).

Short-range communication

Short-range communication can be used between vehicles (V2V), between vehicles and pedestrians (V2P), and between vehicles and infrastructure (V2I), all using either ITS-G5 or direct cellular C-V2X as communication technology.

From the beginning (i.e. from the early 21st century), short-range vehicle communication protocols were based on the WLAN IEEE 802.11 family of standards known in the U.S. as Wireless Access in Vehicular Environments (WAVE) and in Europe as ITS-G5. It is also referred to as DSRC, mostly in the US

as well. The C-ITS community, including ETSI (European Telecommunications Standards Institute), has designed this ITS-G5 technology using IEEE 802.11p as an access layer basis. IEEE Std 802.11p is an amendment to the IEEE 802.11 standard introducing the new ad hoc type of communication for V2X in this standard (IEEE, 2010). This was, until recently, the only short-range technology available and has been tested extensively in Europe, the U.S., and other regions with different use cases for road safety and traffic efficiency. Although the exact messages differ a bit between the US and Europe, the used technology itself is the same.

More recently, the alternative direct Cellular V2X (C-V2X), using the 3GPP PC5 interface, has been introduced in 3GPP standards as alternative to the IEEE 802.11p as underlying technology for short-range V2X (and possibly V2I and V2P) communication. C-V2X is using a different technology than ITS-G5, the two technologies are not interoperable and will in fact influence each other.

Both types of technologies intend to make use of the same 5.9 GHz frequency band (allocated for C-ITS services) to send and receive data, which is causing debate, as the available spectrum is limited and the two technologies cannot make use of the exact same frequencies (as they will interfere). As the two technologies are also incompatible, this is also complicating choices to be made for the technologies to be deployed at the roadside and in the vehicles.

At this moment, commercial vehicles equipped with this ITS-G5 technology have recently become available[3]. Also, at several locations in Europe this technology has also been deployed at the infrastructure[4].

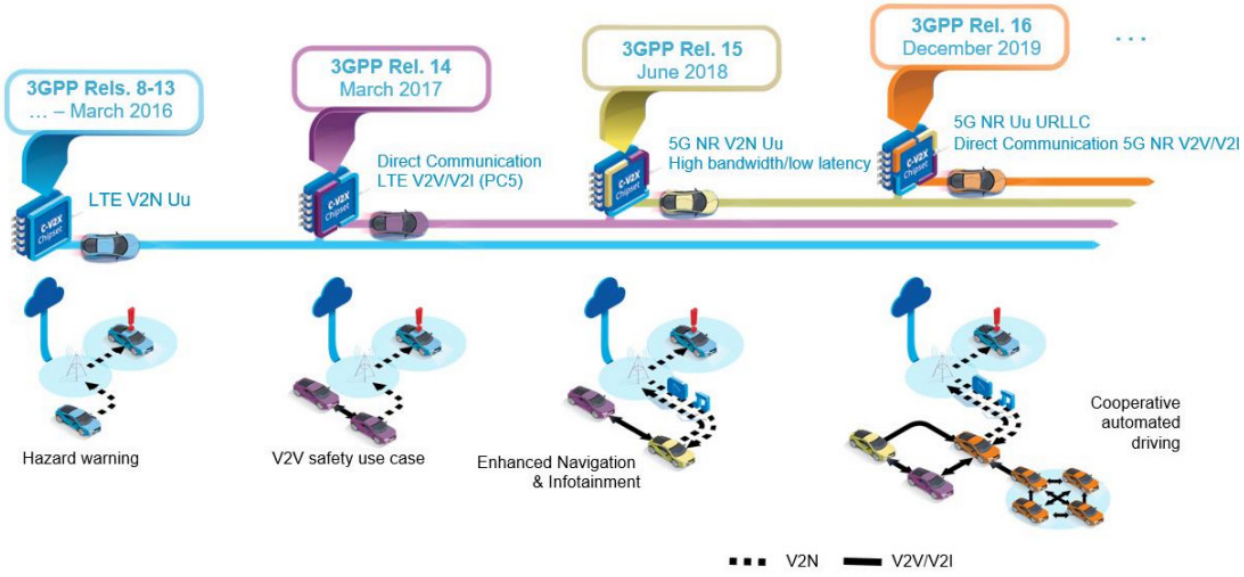
Where ITS-G5 have already been tested (and applied) for more than a decade, the alternative direct cellular C-V2X standard has just been published by 3GPP (Third Generation Partnership Project) in 2017, where the LTE-V2X protocol was described to enable short-range communication (see Figure 5, release 14). Currently, LTE-V2X (release 15) is becoming available in commercial chipsets. Deployments of vehicles equipping C-V2X chipsets (with release 15) are expected to start as early as 2021. A new release, release 16, with more functionality has already been announced. This C-V2X short range communication product is from release 16 on referred to as 5G-V2X. This would introduce additional capability to 5G in terms of short-range direct communication by further increasing bandwidth and reducing latency in the so-called Ultra Reliable Low Latency Communications (URLLC). Release 16 also aims to meet the requirements of highly and fully automated cooperative driving use cases such as real-time situational awareness and high-definition maps, cooperative manoeuvre of autonomous vehicles (e.g. platooning[5]), sensor data sharing (collective perception), tele-operated driving, and remote software update. However, first deployments using release 16 are expected not earlier than 2023. Backwards compatibility of 5G-V2X and LTE-V2X is also a point of discussion. The idea is that chipsets implementing release 16 and associated communication stacks are expected to integrate both LTE-V2X and 5G-V2X radio technologies, thereby supporting backward compatibility at service level.

[3] See for instance: Volkswagen: Car2X: The new era of intelligent vehicle networking

[4] See for instance the C-ITS deployments at the C-Roads deployments.

[5] Vehicles driving automatically in convoy. To be able to do this the vehicles constantly communicate to each other their speed and position, among others.

Figure 5: C-V2X: evolution in 3GPP standards



Source: 5GAA (2019).

As mentioned before, it is important to realise that ITS-G5 and C-V2X are not interoperable, i.e. in their current form neither of the two standards defines a mechanism to communicate with each other. Also, as they both intend to use the same frequencies (around the 5.9 Ghz), the available (limited) spectrum will have to be shared between them. This will have an impact on the market, as will be explained in Chapter 4 (impact on the infrastructure) and Chapter 6 (solution to accommodate the technologies). At the moment it is difficult to predict whether one of the technologies will in the end be the dominant technology (or even: winner takes all) or if the two technologies will coexist.

It is important to realise that for the services which will be making use of the direct communication (see Sections 2.3.1 and 2.3.2), C-ITS and CCAM, it is "irrelevant" which specific direct communication technology is used. The offered functionality is the same, and hence the services should function properly on both technologies. However, these services are cooperative services, meaning they are based on the fact that they can communicate with other road users and/or the infrastructure. It will limit the potential of the services when part of these road users or infrastructure is using another technology, which they are unable to communicate with.

Finally, when discussing V2X short-range further in this report, it refers to both ITS-G5 and direct C-V2X communication protocols like LTE-V2X and 5G-V2X (not yet available).

Long-range communication

Long-range communication – vehicle-to-network (V2N) occurs between vehicles and cloud backend servers via regular 4G (LTE) and 5G mobile network. 5G promises much more bandwidth, lower latency and possibilities to connect numerous devices, compared to LTE. At the moment, a lot of research is being done to find out how exactly these potential benefits can be achieved. Several European projects (e.g. 5G-MOBIX, 5G-CARMEN, 5G-CROCO, 5G-Blueprint, 5G-MED, 5G-HEART) are taking place at the moment.

V2X long-range communication can be combined with either one of the short-range communication technologies described before. A combination of short- and long-range communication is called hybrid communication. In combination with regular long-range communication implementation, in

which devices connect to central servers, edge servers can be deployed physically close to the transport infrastructure in order to support services with stricter low-latency requirements and to provide up-to-date traffic information that is most relevant to vehicles in the vicinity.

Long-range vehicle communication enables vehicles to receive information about e.g. software updates, infrastructure conditions and traffic in the area, beyond the driver's (or vehicles) line of sight or range achieved with short-range communication. In this mode, the cellular equipment in the vehicles operates in the spectrum that has been licensed to mobile operators to provide connectivity to their customers.

As of 3GPP release 16, C-V2X set of technologies promise to seamlessly integrate protocols for both short and long-range communication to achieve higher network capacity, lower latency, improved reliability and availability, thereby meeting the requirements for more advanced vehicular applications and services.

Challenges in relation to connectivity

In order for C-V2X to enter the vehicle market, regulatory and technical challenges need first to be addressed:

- *Lack of deployment, coverage, and roadside infrastructure*: road operators and telecom operators should extend their infrastructure support to meet the requirements of more advanced use cases. To this end, business models are still unclear for MNOs, OEMs and road operators which makes them hesitant with respect to whom should take the first investment action. Also, the interoperability issue of the two competing technologies (ITS-G5 vs C-V2X) is slowing down deployment.
- *Regulation*: In Europe, the Delegated Act is currently being finalised under the Intelligent Transport Systems Directive (Directive 2010/40/EU). The initial version has been rejected by EU *Member* States and the European Parliament on the basis of the debate on the nature of the underlying communication technology (see Chapter 5 for more information).
- *Cross-border continuity of services*: use cases' requirements should still be met in cross-borders *scenarios* where vehicles' connectivity and services must guarantee continuity even when roaming from one MNO to another. This brings implications in terms of interoperability of services and cellular network technologies across telecom operators, OEMs, and road operators.

2.2.3. Blockchain

A blockchain is a shared ledger that everyone trusts to be accurate forever.[6] It is useful to look at this word by word:

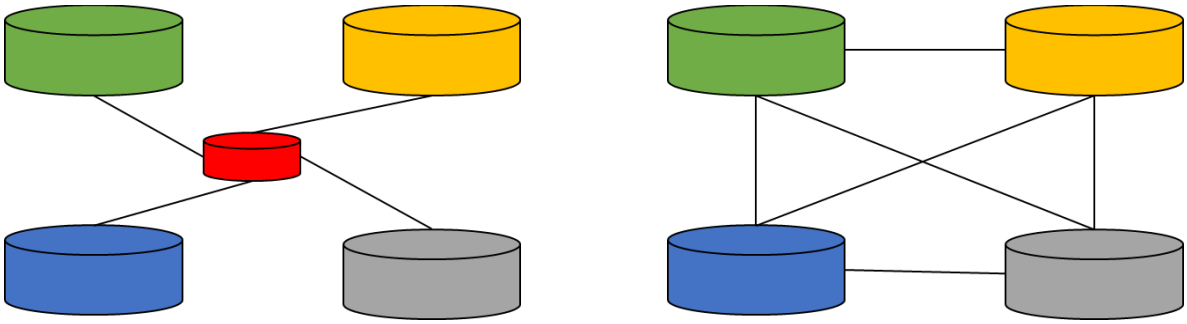
- A ledger is an administration of transactions. A bank maintains a ledger of the financial *transactions* that it handles. A transhipment company maintains a ledger of its incoming and outgoing shipments.
- A shared ledger is a ledger that is maintained by multiple parties together. Distributed ledger ("blockchain") technologies assure that all copies of the ledger remain synchronised.

[6] What is this Blockchain Thing?

- Accurate *forever* means that no single participant or colluding minority can change historic records.

The key concept is that everyone trusts the shared ledger. Traditional database technologies can in principle achieve all of the above, if there is a central organisation that maintains a primary database that keeps the local replica databases of the participating organisations up to date. However, there is a lack of trust in many industry sectors towards centralisation, especially in service-oriented sectors like supply and logistics. A fear is that a central organisation becomes too dominant and would exert control over its participants. This fear is alleviated in a blockchain, as all decentralised databases are constantly synchronised without involvement of a central player (see Figure 6). Blockchains can be classified by which parties can read, submit or write transactions: "public", "private", "permissioned" and "unpermissioned". Blockchains in the transport sector are typically permissioned "consortium" blockchains. Some provide public read and submit access, but many are private member-only blockchains.

Figure 6: Synchronising a shared ledger via a central organisation or with "blockchain"



Many organisations experiment to get acquainted with the technology of blockchain. But for the moment, not many experiments have led to real implementations. Experiments are on the level of supply chain visibility, fraud reduction, reduction of the administrative burden, and linking and indexing data stored by traditional platforms or database systems:

- Supply chain visibility - TradeLens[7] is an operational platform with a blockchain component creating visibility of container transport by sea. It has been developed by Maersk and IBM and operated *by* IBM. Another example is CargoLedger for road transport[8].
- Fraud *reduction* – Vinturas[9] is a blockchain based platform for transport of (used and new) cars in Europe. Starting with visibility, its main objective is to reduce fraud of used cars. It is developed by IBM. Vinturas is in the start-up phase after piloting.
- *Reduction* of the administrative burden – Deliver is a development of Blocklab, a joint initiative of the Rotterdam municipality and the Port of Rotterdam, ABN AMRO and Samsung for digitisation of trade documentation. It is expected to become operational by

[7] Tradelens: Trade made easy : Transform container logistics by freeing yourself from legacy data systems, manual document handling and poor visibility

[8] Cargo-ledger: Digital Transformation of your Supply Chain

[9] Vinturas: Supply chain transparency creates better business

the end of 2020 after two years of experimentation. Other initiatives are focussing on single documents like Bills of Lading for sea transport.

- Linking *and* indexing – Digi-Transit[10] creates an index to access eCMR data stored by various platforms and enables the interoperability amongst these platforms.

Many countries, including China[11], aim to apply blockchain to cross-border trade and multimodal transport (road, rail, water, air). Here blockchain helps to more effectively connect carriers, trace goods, supply chain SME (Small and Medium sized Enterprise) financing and provide accurate logistics data.

Many current developments result in 'closed' communities, where governance is organised by its users (e.g. Tradelens and Vinturas) or where they provide a particular service (Deliver). Thus, they can be viewed as replacing platforms and/or creating a new market of (ledger-based) platforms. The expectation is that costs will decline in the coming years (both capital investment and operational expenditure), and that these ledger-based applications become more accessible. It is expected that these developments will continue and evolve in practical applications, possibly by 2025.

Challenges and stakeholder roles in relation to block chain

The following challenges are associated with the implementation of block chain in practise.

Level playing field (open and neutral):

- New infrastructures ('platforms') by big tech players are not open and neutral, and lack of focus on the large number of SMEs in the EU.
- Proprietary solution: No uniformity in the services provided by the solutions. A vender lock-in is created.
- Data sovereignty: Since the technology is still in development, organisations do not yet fully trust the application. They want to keep in control of their data, sharing data only to support their strategic position and business processes.
- Data Regulation: New ledger-based platforms consider a network effect with data agreements. For instance, the data agreements of Tradelens are such that users will commit to customs authorities receiving a copy of the data for free, where IBM assists these authorities on capitalising on this free data.

These challenges can be addressed by:

- standardising services provided by these new platforms;
- creating interoperability between the various solutions; and
- regulating the implementation of these services.

These efforts fit well with the European Data Strategy and the intention to create a European Data Space. EC DG Move is addressing these matters via an expert group, the Digital Transport and Logistics Forum (DTLF), to develop the necessary regulations and standards.

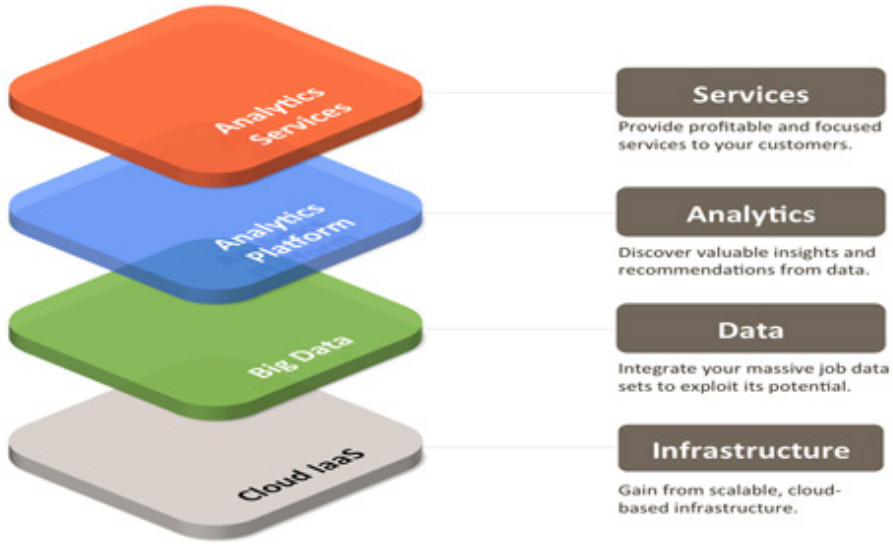
[10] Digi-Transit Consortium : e-Documents Single Window initiative

[11] China launches cross-border trade blockchain for multimodal transport

2.2.4. Digital platforms

Platform technologies are systems built upon a platform architecture that distributes the system into different levels of abstraction. This is done in order to differentiate between functions or services needed at specific levels. Every layer of abstraction builds upon the underlying services of lower layers. The highest layers will deliver the services on which applications are built. The lower layers deal with the (connected) infrastructure and (raw) data.

Figure 7: Illustration of a digital platform



Source: itviconsultants

Platform technologies are not new, but with the increase in connectivity and the numerous possibilities of communication technology, a separation of concern is of major importance. Applications need not to be aware of where data is located or what protocol is needed, they just need services to access the required data. It is the responsibility of the lower layers in the platform to support these services.

Currently, there are multiple platforms developed and available in the transport and mobility sector. Examples are the PlanIT Operating System of LivingPlanIT, the IBM® Intelligent Operations Center, Oracle's Smart City Platform Solution, MOBiNET, In-Time, i-Travel or TNO Urban Strategy platform. These platforms have the functionality to provide information to end-users, streamline processes, and integrate sensors to provide value-added services to end-users.

Platform technology is applied in many innovative services, like Amazon, Airbnb, Deliveroo and Uber. All these services share the following key components:

- information instead of physical goods and products is the core element;
- a magical user experience (user needs plus something 'unimaginable');
- on-demand service provision (when the user needs it);
- design around network platforms (ICT platform with defined rules);
- coordination by algorithms (no human intervention needed);
- employees are supported by technology (technology instead of training/education); and
- on-demand asset and labour management (no unused capacity).

Due to the significant cost reduction and service improvement that can be achieved simultaneously, these services (will) disrupt traditional markets. Since usage is made of a platform and decisions are made by algorithms, the rules for all parties involved are very clear but rigid. The platforms on which these services are offered set the rules to be followed by the suppliers and users of services. Also, quality monitoring of services delivered, and fair pricing mechanisms based on real-time demand and supply information can be embedded. For the operational activities where labour is still needed, no specific training/education is necessary so suitable workers can easily be found. Ownership of assets is where possible avoided and is organised such that the risks for unused capacity is minimised and the organisation is resilient to fluctuations in demand. Availability of real time and integrated information is a key requirement. This is easier to establish when the whole process is in the hands of one organisation. The likelihood of matching demand and supply is larger and therefore the service level higher when more people make use of the same service; this creates a tendency towards lower market competition, with few large players eventually dominating the market.

The availability and acquisition of data is increasing rapidly. Platform technology still needs to be able to handle and quickly process large amounts of (real-time) data. Integration of cloud technology, HPC clusters (High Performance Computing clusters) or grid computing (i.e. multiple computers, often geographically distributed but connected by networks, working together) and AI analytics should therefore be supported by modern platform technology.

Challenges

Digital platforms provide specific solutions to specific problems. But in general, the following challenges are relevant:

- Vendor lock-in can occur if building blocks are not open, meaning that proprietary platform services provided by service providers with their particular governance and business models are offered. They are open to everyone that is willing to conform to these. Thus, it is not easy to extend the platform to provide new services, without consultancy services from the vendor. Interoperability and standardisation are desired in order to easy integrate building blocks into other services.
- Most platforms are aimed at integrating services from particular domains.
- Apps and services developed for a platform only run on that specific platform.
- Current platforms have difficulties with respect to security and privacy of data. Every platform has its own way of dealing with this and the average technology is not flexible enough to deal efficiently with the privacy and owner aspects of data and the ability to track where this information is used.

2.2.5. Big data

According to Gartner's definition[12] (from 2001, still the go-to definition), big data is data that contains greater variety arriving in increasing volumes and with ever-higher velocity. This is known as the three Vs. Put simply, big data is larger, more complex data sets, especially from new data sources. These data sets are so voluminous that traditional data processing software just cannot manage them. But these massive volumes of data can be used to address business problems which could not have been tackled before.[13] The three V's of big data are:

[12] Gartner Information Technology, Glossary Big Data

[13] Text mainly taken from Oracle Website

- Volume: The amount of data matters. Big data is about high volumes of low-density, unstructured data. This can be data of unknown value, such as Twitter data feeds, clickstreams on a webpage or a mobile app, or sensor-enabled equipment.
- *Velocity*: Velocity is the fast rate at which data is received and (perhaps) acted on. Some internet-enabled smart products operate in real time or near real time and will require real-time evaluation and action.
- *Variety*: This refers to the many types of data that are available. Traditional data types were structured and fit neatly in a relational database. With the rise of big data, data comes in new unstructured data types. Unstructured and semi structured data types, such as text, audio, and video, require additional pre-processing to derive meaning and support metadata.

Two more Vs have emerged over the past few years: *value* and *veracity*. Data has intrinsic value. But it is of no use until that value is discovered. Equally important: How truthful is the data, how much can one rely on it?

Today, big data has become capital. A large part of the value of the big tech companies' offer comes from their data, which they are constantly analysing to produce more efficiency and develop new products. Recent technological breakthroughs have exponentially reduced the cost of data storage and computing, making it easier and less expensive to store more data than ever before. With an increased volume of big data now cheaper and more accessible, more accurate and precise business decisions can be made. Finding value in big data is not only about analysing it (which is a whole other benefit). It is an entire discovery process that requires insightful analysts, business users, and executives who ask the right questions, recognise patterns, make informed assumptions, and predict behaviour. Here another emerging technology becomes very important, artificial intelligence.

2.2.6. Artificial intelligence

European Commission (2019f) describes Artificial Intelligence as systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. More specifically, artificial intelligence (AI) systems are defined as "*software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions.*"

There are other slightly different definitions as well, but in general it can be stated that AI systems can perceive their environment (*sensing*), analyse collected data (*thinking*) and take decisions with a certain degree of autonomy (*acting*):

- *Sensing* is about data acquisition. This may concern local data such as the situation on the road, but also contextual information such as weather conditions. Next, it is important to merge data or relate it to each other ("link") and classify it, that is to say convert it into information. Based on this data acquisition, merging, linking and classification, an image is built of the current situation, which is called a "world model".
- *Thinking* can play a facilitating role in creating insight through data analysis and decision support, based on the world models available from 'sensing'. Data analysis allows the user

- human or AI - to assess the current state of the process or of the object and potentially also understand how that situation came about. Decision support, assisted by AI, can predict future situations as a result of possible actions. For example, at system level, this means that data analysis is used to estimate and predict the state of the mobility system. This includes, amongst other things, anticipating disturbances, maintenance and the behaviour of transport users.

- *Acting:* ultimately the service using AI directly, or a human supported by AI, makes a decision in the *acting* phase. That decision leads to action, or to no action. In all cases, it is important that the decision can be explained and that the decision-maker is capable. The authority to make decisions may be transferred to AI, but responsibility cannot. It is therefore essential that it is possible to be able to detect unwanted and unforeseen situations through sensing, and - as a person or as an AI - to be able to intervene and adjust. Where AI can support humans, AI must also be supported by humans. When time-critical processes or objects operate autonomously, we are faced with decisions that have to be made based on conflicting or incomplete information. The robustness of an algorithm must be thoroughly tested before implementation.

At the moment, many data techniques are labelled as AI, also techniques that have been used for years. There are two capabilities that really distinguish AI technique from other techniques:

- *Reasoning and Decision Making;* to be able to do this, one needs to transform data to knowledge, so one area of AI has to do with how best to model such knowledge (knowledge representation). Once knowledge has been modelled, the next step is to reason with it (knowledge reasoning). The final step is to decide what action to take. The reasoning/decision making part of an AI system is usually very complex and requires a combination of several of the above mentioned techniques.

- *Learning;* this includes machine learning, neural networks, deep learning, decision trees, and many other learning techniques. These allow an AI system to learn how to solve problems that cannot be specified, or whose solution method cannot be described by symbolic reasoning rules. Examples of such problems are perception capabilities such as speech and language understanding, as well as computer vision or behaviour prediction.

AI in the transport sector

Also in mobility and logistics, the amount of data is increasing rapidly and the complexity of control of vehicles, transport chains or transport networks is expected to grow. As a result, it is expected that with manual planning or simple data analytics methods it will not be possible to make optimal choices. Therefore, AI solutions have the potential to support or even take over control of humans to deal with the large amount of data and the complexity of control in (real-time) situations.

As explained in TNO and TKI Dinalog (2020), AI applications can focus on either:

- *persons and objects*, including road users, vehicles, cargo, sorting belts and infrastructure;

- *processes and systems,* including supply chains, traffic centres, traffic, policy and regulations.

Only with an integral ecosystem approach, considering these two elements as well as technological elements (sensing, thinking, acting), it is possible to use AI effectively. Joint efforts are needed for the development of the required technologies. Domain specific knowledge is needed to successfully

implement AI, where it is important to take into account the interaction between object and system and vice versa.

Promising AI applications in mobility and logistics are, for example, self-driving vehicles (cars, trucks, trains, barges), smart electric charging, predictive maintenance, self-learning energy and emission management, cooperative mobility, sharing economy and self-organising logistics. Although these kinds of applications of AI are not yet applied, they will be further developed and tested to support humans in their activities in the next years.

Challenges related to Artificial Intelligence

There are still a lot of challenges for the wide use of AI applications in mobility and logistics. These include:

- Data availability. For many applications a lot of (shared) data is required that is currently not available.
- Cybersecurity. With more data being shared and a larger dependency on data, cybersecurity is getting more important.
- Data sovereignty. Lots of data are required, in many cases based on shared data. However, because of privacy and keeping control over data, this is not straightforward.
- Responsible AI. The privacy of data owners is very important and should be guaranteed.
- Explainable AI. Since the purpose of the applications is decision making, it is important that the results of the applications are explainable to humans.
- Controllable AI. It should be possible to include appropriate safeguards to enable human intervention and control when necessary in case of unsafe, unethical or other unwanted decisions made by the AI application.

2.2.7. Internet of Things (IoT)

The internet of things is not a technology in itself. It is a concept (ecosystem) of interrelated computing devices, (smart) sensors, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction (Rouse, 2019). These things can be "anything", in all kind of sectors, also in the transport sector. In the transport domain, IoT devices like smart sensors from vehicles and smartphones can collect data (by what they 'see' and 'hear'), and by using connectivity this data can be shared with others. Business applications and/or other road users (vehicles and Vulnerable Road Users, like cyclists and pedestrians (VRUs) can make use of this data.

Different mobility applications, like the ones explained in the next section, C-ITS, CCAM, MaaS and SoL, make use of the IoT concept. They all rely on information from others. These applications make the concept more concrete: they create standards, so information exchanged can be understood by others. They investigate scalability of their implementation (sharing everything with everything is impossible in practise, and unnecessary as only information potentially useful for the other needs to be exchanged), and security/privacy. Not everything should be exchanged, and if exchanged, this should be done in a secure manner.

2.3. Applications of emerging technologies in the transport sector

In the previous sections we have described (clusters of) emerging technologies which may change the transport sector. Especially combinations of technologies provide promising possibilities. In this sector

we present the four main – as verified by the various interviewees - applications which use (combinations of) emerging technologies: C-ITS (Cooperative Intelligent Transport Systems), CCAM (Connected Cooperative Automated Mobility), MaaS (Mobility as a Service) and SoL (Self-organising Logistics). Other applications and technologies will emerge, like air taxis and hyperloop[14]. However, these applications are not expected to be implemented at a large scale within the next 10 years. The mentioned four Smart Mobility applications are expected to have a major impact on the transport sector in the period up to 2030, while at the same time having deployment challenges which need attention. These impacts are discussed in Chapter 3 and Chapter 4, while the challenges are discussed in Chapter 6. In the remainder of this section, the four types of applications are introduced in more detail.

2.3.1. Cooperative Intelligent Transport Systems (C-ITS)

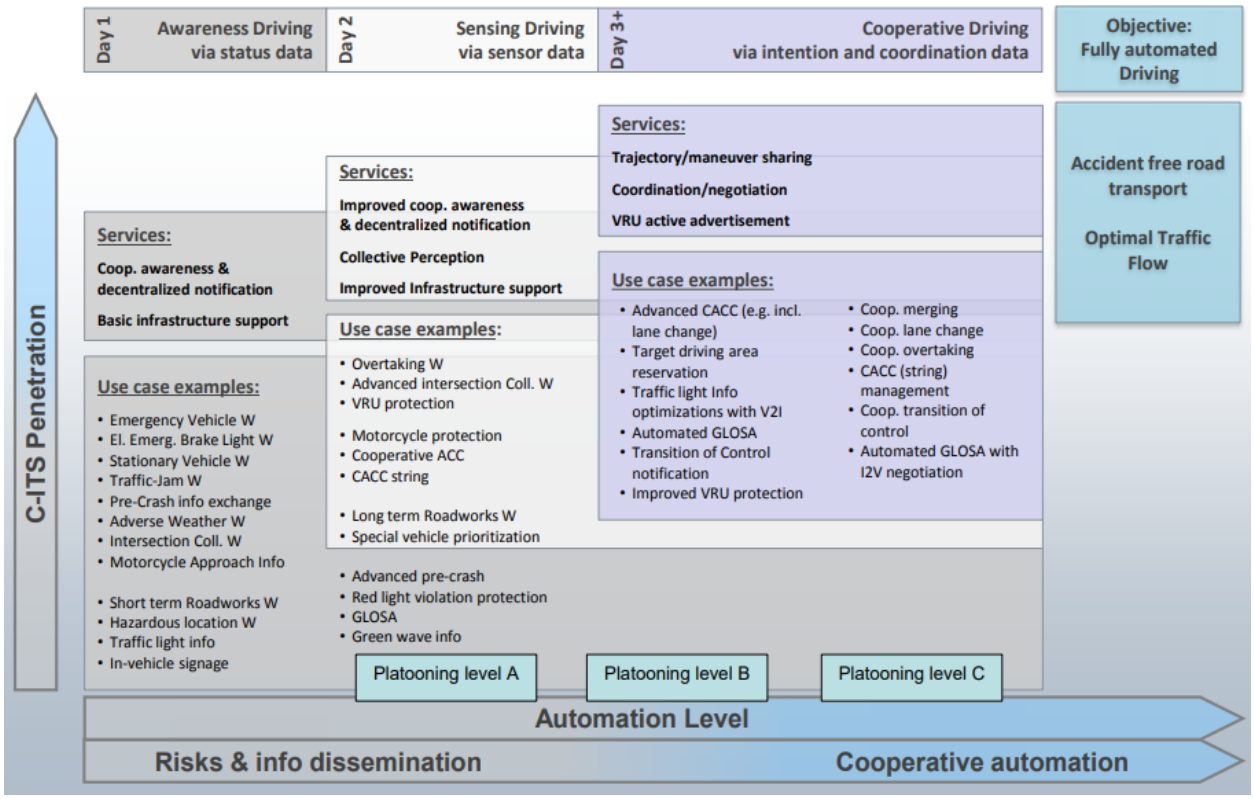
Figure 8 shows the roadmap of C-ITS applications and services in road transport as defined by the Car2Car consortium, making a distinction between various stages (so called day 1 to day 3 applications) before full automated driving is reached.

Day 1 applications target awareness driving via status data by relying on cooperative awareness and decentralised notifications. The specifications and profiles for these Day1 applications are available, through Car2Car and C-Roads, who have been harmonising them. Examples of Day 1 use cases are:

- *Emergency Vehicle Warning*: The driver is alerted of the presence of nearby emergency vehicles, allowing him or her to create free passage in advance;
- *Traffic Jam (ahead) Warning*: A host vehicle is alerted of a traffic jam ahead;
- *Intersection Collision Warning*: Drivers are alerted of potentially dangerous traffic situations when they approach an intersection.

[14] The Hyperloop offers the opportunity to travel in a pod substantially free of air resistance or friction in a sealed tube with low air pressure. The Hyperloop would convey people or objects at airline or hypersonic speeds while being very energy efficient.

Figure 8: Roadmap of C-ITS applications and services



Source: Car2Car Communication Platform (2019b).

These applications are currently been deployed at different locations in Europe (see case study C-ITS).

Day 2 applications target sensing driving via sensor data by using improved cooperative awareness and decentralised notification. Examples of Day 2 use cases are:

- *Vulnerable Road User (VRU) protection*: A host vehicle is alerted of VRUs on the road or crossing an intersection and is warned of any risk of collision.
- *Cooperative Adaptive Cruise Control (C-ACC)*: Vehicles driving behind one another use V2X communication to cooperatively and synchronously brake and accelerate allowing the vehicles to follow more closely, accurately, and safely.
- *Green Light Optimised Speed Advisory (GLOSA)*: GLOSA uses traffic signal information and the current position of a vehicle to display a speed recommendation intended to allow drivers to pass traffic lights during a green interval, in order to help reduce the number of stops at red lights.

Day 2 application implementations are mostly still in experimental stage. VRU protection and C-ACC are subject of investigation in several European and national projects, like C-Mobile[15] and ENSEMBLE[16]. GLOSA is already more widely deployed[17].

[15] C-Mobile project : Architecture

[16] ENSEMBLE: Platooning Together

[17] THE FOLLOWING DAY 1-SERVICES ARE IN THE FOCUS OF THE C-ROADS PLATFORM

Finally, Day 3+ applications focus on cooperative driving via intention and coordination data. Related services include trajectory and manoeuvre sharing, coordination and negotiation among vehicles, and VRU active advertisement. Examples of use cases are:

- *Cooperative lane merging*: Vehicles involved in a lane merging scenario share their location and intended trajectories and cooperatively negotiate how the merging manoeuvre should take place.
- *Automated GLOSA*: Traffic light phases are precisely computed using vehicle trajectory intention data and calculated speed advices are communicated to be automatically followed by receiving automated vehicles.
- *Truck platooning*: Truck platooning refers to a group of lorries travelling safely and automatically in convoy, a short distance apart. Since the lorries communicate with each other, they can travel in sync. The vehicle at the head of the convoy acts as the leader.

Several of the Day 2 and Day 3 applications are (mainly) intended for automated vehicles. Here, C-ITS (mostly referring to connected and cooperative vehicles) converges into CCAM (connected cooperative automated mobility - see next Section). The Day1 applications can be used by connected automated vehicles as well. It is important to notice that these CCAM vehicles are different from autonomous vehicles, in which vehicles are depending only on their own (smart) sensors.

The 5G Automotive Association also provides a comprehensive list of use cases focusing mainly on the use of 3GPP standards for V2X communication for both direct C-V2X and 5G set of protocols (5GAA, 2020a; 2020b). In addition to use cases that depend only on short-range communication, it also specifies use cases that are only possible with long-range communication. Example of such use cases are:

- *Tele-Operated Driving*: Remote driver (human or machine) operates a host vehicle;
- *High-Definition Map Collecting and* Sharing: Vehicles share their sensor data with an HD map provider, which then builds and shares HD maps with vehicles;
- *Vehicle Health Monitoring*: Owners and fleet operators monitor the health of a vehicle and are alerted when maintenance or service is required;
- *Automated Valet Parking (AVP)*: A vehicle requests access and a suitable parking spot to a parking infrastructure service which assists the vehicle to park itself autonomously;
- *Software update*: Remote update of the software/firmware of the vehicle.

C-ITS applications in non-road modes

Although road transport is dominant in applying C-ITS services, also for the non-road modes C-ITS applications are developed and tested. For example, the French national railway company SNCF are currently testing several C-ITS applications (SNCF, 2018), including train-to-railway crossing communication to improve rail safety, train-to-train communication (e.g. to facilitate coupling/platooning of trains), train-to-infrastructure communication (e.g. to facilitate predictive maintenance schemes). Another relevant initiative in the rail sector is the deployment of the European Railway Traffic Management System (ERTMS), which is the European standard for the Automatic Train Protection allowing an interoperable railway system in Europe.

In aviation, C-ITS applications are developed a part of the SESAR program. For example, SURF ITA + is an application that uses cooperative systems to alert the pilot in case of risk of collision on ground with

other airplanes (SAFE, 2018). The System-Wide Information Management (SWIM) system provides a useful base for C-ITS applications. It may, for example, provide air navigation service providers the opportunity to re-route an airplane based on real-time weather information produced by a weather centre on the basis of data received from another airplane. However, as mentioned by (EC, 2017a), the progress of C-ITS in aviation is going slow due to the criticality and complexity of the operations and the safety and security challenges it brings to certification processes.

Emerging technologies applied in C-ITS applications

C-ITS uses connectivity (long-range and/or short-range communication) as technology. The higher level application also use smart sensors, from the vehicle and/or infrastructure. C-ITS refers to the applications, the communication technology and the direct exchange of messages/ information between transport users/vehicles and the infrastructure using this communication technology. When also sensor data is involved it is usually referred to as CCAM (see next Section). There is no strict dividing line between C-ITS and CCAM, both blend into each other, as illustrated by the application roadmap in Figure 8.

An important aspect of C-ITS is the safe and secure exchange of messages. For this, a public key infrastructure (PKI) is used, specifically designed for C-ITS. For this, the EC has put in place the certificate Policy and security policy. ETSI standards are also available. A trustful entity will be responsible for providing certificates, establishing and distributing CTLs (certificate trust list) and CRLs (Certificate Revoke List). This will be done per member states, but also Europe wide CTLs and CRLs will be exchanged.

2.3.2. Connected Cooperative Automated transport (CCAM)

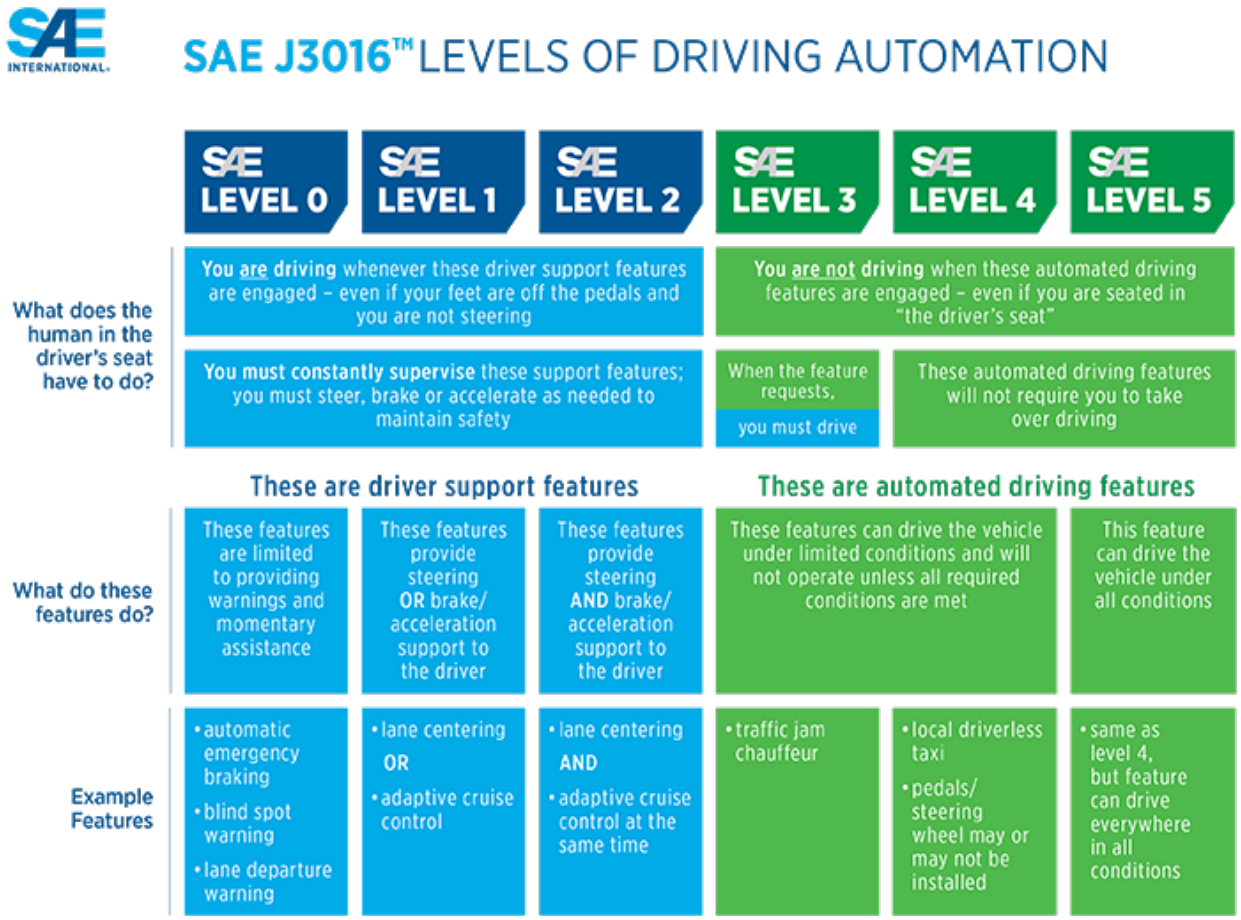
Increased connectivity and automation are important trends in the mobility and transport sector. There is a lot of attention for the development of automated road vehicles, but also for the other transport modes connectivity and automation are key elements (EC, 2017a). Moreover, connectivity and automation technologies are already well embedded in (some segments of) the rail and aviation market. In this section, we start by discussing CCAM for the road sector, followed by a discussion on the application of CCAM in the non-road modes.

CCAM in the road sector

In the last decade, the automotive industry has invested enormously in assisted and automated driving. This has led to the introduction of features like adaptive cruise control and automated lane keeping in most new cars. The ERTRAC 2019 AD roadmap shows the incremental addition of new CCAM functionality developments (ERTRAC, 2019). However, the expectations for speedy development and adoption of autonomous driving have been toned down. Experience has shown that it is not so easy to handle all possible situations on the road.

The level of automation is often indicated with the SAE (Society of Automotive Engineering) levels of driving automation, see Figure 9).

Figure 9: SAE levels of driving automation

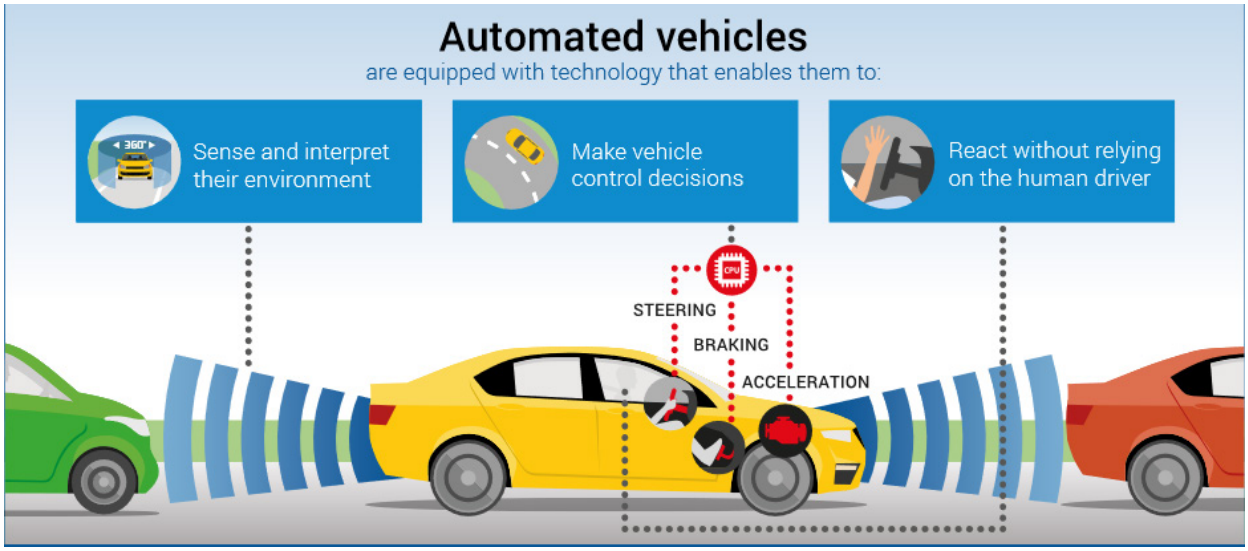


Source: SAE (2020).

Informally, Level 2 is sometimes called 'Hands off', Level 3 'Eyes off', and Level 4 'Mind off'. ACEA recently published its Automated Driving roadmap (ACEA, 2019b) with levels of automated driving: assisted, automated and autonomous.

In general, CCAM developments start at highways and evolve into the more complex urban environment, with exceptions being: shuttles on a fixed trajectory (e.g. Navya, 2GetThere, EasyMile), RoboTaxis (e.g. Uber, NuTonomy, Lyft, Waymo), and freight in confined areas with no pedestrians or only dedicated staff (harbours, loading areas). Technologies emerge mainly according to the Sense-Think-Act functional chain (see also Figure 10):

Figure 10: CCAM functional chain



Source: ACEA (2019b).

- *Sense*; Advanced sensor systems including object detection and object classification have been the seed for most CCAM advancements. Sensor types are combined to obtain a complete and robust view. Artificial Intelligence has helped to efficiently detect and classify objects. The coming decade, in the 'sense' area, there will be developments in low-cost lidar, radar-camera combinations, V2V communication (improving the quality and speed by which a shared world model can be created amongst vehicles), V2I communication (enabling collaborative driving) and 5G communication in consumer applications.
- *Think;* Since the driver will no longer be in control all the time, the vehicle control will have to handle many situations independently. As the number of situations is endless, the concept of Operational Design Domain was introduced by NHTSA and defined by SAE. it specifies what conditions the system is designed for. In the case of technical failures, the system will have to handle these by itself for at least a short time. Therefore, safety monitoring subsystems and fail-safe / fail-operational / fail-gracefully principles are applied in the control design. In the 'think 'area, there will be developments in internal system supervision, prediction and anticipation models (using prediction algorithms based on sensor data of the past) and AI control (e.g. to control steering, throttle and braking) and containment (i.e. AI functionality is only allowed to operate within predefined boundaries and once these boundaries are passed a conventional - deterministic, predictable - system will take over).
- *Act*; In order to ensure safe operational behaviour, some crucial subsystems may need to be included in a double or triple fashion (redundancy) to handle the system in case of failure of one subsystem. This can be done through duplicate systems (e.g. double brake systems) which is very costly, through combined hardware and software systems (electronics correcting steering and braking in case of a flat tyre) or through supervision systems (safety monitoring system reassigning tasks in case of failure). In the 'act' area, there will be in the coming years advancements with fail-safe vehicle components (e.g. by including self-monitoring and fail-safe functionality as an integrated part of a steering or braking sub system) and malicious actuation to counter cyber threats.

A CCAM vehicle is part of a traffic system and supports a variety of business models. With regards to business, there are also emerging technologies coming up: integration with service apps using the vehicle GPS and V2X (such as ride hailing, car or ride sharing and ad hoc delivery), distributed control principles in traffic management (predicting micro-behaviour of the vehicles), V2I communication in traffic management. Notwithstanding these novelties, traffic will continue to consist of a mixture of conventional, assisted and automated vehicles. In urban situations, vulnerable road users like cyclists and pedestrians may be surprised by unexpected automated or non-automated behaviour of vehicles as it is not possible to tell from the looks of the vehicle whether it is automated or not. This mixed traffic, especially in urban situations, demands a lot of flexibility of traffic management and CCAM vehicles. For at least a decade, traffic management will have to deal legacy vehicles on a given road, meaning that traffic management interventions will be partially received by humans alone, partially by perception and connectivity systems and the level of execution of the instructions will also vary largely. This means that e.g. in an accident 1 km ahead, some of the automated vehicles may start slowing down automatically based on a I2V or V2V warning message, where other manual drivers have no idea of the reason for the slow down and start changing lane frantically to eliminate delay. At the same time, CCAM vehicles cannot count on all other vehicles to be equipped with V2V or automated braking in all cases, meaning that response times of other vehicles remain unpredictable.

World-wide, the US and Europe have been leading in introducing CCAM vehicles market (CATRE, 2018). In the US, numerous start-ups and new companies have fertilised this research area and market, with Tesla as the most visible leader for passenger cars. The focus is on fast introduction of new features and collection of additional safety evidence in long field tests and production vehicles. In Europe, the well-established brands have introduced various CCAM features where the focus is on integration of functions in a coherent driving experience and a well-controlled introduction with proven safety. Clearly, the various US and EU regulation approaches are reflected in the industry approaches. Many methodological and technical exchanges exist which slowed down during the current US government (2016 – 2000).

The Chinese ambition at CCAM is considerable and very well-funded. Large initiatives like the Baidu Apollo program have attracted many Western partners. The Chinese home market is sufficiently large to introduce and mature CCAM in this market alone.

CCAM in the non-road modes sectors

CCAM applications are already used in rail-bound transport modes like metro systems, and in some cities (e.g. Paris) even driver-less metro systems are implemented. In other segments of the rail sector (suburban rail, long distance rail), the implementation of CCAM applications is slow, amongst others, due to fragmentation of the EU rail market in terms of safety and operational principles, technical solutions and life-cycle stages (EC, 2019a). As mentioned by EC (2017a), the rail sector acknowledge that further steps in this field are required and hence several European and national CCAM-related projects have been started. For example, in France pilots are executed with remote train driving and highly automated and autonomous trains (from level 2 to 4) in mixed railway traffic environments (EC, 2019a).

Automation is well advanced in the shipping sector as most modern ships are equipped with autopilots and track pilots and automated warnings for crossing traffic. Also automated berthing has been tested in several cases. The technical systems on board have a high level of automation and some ships could potentially be controlled from shore (although not generally allowed by authorities). There have also been some demonstrations with fully autonomous ships, but these ships are in the early stages of development (EC, 2019a).

In aviation, automation on board of the aircraft at lower levels of automation is already applied at large scale. Research has been done on fully autonomous aircrafts, but it seems some human intervention will remain necessary on regular flights to deal with unforeseen events (AAE, 2018). Automation have led to new concepts in air transport such as (unmanned) drones and a further evolvement of these concepts is expected (EC, 2017a). However, as mentioned before, these applications will not be discussed in detail in this report. Automation will probably also provide new features to improve Air Traffic Management performance. For example, departure, arrival and taxiing managers are being integrated by using higher levels of automation what will improve capacity and efficiency (EC, 2017a).

2.3.3. Mobility as a Service (MaaS)

MaaS is a relatively new concept and has the potential to impact the transport sector similarly to the way online retailers have impacted traditional street shopping. It offers transport users access to plan, book and pay for a range of modes and travel experiences, which can be easily accessed from smart phones or tablets. MaaS envisions a shift from the current transport model, where individuals move primarily in privately owned vehicles, towards a model where users have a range of travel services they can use according to their needs.

MaaS has two primary parts, transportation services (the wheels on the ground that transport you) and the MaaS platforms (the apps) which allow interoperability and easy use of and between multiple transportation services and modes. These travel services are on-demand, do not require user ownership of any particular vehicle, and can be mixed within a single trip. It is a shift from mobility as a commodity ('I purchase a vehicle to move around') to mobility as a service ('I purchase a ride to move around') (Araghi, et al., 2020). This development of moving from ownership to access is also referred to as the sharing economy or access versus ownership (Münzel, 2020).

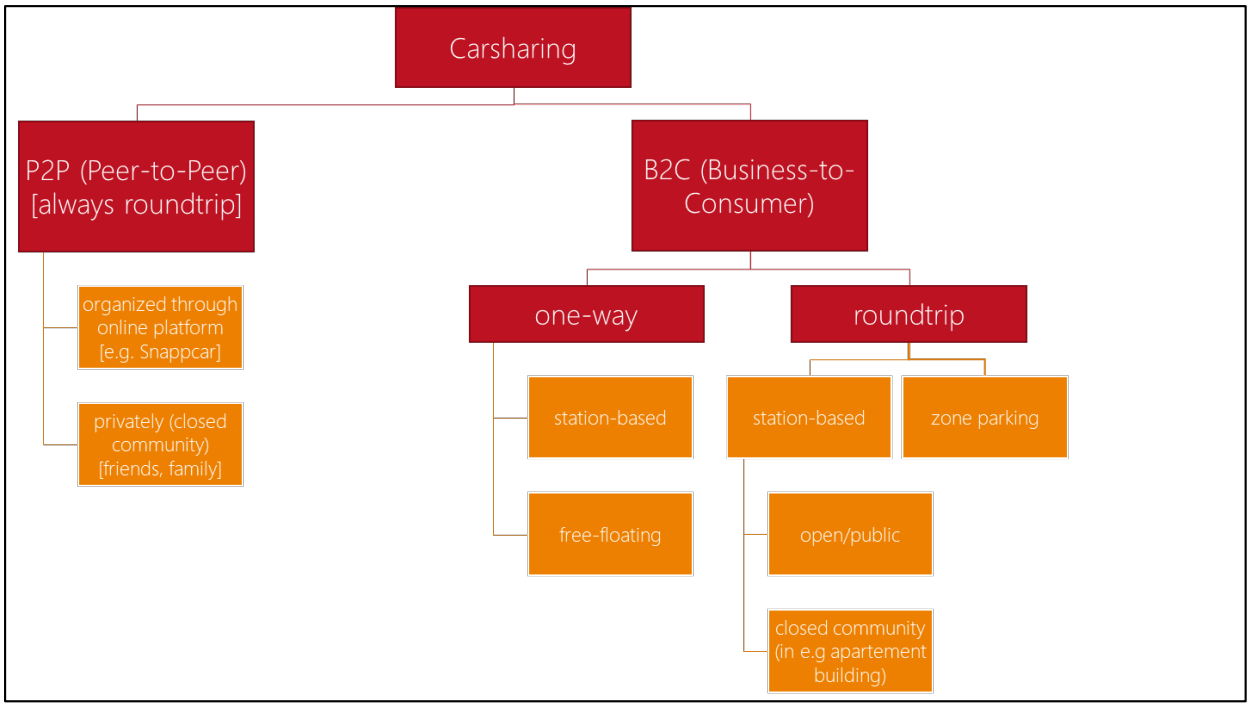
Although there is little agreement on a 'definition' of MaaS, on what makes a service a 'MaaS service' (Sochor, et al., 2018), the central elements in addition to access instead of ownership include:

- User needs as the main focus;
- Mobility rather than transport;
- Integration of transport services, information, payment.

In other words, MaaS "is the integration of various forms of transport services into a single mobility service accessible on demand." (MaaS Alliance, 2017)

A wide range of transport services can be part of a MaaS such as public transport, ride-, car, bike and scooter-sharing, taxi, car rental or lease, or a combination. MaaS is also not limited to road transport as particularly rail transport options can be part of a MaaS ecosystem. The transport options can be owned by users, the transport operator or by a MaaS provider. Vehicles can also be shared. These different forms of governance of mobility services is illustrated for car sharing in Figure 11. Hence, MaaS can use traditional and new transportation services and integrate these into mobility services for the user.

Figure 11: Different forms of shared mobility



Source: Münzel (2020)

Not all different types of transport services are available in each European country or in any given city or metropolitan region. For example, e-scooters are currently not allowed in The Netherlands and the UK (TNO, 2020b). Shared mobility, especially free-floating services, are highly regulated in most European countries. Also ride-haling services are generally not allowed in their original form in Europe, but instead often have to follow (taxi) regulations (which requires a professional driver often accompanied by a taxi licence).

Motivations to apply MaaS

There may be various motivations to implement MaaS schemes. For the private sector, MaaS may offer ample business opportunities for new as well as existing players, and opportunities for disruption of the status quo of the mobility market. On the other hand, for the public sector MaaS services may be seen as an option to battle some of their mobility, sustainability and urban space problems. The latter is illustrated in the case of Finland where MaaS is part of a broad policy package aimed at attaining sustainable transport.

The goals and phase of development of MaaS can be characterised using the MaaS levels ranging from no integration 'level 0' to 'level 4' where MaaS service provision can be steered towards societal goals on a systemic level (Sochor, et al., 2018). Policies and incentives can be used to steer users and providers to optimise the mobility use towards societal goals, such as sustainability and equity (see Figure 12).

Figure 12: Levels of MaaS

Source: Sochor et al. (2018).

Emerging technologies facilitating MaaS

As a MaaS scheme incorporate several mobility options, the multimodal nature of the service results in a need for standardised data from all the included services. The services can be provided by a wide range of parties, public and private, small and large companies. The more diverse the data is as well as the number and the diversity of involved stakeholders, the more complex the data handling.

Emerging technologies like big data techniques and AI techniques can support some of the data complexity challenges such as:

- Data of a diverse nature (data from various modes of transport, data from different stakeholders in various formats, data concerning different aspects of user behaviour).
- Large amounts of data (e.g. if location data is collected from a group of travellers for multiple days, the amount of data can grow fast).
- Predicting future behaviour of travellers, traffic and vehicles (e.g. mode choice prediction, congestion prediction and availability of vehicles at certain times and locations).

Furthermore, emerging technologies like platform technology and data communication technology (Wi-Fi, 4G or 5G) can support the integration of travel options and the communication of information used by MaaS services. A digital platform needs a front office (e.g. a website or mobile app) to communicate to the customers and a back office to communicate with the different parties involved. A MaaS platform can manage "business processes related to the collection of data from the various service providers, including trip information, routing, and transactions, takes care of the various B2B clearing processes, and makes relevant data available to MaaS operators in the form of APIs" (MaaS Alliance, 2017).

The future development of MaaS

The development of MaaS is dependent on technological, societal, market and governance developments. Technological developments are for example the accessibility and sharing of data, the interoperability of data and services (requiring standards), the ability to remotely book and pay for services, and the use of smart phones and cloud services. Societal developments are the willingness of users to share vehicles, reduce vehicles ownership and the openness for (new innovative) mobility services. Market developments are the entry of new parties in the mobility domain, the offering of new services such as subscription-based mobility and development of platforms. The developments in the governance of MaaS are dependent on the goals and motivations of (different levels of) governments to influence MaaS and steer the development of MaaS, ranging from no regulation to strong regulation by the government. Once MaaS scales up from providing services to early adopter to larger consumer groups and becomes more of a mature market, the influence on the overall mobility sector can change drastically.

2.3.4. Self-organising Logistics (SoL)

For the successful organisation and performance of logistic chains, many organisations are dependent on each other. Currently, in many cases coordination of activities between these organisations is still limited which leads to inefficient and unsustainable logistic chains. Because of this, and driven by the digitalisation trend which makes exchanging data more easy, there is a strong need for more coordination between logistic activities.

In several projects and initiatives, so-called control towers are being developed and implemented for central coordination of (parts of) the logistics chain. Data has to be shared with the control tower, which the control tower processes and uses to make coordinated decisions for the companies in the logistics chain, and the companies have to accept and apply the decisions accordingly. In situations where the involved companies trust such a control tower and where there is enough time for sharing and processing this data (situations that are not very dynamic), this central coordination approach can work. However, in many cases companies do not trust a control tower and/or do not want to be dependent on a control tower. Besides, many situations are very dynamic and there is no time to share and process data and make data driven optimised solutions by the control tower. For these dynamic situations, decentral coordination of the logistics chain will probably be a better approach.

Decentral coordination of the logistics chain – also called self-organising logistics (SoL) – means that individual agents in the logistics chain (either companies, vehicles, loading units such as containers or packages) make autonomous decisions based on local intelligence and local data. Companies are doing this already, but mainly based on limited data in terms of quality and completeness. For other agents such as vehicles and loading units also, high quality and complete (near) real-time data is needed to create situational awareness. The trend towards digitisation and automation is expected to make it feasible and easier to create this situational awareness. Main advantages of this approach are that companies are not dependent on a control tower and only limited amounts of data have to be exchanged with only a limited number of other agents. Self-organising logistics is strongly driven by digitalisation and automation and is a next step from synchromodal transport[18] towards the physical internet[19].

[18] Flexible and sustainable allocation of cargo to different modes and routes in a network under the direction of a logistics service provider who gets the freedom from the shipper to do this.

[19] Synchromodal transport with shared assets over shared transport networks and shared hubs with modular loading units.

Currently, developments are ongoing to support planners with algorithms in their synchromodal planning. The algorithms deliver advice and it is up to the planners to use this or not. Such applications are currently developed, tested and implemented. Autonomous data driven decision making by algorithms for individual agents in the logistics chain (with digital twins) is still in the development phase, but several research projects and pilots have started on these topics. For instance, TNO developed an autonomous algorithm for the planning of demand of transport and supply of transport for a fleet of trucks together with a logistics service provider and a transport operator (Ommeren, et al., 2020). Given the large expected benefits, and driven by the strong development of digitalisation and automation, it is expected that self-organising logistics will show a strong development the coming years.

Further use of emerging technologies in SoL

For the successful implementation of self-organising logistics sensing, thinking and acting are important topics (see Section 2.2.6 for more explanation). The challenges for further development can be described as follows:

- Sensing – For autonomous decisions made by individual agents based on local data it is necessary to measure indicators and to collect the data real-time. For this sensing IoT and 5G are important to get real-time information about the status of all kind of assets. Besides, for storing, sharing and processing the data, technologies such as blockchain and data spaces (like IDSA) are important to create visibility in the logistics chain, (near) real-time situation of goods and assets such as the confirmation of delivery of goods, (including data/time or estimated time of arrival of a truck or a barge), under the condition that data will only be shared with organisations that are allowed to get. This data will be made available through digital platforms.
- Thinking – Lots of data will become available if all kinds of assets are sharing real-time data about their status. To get information out of this big data, data analytics is required to understand the current situation of the logistics chain and autonomous algorithms (i.e. intelligent software that can act independently and that can support more and more activities of people, or even take over activities completely such as self-learning algorithms) in order to predict future situations. AI will help and speed-up this thinking step.
- Acting – Finally, data driven decisions are being made in the acting step. Autonomous algorithms can support human planners to make better decisions or take over simple repetitive planning work. Algorithms can also replace human actions and decisions for individual agents in the logistics chain. It is expected that self-learning algorithms (AI) can improve decisions and therewith the performance of the logistics chain based on big data from sensors a lot.

2.3.5. Integration of various applications

In this chapter we have described some applications which will become possible thanks to the emerging technologies. We have described them separately, but it is important to realise that these services will most probably (partly) merge in the future. This is most clear for C-ITS and CCAM, as the full benefits of automated mobility are only achieved if vehicles are connected to each other and to transport infrastructure (EC, 2019e). C-ITS services may also become a central element of Self-organising logistics. Furthermore, MaaS schemes are often considered as an important facilitator for the deployment of autonomous vehicles, particularly as the high investment costs of these vehicles

can be allocated to many users in this way. At the same time, autonomous vehicles may provide the high level of flexibility that may be required to successfully implement MaaS schemes. For all these reasons, it was mentioned by several interviewees that in the long run the various applications should not be considered separately, but in an integrated way. Boundary conditions for successful implementations like standardisation, interoperability and trust (in the data itself as well as how data is used), already important within one type of application, become even more important when merging applications. Lack of compatibility can lead to local, suboptimal implementations or to more expensive solutions, as the interoperability has to be achieved afterwards.

For the sake of clarity, we will continue to describe the applications separately in this report, so to be able to assess their individual impact on the transport sector. Where relevant, any interactions between the various applications will be discussed.

3. IMPACTS OF EMERGING TECHNOLOGIES ON THE TRANSPORT SECTOR AND SOCIETY

KEY FINDINGS

- The Smart Mobility applications are expected to provide significant benefits for transport users, both passengers and goods. If designed, implemented and managed well, C-ITS and CCAM are expected to result in safer and more efficient driving and a higher sense of comfort. For MaaS and SOL, lower user costs and higher levels of transport efficiency (e.g. flexibility) are important potential benefits for transport users.
- The Smart Mobility applications also have the potential to contribute to the achievement of societal goals, like less Greenhouse gas and air pollutant emissions, higher levels of transport safety and lower congestion levels. To fulfil this potential, it is important to minimise any rebound effects of the deployment of these applications (e.g. increased transport demand).
- The Smart Mobility applications may improve the competitiveness of the EU transport sector (by improving transport efficiency) and industry (new business opportunities). With respect to the latter, the EU's competitive position on the international market for Smart Mobility is key.
- The actual design, implementation and management of the Smart Mobility applications and the policy context in which they will be implemented is crucial to fulfil the high potential of these applications to contribute to a more sustainable, safe and efficient transport system. If not managed well, Smart Mobility can also lead to a range of negative impacts.
- The full impacts of all Smart Mobility applications will only be realised on the long-term. First of all, because most of the applications need a critical mass to become fully effective. Secondly, because all Smart Mobility applications are still in development and are expected to become more effective in the next decade due to technological improvements.
- Evidence on the impacts of the various Smart Mobility applications is only available from small-scale pilots, (mainly qualitative) scenario analyses and stated preference studies. Therefore, the uncertainty on these impacts (the direction and magnitude) is very high.

3.1. Introduction

The previous chapter has introduced several types of emerging technologies and their main applications within the transport sector. In this chapter the (potential) impacts of these applications are being described, distinguishing the four categories of applications identified in Section 2.3.

In Sections 3.2 to 3.5, potential impacts of the four Smart Mobility applications are discussed, considering the impacts on the transport sector (i.e. transport demand, vehicle ownership, modal shift, transport efficiency, travel experience), environmental impacts (i.e. climate change and air pollution), social impacts (i.e. safety, congestion, accessibility) and economic impacts (i.e. impacts on the European industry and financial impacts for the end-user). At the end of each section, the expected trend in these impacts over the next decade is briefly discussed as well as the main drivers explaining these expected

trends. Furthermore, it is briefly discussed whether differences in impacts between different spatial settings (e.g. urban, rural, highways) may be expected.

The Smart Mobility applications considered in this study are highly innovative and in many cases the evidence on their impacts is limited (as evidence is often only available for a small number of pilots) and/or rather explorative (as the evidence is partly based on expert interviews or simulation exercises). Therefore, the uncertainty on the direction and level of the impacts is often large. Therefore, we explicitly discuss the level of certainty for each of the impacts (for each of the Smart Mobility applications) in this chapter.

3.2. C-ITS applications

3.2.1. Impacts on the transport sector

Transport demand

The impact of most C-ITS applications on road transport demand is expected to be low/negligible (TNO, et al., 2014). Only applications considerably lowering the average speed (and hence increasing the overall duration of journeys), like in-vehicle speed limit signalling, may affect transport demand to a certain extent. Some C-ITS applications may, however, affect the total number of vehicle kilometres. For example, smart routing applications and applications providing parking information may result in a lower total number of vehicle kilometres. On the other hand, smart routing applications may also provide the fastest routes that takes more kilometres. Therefore, the impact on total number of vehicle kilometres is unknown.

For the non-road modes also, C-ITS (and traffic management) are, in general, not expected to significantly affect total transport demand. A reduction in vehicle kilometres may, however, be achieved for these modes as well. For example, within the public-private partnership SESAR it is expected that innovative air traffic management services may reduce en-route aviation distances by up to 2.5% (SESAR, 2020).

Vehicle ownership

The installation of in-vehicle technologies to make vehicles ready for specific C-ITS applications may increase the vehicle production costs and hence purchase prices. This increase in purchase prices may discourage the purchase (and ownership) of vehicles. However, for most C-ITS applications the costs per vehicle are probably relatively low (TRL, 2017) and therefore we expect that this impact is very small/negligible.

Modal shift

For the various transport modes, it is claimed that applying C-ITS applications may improve the attractiveness of those modes because of increased traffic efficiency (i.e. reduction in travel times). Ricardo & TRT (2016), for example, estimate that the deployment of a set of C-ITS applications in road transport might result in a slight modal shift (less than 1%) away from trains and air travel to cars and busses. On the other hand, the deployment of the European traffic management system for rail transport ERTMS is claimed to contribute to a modal shift away from aviation and road transport to rail transport (Zahurul Islam, D.M.; Ricci, S.; Nelldal, B.L., 2016). To our knowledge, no analysis including C-ITS applications for all transport modes have been carried out and hence the overall modal shift impacts for the entire transport system are uncertain (and may differ significantly between different situations).

Transport efficiency

One of the main benefits of C-ITS is the increased transport efficiency that could be achieved (EC, 2017e), particularly in terms of making better use of the existing capacity of the infrastructure. In road transport this results in less congestion, an impact that is discussed in Section 3.2.3. In rail transport, solutions like innovative real-time decision support systems for predictive and adaptive operational control of train movements and the traffic management system ERTMS are expected to significantly enlarge the railway capacity by reducing the headway between trains (EC, 2017e). It is claimed (not validated) that the application of ERTMS could provide up to 30% more capacity on currently existing infrastructure (UNIFE, 2014). In aviation, also, increased air-to-ground and air-to-air interoperability using C-ITS technologies may contribute to optimising the use of airspace and ground resources (EC, 2017e).

Travel experience

The use of C-ITS applications in road transport may have positive travel experience impacts. An increased sense of comfort, safety and a reduction in stress and uncertainty were found by TNO et al. (2014) as drivers for these positive impacts. For example, Green light optimal speed advisory (GLOSA) and traffic jam ahead warning (TJAW) were mentioned as applications resulting in higher levels of comfort, while applications like obstacle warning and car breakdown warning contribute to increased feelings of safety. EC (2017b) specifically mentions that better and more real-time information could provide significant added value to travellers and hauliers, as this gives them the opportunity to make better decisions in, for example, route selection.

More reliable and shorter travel times may also benefit rail transport and aviation, provided by applications like adaptive operational control of train movements in rail transport, and cooperative aviation transport management systems in aviation (EC, 2017e), all contributing to a better travel experience.

3.2.2. Environmental impacts

GHG emissions

Several C-ITS applications for road transport are leading to improved fuel efficiency and reduced CO_2 emissions due to a reduction in the number of kilometres driven (e.g. smart routing devices, parking information) or by facilitating a smoother driving style (e.g. GLOSA). The CO_2 impacts of (Day 1 and Day 1.5[20]) C-ITS application have been studied by several studies, including TNO et al. (2014), Barth et al. (2015), ERTICO (2015), and Kulmala et al. (2012). Most of these studies present data on the CO_2 reduction potential at the vehicle level[21] in specific situations. Ricardo et al. (2018), on the other hand, present CO_2 reductions at the level of the entire transport system, assuming a maximum deployment of the various applications. In Table 2, these CO_2 reduction figures are presented for a selection of applications. In general, the CO_2 reductions of the individual applications range from 0.1 to 3.5%, depending heavily on the type of road considered. Traffic signal priority request[22] by public busses seems to be very effective in urban areas, where it could reduce CO_2 emissions of these vehicles up to 8%. In the estimation of these CO_2 impacts some market penetration of electric vehicles in the period up to 2030 is assumed. However, as this market penetration goes faster than assumed, the size of the CO_2 impacts may decrease.

[20] See Section 2.3.1 for a description of Day 1 and Day 1.5 C-ITS applications.

[21] Mostly passenger cars, but for some applications also at the level of busses or trucks.

[22] This application adjusts the signal-timing plan at intersections according to bus arrivals.

Table 2: CO2 impacts of several C-ITS applications for road transport

C-ITS application	Reduction in CO_2 emissions
In-vehicle speed limits	2.5 % on motorways and 3.5% on interurban roads
Green Light Optimal Speed Advisory (GLOSA)	0.1% on interurban roads and 0.7% on urban roads
Traffic signal priority request by designated vehicles	8.3% on urban roads for busses
Traffic information & smart routing	1.9% across all road types
Parking information and management	0.8% on urban roads

Source: Ricardo et al (2018) based on a review of a wide range of studies.

Ricardo et al. (2018) also studied the CO_2 impacts for several scenarios, deploying a wide set of C-ITS applications, including the ones mentioned in Table 4. These scenarios differ in the level and speed of deployment of the various applications. In the most ambitious scenario, the total net benefit of the CO_2 reduction achieved in the EU27+UK for the period 2020-2035 was equal to € 11 billion. In the least ambitious scenario, the total net benefits were still equal to € 5 billion (about 1.4% compared to the baseline).

In the non-road modes also, C-ITS could contribute to lower CO_2 emissions. For example, simulation runs show that driving advisory systems in trains may reduce the CO_2 emissions of a train by 8 to 26% in specific circumstances (UIC, 2016). In aviation, the European SESAR project's contribution to air traffic management (ATM) modernisation (including the appliance of C-ITS) is expected to result in 10% CO_2 reduction (EC, 2017e).

Air pollution

In addition to a reduction in CO_2 emissions, C-ITS applications may also result in reductions in NO_x and PM emissions. The reduction rates are in general lower than for CO_2 emissions, as is shown in Table 3, ranging from 0.1 to 1.7% for NO_x and 0.1 to 0.8% for PM emissions. Again, significantly higher reduction rates are found for traffic signal priority requests by public busses (about 8%). On interurban roads, in-vehicle speed limits (application providing information to the driver on speed limits) result in higher PM emissions, likely due to increased braking or speed changes when approaching new speed limits.

Table 3: Impact on air pollutant emissions of several C-ITS applications for road transport

C-ITS application	Reduction in NO_x emissions	Reduction in PM emissions
In-vehicle speed limits	0.5% on motorways 0.4% on interurban roads	0.4% on motorways -4.2% on interurban roads[a]
Green Light Optimal Speed Advisory (GLOSA)	0.1% on interurban roads 0.2% on urban roads	0.1% on interurban roads
Traffic signal priority request by designated vehicles	8.0% on urban roads for busses	8.2% on urban roads for busses
Traffic information & smart routing	0.4% on motorways 1.7% on interurban roads 0.5% on urban roads	0.3% on motorways 0.8% on interurban roads 0.1% on urban roads
Parking information and management	0.3% on urban roads	0.1% on urban roads

Source: Ricardo et al. (2018) based on a review of a wide range of studies.
An increase in PM emissions is estimated at interurban roads likely due to increased braking or speed changes when approaching new speed limits.

3.2.3. Social impacts

Traffic safety

The impacts of C-ITS applications on road safety have been assessed in various studies and projects (for an extensive overview see Ricardo et al. (2018)). The results of these studies show that there are several C-ITS applications that could significantly contribute to the prevention of vehicle collisions and hence casualties. According to EC (2017b), the applications for which the technology is sufficiently mature and benefit-cost ratios are positive should be deployed on a short notice. In that respect the applications with the highest safety improvement potential should be prioritised. More specifically, the C-ITS Platform recommends to deploy the applications as presented in Table 4.

Table 4 : C-ITS applications targeting traffic safety and their impacts

C-ITS application	Average reduction in number of fatalities	Average reduction in number of injuries
In-vehicle speed limits	6,9%	3,9%
Emergency electronic braking light	2.7%	2.5%
Road works warning	1.3%	1.1%
Weather conditions	3.4%	3.4%
Hazardous location notification	4.1%	3.1%
Intersection safety	3.8%	7.0%
Vulnerable road users protection	1.8%	1.9%

Source: Ricardo et al. (2018), based on a review of a wide range of studies.

The impact of these individual applications on the reduction in the number of fatalities range from 1.3% to 6.9%, while for the number of injuries this range in reduction rates is 1.1 to 7.0%. Ricardo et al. (2018) also have studied the transport safety impacts for several deployment scenarios of a wide set of C-ITS applications, including the ones mentioned in Table 4. The total net benefits of reduced traffic accidents in the EU27+UK for the period 2020-2035 are estimated at € 98 billion. In the least ambitious scenario, the total net benefits were still equal to € 15 billion, which corresponds to a reduction of 3.700 fatalities and almost 250.000 injuries in that period.

In the non-road modes, also, C-ITS and traffic management applications are used to improve traffic safety. For example, in rail transport safety is one of the key priorities in the development of automatic train protection systems (ATP), advanced trajectory planning and innovative signalling systems (including ERTMS) (EC, 2017e). In aviation, the SURF-ITA+ application (traffic alerts for pilots in airport operations) enhances safety by providing alerts to the flight crew in case of risk of collision on ground, using cooperative systems receiving signals from surrounding traffic (SAFE, 2018).

Congestion

The deployment of C-ITS applications can provide a significant contribution to the reduction of (urban) congestion. Ricardo et al. (2018) estimate that a large-scale implementation of C-ITS in road transport may result in a societal benefit (i.e. travel time savings) of € 218 billion in the period 2020-2035 in the EU27+UK. In monetary terms, this potential benefit of C-ITS is significantly larger than the improved traffic safety and reduced environmental impact of road transport.

For illustrative purposes, the impact of a selection of individual C-ITS applications on (urban) congestion levels are shown in Table 5. Particularly, traffic information and smart routing has a large congestion reduction potential. Optimising routes based on traffic flows, traffic lights and speed limits and by offering re-routing suggestions based on real-time traffic information may result in up to 8% reduction in travel times in urban area.

Table 5: C-ITS applications targeting congestion and their impacts

C-ITS application	Impact on congestion (in terms of average speed or travel times)
Hazardous location notification	Ca. 2% reduction in travel times on urban roads
Traffic signal priority request by designated vehicles	9.2% reduction in travel times of busses in urban areas
Traffic information & smart routing	8% reduction in travel times in urban areas
Parking information and management	0.6% reduction in travel times in urban areas

Source: Ricardo et al. (2018), based on a review of a wide range of studies. The reduction in travel times of hazardous location notification have been estimated by CE Delft & TNO based on the average increase in speed reported by Ricardo et al.

Accessibility

The impact of C-ITS applications on the accessibility of the transport system is to our knowledge not studied in the literature. Given the fact that most C-ITS applications are targeted on transport efficiency, safety or environmental issues, it is expected that the impacts on accessibility are not significant.

3.2.4. Economic impacts

Impact on the European industry

The impacts of the deployment of C-ITS applications on the European economy and industry is studied by Ricardo et al. (2018). For three policy scenarios, varying in the level and speed by which they stimulate the uptake of C-ITS applications, they estimated the impacts on GDP and employment. On the EU level, both impacts were positive but small. For example, in the most ambitious policy scenario, assuming mandatory deployment of V2V communication, EU27+UK GDP will increase by 0.02% in 2030 and 0.03% in 2035. In this scenario, 93.000 additional jobs are realised in 2030 in the EU27+UK, which is an increase of 0.014% of total European employment. It should be noted that these are all economic impacts at the EU level. At the level of individual industries or regions, the impacts could be more significant (and potentially also negative).

Financial impacts for end-users

The financial impacts for end-users are uncertain, particularly because the business models that will be applied for C-ITS are still uncertain (EC, 2017b). The main uncertainty in this respect is who will pay for the upfront investments in transport infrastructure. If these investments are funding from public sources, the costs of C-ITS services for end-users may be modest. However, if these investments have to be funded by private agents, these costs will probably be passed through to end-users via relatively

high prices for making use of the C-ITS services. As is illustrated by the case study on C-ITS (see Annex C), it is unclear whether and to what extent end-users are willing to bear these higher prices.

3.2.5. Synthesis

The main objectives of C-ITS applications are to improve traffic safety and/or transport efficiency (including reduction of congestion) and/or environmental performance. On these indicators, C-ITS scores well, as is also indicated in Table 6. The (other) transport impacts of C-ITS are, in general, limited as are the economic impacts on the European industry.

For most indicators, there is considerable certainty on the direction and level of the impacts. However, as regards the impacts of C-ITS applications on vehicle ownership, modal shift, accessibility and financial impacts for the end-user, the available evidence is not conclusive. Particularly the uncertainty on the financial impacts for the end-user is important, as this is directly related to the difficulties to develop a viable business case for C-ITS applications, which is one of the main challenges for large-scale market deployment of these applications. This issue is discussed in more detail in Chapter 6.

Table 6: Summary of impacts C-ITS

Indicator	Impact
Impacts on the transport sector	
Transport demand	Impacts on transport demand are expected to be low.
Vehicle ownership	The impact on vehicle ownership is uncertain, but probably small.
Transport efficiency	C-ITS improves transport efficiency, particularly in terms of making better use of the existing capacity of the infrastructure.
Modal shift	As C-ITS may improve the attractiveness of all transport modes, the overall impact on the modal split is unknown (also because it has not been studied).
Travel experience	C-ITS applications will improve travel experience, e.g. by providing more comfort, improved feelings of safety, more reliable travel times, etc.
Environmental impacts	
GHG and air pollutant emissions	Deployment of (some types of) C-ITS applications may result in significant emission reductions.
Social impacts	
Traffic safety	C-ITS could significantly contribute to a higher level of traffic safety.
Congestion	C-ITS could significantly contribute to lower levels of congestion.
Accessibility	The impacts of C-ITS on accessibility are uncertain, but probably not significant.

Indicator	Impact
Economic impacts	
Impact on European industry	C-ITS deployment may have slight positive impacts on the European industry (GDP, employment). These impacts may vary widely between industries and regions.
Financial impacts for end-users	The financial impacts of C-ITS for end-users depend on the business models that will be applied and are still highly uncertain.

Note: green indicates that assessment of impact is rather certain, while orange shows that assessment of impacts has a high level of uncertainty.

The impacts of C-ITS applications are expected to increase over time. First of all, because more effective applications will come to market (Day 3+ applications[23]). But also because the effectiveness of the applications are expected to increase as the number of vehicles (and infrastructure) equipped to make use of these applications will increase (as a critical mass is required to fully exploit the benefits of C-ITS applications, as mentioned before).

Finally, the impacts of C-ITS applications may occur in both urban and rural areas, depending on the specific type of application considered. Applications like GLOSA and parking information are, for example, mainly relevant for urban areas, while in-vehicle speed limits is expected to have larger impacts in rural areas (on interurban roads and motorways).

3.3. Connected Cooperative Automated Mobility (CCAM)

3.3.1. Impacts on the transport sector

Transport demand

It may be expected that adoption of CCAM will lead to an increase in transport demand (EC, 2019e). One reason for this is that if traffic becomes more efficient, thereby increasing the capacity of the infrastructure (e.g. by reducing headways between vehicles), more use can be made of the existing infrastructure while still reducing congestion (EC, 2017a). Also, the fact that a driver does not need to pay attention (or at least less attention) might affect the transport demand in several ways. As driving becomes more comfortable, there might be a trend toward longer average trips and a modal shift towards more car traffic. A third potential reason for an increase in passenger car transport demand is that, once level 5 of automation is reached, a new group of current 'non-drivers' (e.g. elderly, disabled, low-income households) could use cars as a means of transport (Cohen & Cavoli, 2019) (Meyer, et al., 2017). Finally, if connected and fully automated vehicles are used in shared shuttle services, additional vehicle kilometres may be travelled as a result of their repositioning, travelling empty to pick up new passengers or reaching a specific location (EC, 2019e) (Legêne, et al., 2020) (Meyer, et al., 2017).

Although there is a shared understanding on the fact that CCAM will lead to an increase in road transport demand, the level of this increase is rather uncertain. Based on a literature review, Milakis et al. (2017) found a potential increase of fully automated passenger car transport demand by 3 to 27%. A comparable trend is mentioned by Cohen & Cavoli (2019), who find an increase in the number of

[23] See Section 2.3.1 for a description of Day 3+ C-ITS applications.

vehicle kilometres of 20-25%. On the other hand, EC (2019e) presents long-term increases of the number of vehicle kilometres up to 50-60%.

For non-road modes, the impacts of CCAM on transport demand is not/poorly studied. However, it may be expected that the increased transport efficiency for these modes (see below) will result in more capacity and hence more transport demand. The size of this additional transport demand is, however, very uncertain, and also depends on a possible modal shift from the non-road modes to road transport (see below).

Box 2: Impact of automated vehicles on vehicle kilometres

The case study on regional impacts of automated driving in Annex D describes the model outcomes of a transport model applied to estimate the potential impacts of automated and shared vehicles in the Dutch Province of North-Holland and the larger Amsterdam region. Model outcomes stress the need for policy interventions to prevent an increase in vehicle kilometres.

Without policy interventions

In the most unfavourable situation, in which fully automated vehicles (level 5) are allowed in unlimited numbers, cities will face major negative consequences on the quality of life and accessibility. In an extreme situation where 100% of vehicles are fully automated, despite the increase in capacity, the number of vehicle kilometres may increase by 74% and congestion in cities may more than triple. The dominant position of the car puts pressure on the profitability of public transport, with all its consequences. It also leads to less walking and cycling.

With policy interventions

If the use of taxi services (using automated vehicles) is stimulated and the use of private cars is strongly discouraged, this increase may level off somewhat. Only if the use of private cabs is also discouraged and ride sharing is strongly stimulated the number of vehicle kilometres can decrease. In an extreme situation where private use of vehicles is no longer allowed at all, the number of vehicle kilometres decreases by 88%.

The case study shows that a strong mix of interventions is needed to keep vehicle kilometres at the same level as in the reference scenario, especially in urbanised areas. In other areas the impact of interventions is more modest.

Vehicle ownership

CCAM is claimed to have a large potential in reducing private car ownership (EC, 2019e). Particularly if a large-scale market penetration of fully automated vehicles is combined with a rise of car-sharing (or ride-hailing) concepts, a drop in car ownership might occur. The level of this drop depends on the automated mode (vehicle-sharing, ride-sharing, etc.), the penetration rate of automated vehicles and the presence or absence of public transport (Milakis, et al., 2017), but according to (EC, 2019e) and (Legêne, et al., 2020) reduction rates up to 90% are possible in the long term.

However, the level by which CCAM will contribute to a large increase in car-sharing concepts is questioned in literature. The Dutch institution KiM for example considers two possible pathways towards a driverless future: one with increased car-sharing and one with predominantly private car ownership (KiM, 2017). The same types of scenarios are presented by (Legêne, et al., 2020), who show that in case of predominantly private car ownership, total car ownership could even increase (as cars become more attractive, easier to use, and readily available for a broader public and multiple purposes). Thompoulos and Givoni (2015) argued based on a literature review that automated driving

could lead to a decrease in car ownership, but only if the technological developments are accompanied by a social change in which sharing is seen as superior to owning as well as the implementation of supporting policies preventing increased car ownership. The important role of policies in avoiding an increase in private car ownership is also highlighted by studies like Livingston et al. (2020) and (Szimba & Hartmann, 2020).

Based on the (weak) evidence in the literature, we expect that CCAM will in the long run lead to lower levels of car ownership, but the level by which this reduction will take place is highly uncertain and, among other things, depends heavily on the policy context (e.g. the extent by which private ownership of cars is discouraged).

Modal shift

CCAM is expected to result in a modal shift of passengers from public transport (or from active modes) to the car, as the convenience of car use improves (EC, 2019e) (Milakis, et al., 2017) (Bosch , et al., 2018). This effect will be highest for level 5 automation, but also at lower levels of automation, increased car use (instead of public transport) may occur as well due to higher levels of convenience and comfort. Another driver for a modal shift towards car travel is that, once level 5 of automation is reached, people without a driver licence can use cars as a means of transportation. This could effectively mean that those people sometimes choose a car when they currently would have to use another transport mode (Cohen & Cavoli, 2019). In the long run, automated shuttle services may complement or replace public transport in last-mile transport (EC, 2019e) (Meyer, et al., 2017). Because of its flexibility and modularity in vehicle concept, it may provide options to efficiently match supply and demand (e.g. by offering demand responsive transport).

For freight transport also, cost saving innovations like platooning for trucks could lead to a shift from rail (or inland navigation) to road (EC, 2017a). Although similar concepts could be applied in rail and inland navigation transport as well, the savings on personnel costs achieved are much larger for road transport than for these two other modes.

Transport efficiency

Theoretically, CCAM techniques provide a significant positive potential for increasing transport efficiency. For example, the specific application of platooning is expected to allow for more optimal use of the available road capacity, as headway between vehicles could be reduced (TNO, 2015). For trucks, this could reduce the use of road capacity on the highway up to 46%.

However, as is pointed out by EC (2019e), there are some elements that should be considered carefully when assessing the impact of CCAM on road capacity. First, connected and automated vehicles are primarily designed to be safe and these vehicles will not take the risks that human drivers will take to minimise travel time and/or costs. Second, because of the focus on safety (and comfort), vehicle manufactures will mainly implement human-resembling vehicle operations (to increase user's acceptance) instead of functionalities that may contribute to more harmonised traffic flows. Furthermore, all vehicles manufacturers will implement different algorithms and technical devices (e.g. different types of sensors) in their vehicles, implying that different types of automated vehicles have to coexist on the roads, which will probably adversely affect traffic flow homogeneity. Because of these different elements, connectivity between vehicles is key to achieve (some of) the transport efficiency potential of CCAM (Atkins, 2016). EC (2019e) shows that without connectivity automated vehicles may significantly worsen the traffic flow as soon as a significant penetration rate (about 25%) is reached. On the other hand, in case connectivity is in place, capacity of the road network is expected to increase by about 20% when a 100% penetration of automated vehicles is achieved.

It will be clear that improvements in transport efficiency will only be obtained when a certain threshold of automated driving penetration has been reached. Based on the existing literature on this topic, Milakis et al. (2017) estimated that 40% penetration of fully automated driving is required for significant improvements in transport efficiency, with a potential doubling of capacity at a 100% penetration rate. Atkins (2016) expects that even higher penetration rates (50% to 75%) are required before major benefits are seen.

For non-road travel, CCAM may contribute to transport efficiency as well. Increased automation in train travel is associated with an increase of frequency of trains and a better recovery from delays (Powell, et al., 2016), resulting in an increase of the capacity of the rail network. In aviation and waterborne transport, increased automation is expected to contribute to more efficient transport operations (EC, 2017a).

Travel experience

CCAM may increase travel comfort, feelings of improved traffic safety, more reliable travel times and the possibility to perform other activities than driving while on the move (Milakis, et al., 2017) (Legêne, et al., 2020). All these aspects will lead to an improved travel experience, an impact that will be larger at higher levels of automation. Part of these elements (e.g. more reliable travel times) are relevant for CCAM in non-road modes as well. Furthermore, automatic train operations may result in smoother changes of acceleration compared to manual control, improving the travel comfort for passengers (Powell, et al., 2016).

3.3.2. Environmental impacts

GHG emissions

Connectivity and automation has the potential to reduce the environmental impacts at the vehicle level of all transport modes (both passenger and freight transport) significantly due to increased efficiency (EC, 2019e). For example, mandatory intelligent speed adaptation has the potential to reduce CO_2 emissions by 5-10%, while also Cooperative Adaptive Cruise Control, or platooning, could reduce CO_2 emissions by 5-10% (ERTICO, 2015). Higher levels of automation and cooperation results in higher CO_2 reduction potentials at the vehicle level, even up to 45% (Milakis, et al., 2017)[24]. Furthermore, the increased market penetration of shared car services that is expected by some stakeholders due to CCAM may accelerate the electrification of the vehicle fleet[25], resulting in lower CO_2 emissions at vehicle level.

However, lower CO_2 emissions at the vehicle level will not necessarily result in lower overall CO_2 emissions. The increase in travel demand and modal shift effects due to CCAM may generate a rebound effect that may (partly) undo the CO_2 reductions at the vehicle level. For example, EC (2019e) mentions that the overall energy consumption of road transport may increase by 9-30% due to CCAM in case the rebound effect dominates. Wadud et al. (2016) show that the net effects of automation on CO_2 emissions depends on which effect dominates. In case the reduction in CO_2 emission at the vehicle level dominates, road transport emissions might be reduced by almost 50%, while CO_2 emission almost double when the rebound effect dominates. Wadud et al. (2016) also find that many emission reduction

[24] It should be mentioned that these environmental benefits are achieved particularly if the vehicles are connected and a harmonised traffic flow can be produced. If automated vehicles are not connected, various brands and settings of automation may jointly create all kinds of emergent speed and lane change patterns like oscillations, acceleration and deceleration waves, etc., reducing the environmental effectiveness.

[25] For private owned cars, the relatively high purchase costs for electric vehicles is often considered an important barrier for the large-scale market implementation of these vehicles. For car-sharing schemes these relatively high upfront costs are less problematic, particularly as the total cost of ownership of electric vehicles are expected to be lower than for conventional vehicles by the end of this decade.

benefits may be realised through partial automation, while the main downside risks are more likely at full automation.

Based on the arguments discussed above, we have to conclude that the net impact of automation on road transport CO_2 emissions is still very uncertain. This is also acknowledged by the results of the case study on connected and automated driving (see Annex D).

For the non-road modes, significant CO_2 reductions at the vehicle level are expected as well. Automation and more efficient operation of vessels can be expected to safe up to 25% of fuel consumption (EC, 2017a). In rail transport, energy optimisation (e.g. by precisely controlling speed profiles of trains) may lead to 20-30% energy savings (EC, 2018d). And in aviation also, more automation is expected to improve the energy efficiency per flight (EC, 2017a). However, as for road transport, part of these CO_2 reductions may be undone by additional transport movements, although the size of this rebound effect is uncertain.

Air pollution

CCAM applications have a significant potential to reduce air pollution at the vehicle level. Automation can result in lower emissions of NO_x and CO (Milakis, et al., 2017). These emission reductions are expected to be larger at higher levels of automation and cooperation. Furthermore, the fact that vehicles which are equipped with the required technology will most likely be electric (Neves & Velez, 2018) also contributes to lower emissions at the vehicle level.

But as for CO_2 emissions, the expected increase in transport demand resulting from CCAM may (partly) undo the positive environmental impacts of CCAM. The net impacts on air pollution are still uncertain.

Improved efficiency of transport in the non-road mode sectors may have a positive impact on the reduction of air pollutant emissions. However, it is unclear to what extent this positive effect is undone by the rebound effect of more transport movements.

3.3.3. Social impacts

Traffic safety

More than 90% of traffic injuries is caused by human error. Automation takes away the human factor from driving; theoretically, the potential increases in road safety are therefore enormous. However, it is very unlikely that before 2030 all vehicles on the road have been fully automated. As long as automated vehicles have to share the road with human drivers as well as other traffic modes such as pedestrians (i.e. mixed traffic conditions), it is very difficult for automated vehicles to function optimally. When confronted with unexpected situations, such as pedestrians suddenly entering the road or walking close to the road on the pavement, it is difficult for an automated vehicle to judge whether to continue or stop. This might lead to sudden braking in situations which would not seem dangerous to human drivers (Neves & Velez, 2018), which may lead to additional risks to other road users. Furthermore, automation may also introduce new causes of accidents such as system failures (BITR, 2017) (Taeihagh & Si Min Lim, 2019) or cyberattacks (Milakis, et al., 2017). Since it is difficult to forecast these various developments, no quantitative figures on the safety improvements of fully automated driving could be given.

At lower levels of automations, also, safety benefits are expected (Milakis, et al., 2017). For example, Lane Departure Warning and Advanced Emergency Braking System can significantly reduce the amount of accidents by human drivers. It is estimated that these techniques could reduce HGV (heavy goods vehicles) accidents by 17-24% for heavy goods vehicles, buses and coaches (ERTICO, 2016). As

mentioned by (Milakis, et al., 2017) and (Taeihagh & Si Min Lim, 2019), part of these safety benefits may be undone by drivers adopting riskier behaviour due to their over-reliance on the system.

For non-road transport modes, automation has a significant potential to increase safety as well. The general reason for this is that transport becomes safer by reducing the human errors by automation of routine but high-stress driving tasks (EC, 2017a) (Powell, et al., 2016).

Box 3: Traffic safety linked to an increase in vehicle kilometres

The case study on automated driving (see Annex D) shows an increase in vehicle kilometres for all scenarios without interventions. Normally, this results in a higher expected number of accidents and more material and immaterial damage. This risk seems to be higher in urban areas because there is a greater interaction between fast and slow traffic. On the other hand, experts assume that further technological developments in vehicle safety will (perhaps more than) compensate for the possible additional risks. In conclusion, the study referred to in the case study assumes that self-driving vehicles have a neutral or possibly positive influence on traffic safety.

Congestion

As discussed above, under the right conditions CCAM could increase the road capacity, e.g. because automated vehicles can travel with smaller headway and in narrower lanes than conventional vehicles. This would have a positive impact on road congestion (Szimba & Hartmann, 2020). Furthermore, improved road safety due to CCAM will lead to less impediments for a free traffic flow. Since a significant fraction of traffic jams can be attributed to accidents, this could be a substantial effect. On the other hand, however, the expected increase in transport demand makes that it is uncertain whether the overall congestion levels would decrease (Smit, 2018). Livingston et al. (2020) finds, based on modelling exercises, that reductions in congestion levels are only achieved at very high market penetration rates of fully automated vehicles and a high rate of shared vehicle usage. In other scenarios, the capacity gains of automated vehicles are compensated by the growth in travel demand. The same conclusion is drawn by Cohen & Cavoli (2019), who note that in a mixed situation, with both autonomous and human drivers, the congestion levels might even increase. Therefore, on the short term CCAM might result in more congestion, particularly in urban areas (see also Box 4). This latter conclusion is also found by (Meyer, et al., 2017). Based on modelling exercises, they find that fully automated vehicles may reduce congestion on highways and in rural areas, while in urban areas congestion levels may rise (as the capacity effect is compensated by the additional transport demand).

As automation provides drivers the opportunity to do other things instead of driving, the lost hours due to traffic jams may affect people's welfare less compared to people travelling with a conventional car (EC, 2019e) (Legêne, et al., 2020). Kolarova et al. (2019) finds, based on two on-line surveys, that the value of reduced travel times is 41% higher for autonomous driving compared to driving a conventional car, however, only for commuting trips. For leisure or shopping trips, no significant differences in the value of travel time savings were found. Furthermore, Kolarova et al. find that the value of travel time savings not only depends on the travel motive, but also on the ownership structure of the automated vehicle: travel time savings in a shared automated vehicle are perceived less positively as in a privately owned automated vehicle (or even in public transport). A switch to automated vehicles may therefore lower the economic costs resulting from congestion, but the size of this impact may depend on several variables like ownership structure of the vehicle and travel motive.

For freight transport, the additional wage costs for truck drivers are an important element in the congestion costs for businesses. For fully automated trucks, these costs are not relevant anymore and hence this will result in lower congestion costs.

Accessibility

CCAM has the potential to improve the accessibility of transport. For level 5 automation, where no driver is required, car travel would become accessible to people who are currently unable to drive. This could benefit, amongst the others, children and the elderly, people without a driving licence and people who can but rather would not drive (Cohen & Cavoli, 2019). At lower levels of automation, autonomous technologies like collision warning and lane-departure warning, may be beneficial to older and less-experienced drivers (EC, 2019e). However, in the transition phase, automated vehicles will likely be expensive, limiting the benefits of these vehicles to high-income groups for a certain time (Milakis, et al., 2017). Potential urban sprawl due to the market penetration of CCAM and possible reductions in public transport services (EC, 2019e) might further limit the accessibility of certain groups of citizens. The aversion of some (e.g. elderly) to use innovative technologies may also lead to more inequality between different groups in society.

Based on the arguments given above, the impact of CCAM on accessibility is still unclear. Particularly on the short to medium term, there are several elements that negatively affect the accessibility of certain groups in society. On the long term, the accessibility impacts of CCAM are probably more positive.

Box 4: Link between accessibility, congestion and vehicle kilometres

All scenarios in the case study on automated driving involve a higher number of vehicle kilometres without interventions. This increase in mobility has a positive effect on the accessibility of jobs, among other things. The downside is that the increase in vehicle kilometres has a negative impact on traffic throughput, especially in urban areas (the increase in vehicle hours lost in congestion takes place mainly in urban areas). In most cases, this increase is not compensated by the assumed (substantial) increase in the capacity of the road network (as a result of cooperative automated driving). In conclusion, the case study shows that self-driving vehicles might have a positive influence on accessibility in rural and less urban areas, and a negative influence on accessibility in the more urban areas.

3.3.4. Economic impacts

Impact on the European industry

In general, it is expected that the development of the disruptive technologies required for CCAM will potentially provide jobs for the European industry in various sectors. These are highly skilled jobs which are amongst others related to the transport industry as well as the IT industry. There is a worldwide race towards vehicle automation, which means that the competitiveness of the European transport-related industry might depend on the success of European research related to CCAM techniques (EC, 2017a). However, there is also the risk of losing jobs in other sectors. Especially jobs in the transportation and logistics sector are at risk for being replaced by automation in the coming decades (Milakis, et al., 2017) (Taeihagh & Si Min Lim, 2019). The effects of these development can vary greatly per region, depending for example on whether the population is highly educated or not or the number of people working in the transport sector. For the non-road modes, no significant adverse impacts on employment are expected (EC, 2018d).

The net impact of CCAM on EU GDP, investment, consumption and trade balance heavily depends on the EU's competitive position on the international market for CCAM (EC, 2019e). Currently, the EU has a strong position in the market for automated vehicles. According to KPMG (2019), the Netherlands is the country in the world which is better prepared for automated vehicles, with Norway coming third.

In general, European countries are well positioned, particularly with respect to policy and legislation, technology and innovation. It seems therefore, that the EU is currently in a good starting position to aim for a leading global role in CCAM.

Financial impacts for end-users

The technology required for CCAM is expected to make vehicles more expensive. Particularly in the short to medium term, the additional vehicle costs for fully automated vehicles are expected to be significant (BITR, 2017) (Milakis, et al., 2017), but due to increases in scale of production and technological advances the additional costs could be gradually reduced to $ 3,000 per vehicle or even less (Milakis, et al., 2017), although these cost estimates are very uncertain. The use costs of automated vehicles may be lower than for conventional vehicles, because of lower fuel costs due to increased efficiency and the possibility to work during traveling. However, it is unclear to what extent transport users are charged a service fee to make use of the digital infrastructure, which may lead to additional user costs. On the short to medium term, potential lower use cost will not compensate for the higher investment cars, particularly for private car owners. For car-sharing (or ride-hailing) companies, automated vehicles may become beneficial from a financial point of view sooner, as the use rate of these vehicles is much higher as for privately owned vehicles. This may also result in lower travel costs for end-users.

For partially automated vehicles, the additional investment costs are considerably lower. According to BITR (2017), the current additional costs of driving assistance systems (e.g. lane centering and pedestrian detection) range from € 300 to € 900 per technology per vehicle. The additional costs of the equipment to facilitate truck platooning is estimated by TNO (2015) at € 10,000 per vehicle at the time of the publication, but the expected costs in the future are stated to be about € 2,000 per vehicle.

3.3.5. Synthesis

CCAM technologies are mainly developed to increase travel safety, transport efficiency and travel comfort (EC, 2019e). On these indicators CCAM scores well, as is shown by Table 7. CCAM is also expected to increase the overall transport demand, which may jeopardise some of the social benefits of CCAM, like emission reduction and congestion levels. Because of the uncertainty on the development of the CCAM market and the future position of the EU in this market, the economic impacts of CCAM for the European industry is uncertain (although there are promising business opportunities).

Because of the innovative character of CCAM and the fact that most evidence is available from small pilots or modelling exercises, there is quite some uncertainty in the size and direction of the impacts discussed. Particularly the impacts on vehicle ownership, environment, congestion levels, accessibility and the economy are quite uncertain and should therefore be considered very carefully.

Table 7: Summary of impacts CCAM

Indicator	Impact
Impacts on the transport sector	
Transport demand	CCAM techniques are likely to increase transport demand.
Vehicle ownership	The impact on vehicle ownership is uncertain and largely depends on the prevailing ownership structure (private or shared) that will arise.
Transport efficiency	CCAM could significantly increase transport efficiently, but only if automated and connected technologies are combined.

Indicator	Impact
Modal shift	CCAM will probably contribute to a modal shift to passenger cars and road freight transport.
Travel experience	CCAM will improve travel experience, e.g. by providing more comfort, improved feelings of safety, more reliable travel times, etc.
Environmental impacts	
GHG and air pollutant emissions	Deployment of CCAM applications may result in significant emission reductions at the vehicle level. However, the overall effects are uncertain due to the expected increases in transport demand.
Social impacts	
Traffic safety	CCAM could contribute to a higher level of traffic safety, particularly on the long term.
Congestion	CCAM could contribute to lower levels of congestion, as it may enhance transport infrastructure capacity. However, especially with low CCAM penetration rates, the total effects are unclear due to the increased traffic demand.
Accessibility	Level 5 automation could increase accessibility significantly. For lower levels of automation, the effects are less certain.
Economic impacts	
Impact on European industry	CCAM deployment can have a positive effect on European industry, although this heavily depends on the EU's competitive position on the international market for CCAM. The current position of the EU on this market is good, but this could change rapidly.
Financial impacts for end-users	On the short term, the high investment costs for CCAM will lead to higher costs for end-users. However, on the long run, it may even result in lower transport costs for end-users, particularly as CCAM is used in shared vehicles concepts.

Note: green indicates that assessment of impact is rather certain, while orange shows that assessment of impacts has a high level of uncertainty.

The impacts of CCAM, as discussed in this section, are more likely to be achieved on the longer term than on the short term. To actually deploy CCAM quite some challenges have to be tackled (see Section 6.3) and hence a possible large scale market penetration of these vehicles will take some time. Furthermore, as for C-ITS applications, a critical mass of connected and autonomous vehicles is required to fully exploit the benefits of these vehicles.

The deployment of CCAM will have impacts at both the urban and rural level. Shared automated vehicle services may be expected first at the urban level, because of the higher initial demand at that spatial level. At the urban level, CCAM may also have the most prominent impact on spatial planning, as it may affect the availability of public space (less parking places required) and the location choices of households and firms resulting in urban sprawl (Gavanas, 2019) (Meyer, et al., 2017).

3.4. Mobility as a Service (MaaS)

Empirical evidence on the impact of MaaS on people's travel behaviour and consequently on broader transport and social impacts is limited, as is highlighted by studies like Feneri et al. (2020) and Ho et al. (2017). There are a few small-scale pilots (in Sweden, Austria and Belgium) for which evaluation studies

are available. Additionally, some studies using surveys, focus groups or stated preference experiments have been applied to study the expected impacts of MaaS. Due to this limited empirical knowledge on the impacts MaaS can have, the discussion in this section is explorative and the (hypothesised) impacts should be considered carefully.

3.4.1. Impacts on the transport sector

Private care use and ownership

The reduction in private car use is often claimed to be one of the main projected impacts of the deployment of MaaS. Pilot studies do indeed show that MaaS may result in decreased private car use (KiM, 2019b). A pilot with the MaaS scheme Smile in Vienna shows a 21% reduction of private car use, while comparable reduction figures are found for pilots with the MaaS scheme Whim. Also for the UbiGo pilot in Sweden similar results were found, as 44% of the participants in this pilot reduced their private car use. In a small-scale pilot study in the Belgium city Ghent, Storme et al. (2020) also found that private car use was lower than before, particularly in routine commuting trips. The reduction in private car use for more non-routine social trips was lower, in line with the expectations of MaaS experts interviewed by (KiM, 2019c).

An important consideration with respect to the evidence found on reduced private car use in the various pilot studies is that participants to these pilots often receive a financial incentive to lower the use of their own car (e.g. by penalising the use of a private car or by receiving a financial reward if they sell (one of) their cars). Furthermore, participating in this kind of pilots is voluntary (attracting a self-selected group of people interested in innovative mobility concepts) and hence the group of participants is probably not representative for the general population. Because of these reasons, it is difficult to generalise the results from the pilot studies to the entire transport sector (KiM, 2019b). Based on the arguments presented above, there is some evidence that MaaS may result in reduced use of private cars, but this impact is still uncertain and could be different from the figures found in the various pilot studies.

In addition to reduced private car use, a reduction in private car ownership is also often mentioned as one of the impacts of the deployment of MaaS. Based on a stated choice experiment, Kamargianni et al. (2018) found that 33% of the car owners in London indicate that MaaS would help them to depend less on their cars, while about a quarter of them would be willing to give up their private car for unlimited access to car sharing. Among the non-car users, 40% of the respondents stated that they would not purchase a car at all if MaaS were available, while 36% of the non-car users indicate that the availability of MaaS would delay their purchase of a private car. However, as mentioned by KiM (2019b), it is unknown to what extent these results of a choice experiment will be achieved if MaaS is actually offered in London. In this respect it is interesting to see that Storme et al. (2020) conclude, based on an evaluation of a MaaS pilot in Ghent, that it cannot be assumed that MaaS schemes will drastically reduce car possession. Even the highly motivated participants in this pilot did not want to give up the possession of their own car, because of the flexibility, reliability and certainty it offers to them. Therefore, Storme et al. (2020) sees MaaS, at least in the short to medium term, rather as a complement than a substitution of private car possession. This opinion is shared by the participants of some focus group meetings organised by KiM (2018). The main impact of MaaS on private car ownership may probably be expected with respect to second cars (in urban areas), as is also indicated by MaaS experts interviewed by Smith et al. (2018).

Conversely, it could be that private car use and ownership reduction figures might be similar or even higher for the general public as more mature MaaS models are made available. If, on the longer run, MaaS reaches a sufficient critical mass, it may become more attractive for people to give up their own

car (Smith , et al., 2018; Storme, et al., 2020). In this respect, the introduction of shared automated vehicles may be a boost for MaaS schemes (Kamargianni & Matyas, 2017), as sufficient vehicles are available and users can select a car meeting their expectations. MaaS pilots are arguably immature and often do not yet offer a sufficient range or long-term reliability of mobility services. This might lead a user to feel that all of their needs cannot be met through the MaaS service, and hence a need to continue to own private vehicles. As MaaS services and offerings expand and mature, car ownership could drop further.

Modal shift

By integrating the various transport modes and offering tailored transport services based on customer needs that could be accessed via a single platform, MaaS is intended to incentivise travellers to reconsider their mode choice. As mentioned by Matyas (2020), MaaS will increase traveller's awareness of the various transport modes and may change the perceived set of modes suitable for a specific trip. In the end, this may contribute to shifts in modal choice and hence a different modal split.

As mentioned above, MaaS could contribute to a decrease of private car use, although the magnitude of this impact is uncertain. To fully benefit from the societal benefits of MaaS, these reductions in private car kilometres should preferably be replaced by public transport or active modes like cycling and walking (or on the long run electrified shared automated vehicles). Therefore, public transport should be the backbone of MaaS (at least at the short to medium term), particularly in urban areas (Gonzalez, et al., 2017). Evaluation studies from existing MaaS pilots do show that these schemes result in more public transport use (Karlsson, et al., 2016; Karlsson, et al., 2017). These findings are in line with the survey results of Kamergianni et al. (2018), who found that 35% of regular car users in London state that they would substitute to public transport if MaaS was available. Gonzalez et al. (2017) indicates that respondents have a higher preference for inclusion of public transport in mobility bundles than of demand responsive transport or taxi-like services.

However, it should be noted that another impact of MaaS could be that regular public transport users switch to car sharing schemes (Pangbourne, et al., 2020). For example, Kamergianni et al. (2018) find that 12% of the regular public transport users in London state that they would substitute part of their public transport trips with car sharing and bike sharing respectively. This rebound effect would partly undo the positive environmental and social impacts that could be achieved by realising a shift from private car to public transport. Looking at the United States, where ride-hailing services such as Uber are widely available, numerous studies have shown these services significantly reducing public transport use ((Schaller Consulting, 2018; Graehler, et al., 2019). As early adopters are expected to be young and active people using public transport on a regular basis (KiM, 2019a), this rebound effect may be particularly relevant for the early phase of the market penetration of MaaS. Furthermore, the size of this rebound effect also depends on the design of the MaaS scheme, the incentives that are provided within this scheme for the various mobility options and local specific factors like the quality of the various mobility options, service costs, the density and form of the city, etc. (Arup, 2018). Off course, there may also be a shift from private car use to car sharing schemes as was discussed above.

Finally, MaaS may also, depending on the actual design of the scheme, contribute to increased use of active modes. For example, Kamergianni et al. (2018) finds an expected increase of 14% and 17% of cycling due to MaaS for regular public transport and car users, respectively. From the regular car users, 12% expects to walk more as part of their trips if MaaS is implemented. As for public transport, there may be a risk that the implementation of MaaS shifts regular cyclists (or pedestrians) to other modes.

Total transport demand

The improved access to the transport system MaaS schemes could offer may result in an increased number of trips made (Karlsson, et al., 2017) (Smith , et al., 2018). Better services for personalised mobility (e.g. for disabled persons) could, for example, serve currently unmet travel demand, as appropriate travel options are currently not available. Additionally, Pangbourne et al. (2018) identified a potential rebound effect of pre-paid MaaS packages, i.e. packages providing unlimited access to certain transport modes may incentivise MaaS users to increase their use of that transport mode and even their total transport demand.

To what extent this potential increase in number of trips result in additional vehicle kilometres also depends on the modal shift changes realised by MaaS. In case a significant shift from private car use to public transport is achieved, a reduction in the total number of vehicle kilometres may be realised. However, if there will be mainly a shift to car-sharing (and ride-sharing) services, there may even be an increase in the total number of vehicle kilometres. Based on the evidence available now, no final conclusion could be drawn. However, as mentioned above, the actual design of the MaaS scheme, its cost and local specific factors will affect the modal shift effects and hence also the impact on the total number of vehicle kilometres.

Transport efficiency

MaaS has the potential to increase the efficiency of the overall mobility system by making better use of existing transport services and resources. For example, it could optimise public transport supply by better understanding the expected demand through data collection and analysis (IET, 2019). By harmonising data sources and transferring data between players within the MaaS community, the network performance could be improved with more informed and reliable intermodal choices and travel times. For example, if it is detected real-time that there is a high demand on a certain bus line during peak hours, travellers could be redirected to other (underutilised) routes (Kamargianni, et al., 2018). The integration of various transport services, including more innovative mobility concepts like shared taxis are forms of demand-responsive transport, also contributes to a more efficient use of resources (i.e. higher average occupancy rates, lower waiting times, etc.). Finally, MaaS and new mobility solutions could offer a variety of solutions to first/last kilometre issues that are barriers to public transit use, giving users an easy way to arrive to or leave from transit stops to their destinations. Note that it depends on the specific policy goals, what is considered efficient or not – in both the current transportation system and a system with MaaS and new mobility solutions. For example, subsidising a specific transport service can be seen as inefficient from an economic point of view and efficient from a social equity point of view.

Travel experience

The implementation of MaaS aims to result in more flexible, reliable and convenient transport for travellers (IET, 2019; Kamargianni, et al., 2018). The tailor-made services based on customer needs improves the current mobility options travellers have. Furthermore, the single platform providing all relevant transport options would increase the travel convenience and provides travellers options to be very flexible if needed (e.g. in cases of disruptions). However, there are – particularly when private companies offer the MaaS services – also concerns regarding the safety, security and social equity when not all user groups are serviced. Again, it all depends on the actual design of the MaaS services, its characteristics and local specific factors of the transportation system, what the impact on the travel experience will be.

3.4.2. Environmental impacts

The impact of MaaS on the level of GHG and air pollutant emissions depend on the number of trips made, the trip length, the level of modal shift from private car use to public, active and/or shared transport, and the composition of the car fleet used (e.g. share of electrified vehicles used) (Karlsson, et al., 2017). As mentioned in Section 3.4.1, MaaS might result in a higher number of trips (and maybe also an increase in the average trip length). This adverse impact on the level of emissions may be compensated by a modal shift to more sustainable transport modes (Decisio , 2017; Laine, et al., 2018). However, as mentioned above, the modal shift impacts of MaaS are uncertain and, among other things, depend on the actual design of the MaaS scheme. If MaaS schemes prioritise public transport use and use other modes to feed into that system or to serve trips that are impossible or inefficient for public transit, overall mode shift towards more sustainable modes would have an overall positive environmental effect. Conversely, regular public or active transport users switching to car- or ridesharing services may, for example, contribute to higher emission levels. This reversed modal shift impact of MaaS may be particularly relevant in the early phase of the market introduction of these kind of schemes, as regular public transport users are seen as potential early adopters of these services (KiM, 2019a).

The shift from private car use to car-sharing schemes may have an additional impact (to reduced car use) positively affecting emission levels, i.e. the higher rates of electrification in the fleet of car sharing services compared to private car fleets (Laine, et al., 2018). Particularly, on the short term this impact may be relevant as electric vehicles are not that attractive as private vehicles due to the relatively high purchase costs. On the longer run, the expected reduction in purchase costs of these vehicles will contribute to higher shares of electric vehicles in the private fleet, reducing the environmental advantage of car sharing schemes.

To conclude, MaaS does have the potential to contribute to a reduction of GHG and air pollutant emissions of transport, but whether this potential will be exploited heavily depends on the modal shift impacts that will be achieved. With regular public transport users being the most promising group as early adopters of MaaS, particularly on the short term positive environmental impacts could not be guaranteed. On the longer term, the environmental impacts of MaaS will probably be more positive, although still uncertain and depending on the actual design of the schemes. This uncertainty on the environmental impacts is also shown by the results of KiM (2019c), showing that only 40% - 50% of the MaaS experts interviewed expect that large-scale implementation of MaaS schemes would result in significant reduction in emissions.

3.4.3. Social impacts

Traffic safety

The impact of MaaS on traffic safety is not exhaustively studied in literature. The most important driver of safety impacts of MaaS is probably the expected change in the modal split. A shift from car kilometres to public transport kilometres will contribute to less traffic accidents, as the number of casualties in public transport modes are significantly lower than in passenger cars (Moving Forward Consulting, 2016). On the other hand, a shift to car sharing schemes will probably not affect traffic safety in a significant way. Finally, increased cycling and walking due to MaaS may result in more casualties, as people using a bike and pedestrians are more vulnerable than other transport users.

Another potential driver of traffic safety impact is the total transport demand. However, it heavily depends on the local situation whether an increase (or decrease) in total transport demand will result in more or less traffic safety (CE Delft; INFRAS; TRT, 2019). On the one hand, more vehicle kilometres will

lead to more vehicles and more vehicles of different modes crossing each other and hence higher accident risks. But on the other hand, drivers will become more cautious when traffic flows become denser, resulting in lower accident risks. Combined with the fact that the overall impact of MaaS on transport demand is uncertain (see Section 3.4.1), the impact of this driver on traffic safety cannot be determined without further research.

From the reasoning above, it is clear that the impacts of MaaS on traffic safety are uncertain. Although improvements of traffic safety are sometimes mentioned in literature as potential impact of MaaS (IET, 2019), it is not seen as one of the major benefits MaaS could offer (KiM, 2019c).

Congestion

The potential of MaaS to reduce (single-occupancy) car trips and stimulating a shift towards public, shared and active transport may result in a reduction in traffic congestion (IET, 2019) (Kamargianni, et al., 2018). According to (KiM, 2019c) 65% of interviewed MaaS experts state that if MaaS will be implemented at a large scale, significant reductions in congestion levels may be expected.

The extent by which the potential of MaaS in reducing congestion could be exploited heavily depends on the design of the MaaS schemes implemented. In case the deployment of MaaS schemes lead to increased used of car and ride sharing schemes resulting in additional car trips and undesired shifts from public transport, congestion may even stay at the same level or increase (IET, 2019). The additional number of car trips due to better access to the transport system (e.g. for disabled people) (Utriainen & Pollanen, 2018) or due to the design of the MaaS schemes (pre-paid package models) (Pangbourne, et al., 2018) may also (partly) undo the positive congestion impacts of MaaS.

Accessibility

The integration of the various elements of the mobility system in combination with personalised journey plans is expected to improve access to this system for all people in society, but in particular to vulnerable groups like elderly and disabled. The personalised approach of MaaS may provide opportunities to offer door-to-door mobility options to these groups, replacing traditional public transport services that may be difficult to use to these groups (IET, 2019) (Pangbourne, et al., 2018). In this way, MaaS solutions could contribute to higher levels of social inclusion.

A factor that should be critically considered in designing MaaS schemes is that some groups of people may be excluded from the 'new' mobility system whether due to distance, costs or technology aversion (Pangbourne, et al., 2020). MaaS schemes could be mainly implemented in urban areas (as it is easier for private companies to realise a positive business case), potentially leading to exclusion of people in rural areas. MaaS's reliance on digital technologies might exclude social groups experiencing difficulties in handling these new technologies (like elderly and low-literate people). Finally, the relatively high costs of the services offered may exclude low-income households from participating in MaaS. These different elements may increase the gap between different groups with respect to the mobility options they could actually make use of (particularly if public transport is not the backbone of a MaaS system) and hence may result in higher levels of social exclusion for some of them. In order to optimise the contribution MaaS could provide to a more accessible transport system, these effects should be considered carefully in designing the MaaS schemes.

3.4.4. Economic impacts

Impact on the European industry

The deployment of MaaS schemes provides business opportunities to the MaaS operator (i.e. the entity that owns and provides the MaaS service and customer interface) and the transport companies (public

transport, car sharing schemes, bike sharing schemes, etc.) (IET, 2019). In general, MaaS may provide additional economic value to these entities – and to entities that build and manage infrastructure, by realising cost savings due to optimising transport efficiency on existing infrastructure and increased ridership. Commercial activities like providing ads on the MaaS platform may be an additional source of revenues. MaaS platforms could also move beyond transportation offerings to capitalise on user attention and provide additional services and bundled offerings. The data generated by MaaS platforms has been identified as a source of revenue, although there are privacy considerations in user data. To achieve these potential benefits, significant investments are required to develop MaaS services, particularly at the initial stages of this innovative mobility concept.

An important aspect with respect to the economic impacts of MaaS schemes is how the costs and revenues will be divided by the operator, the transport companies and other (public) entities involved. In general, two types of business models can be distinguished (UNECE, 2020):

- The operator may act as broker, buying services from the transport operators and selling it to travellers. In this model, the operator takes all the risks, but will also enjoy all the benefits.
- The operator may act as coordinator within a partnership of actors. In this model, the operator receives a fee for their activities and the revenues have to be allocated to the various partners.

Currently, most MaaS pilots do apply the broker model, where the transport companies are compensated for their participation through 1) a potential increase of their market share and b) any price differences that may exist between the price of the service when sold individually and the price of the service when sold to the MaaS operator (UNECE, 2020). A risk in this model is that on the long term there will be some large operators with a lot of market power, which will reduce the profit margins of the individual transport companies (Decisio , 2017). Regulation to avoid such oligopolies is therefore key. An additional risk is that large transportation operators will, themselves, become platform operators – limiting competition and market entry for smaller players.

In addition to the economic impacts for MaaS operators and transport services providers, the implementation of MaaS could also provide business opportunities for companies like (Kamargianni, et al., 2018):

- Data providers, as the requirements for high quality, real time data processing will be high.
- Journey planning companies, ticketing and payment companies, and IT companies. MaaS operators may outsource the development of parts of their platform to these kind of companies (or integrate existing journey planners and/or payment and ticketing schemes in their platform).
- ICT companies, as the operation of MaaS will require high-level ICT infrastructures and widespread geographical internet coverage.
- Media, advertising and entertainment companies, as their services could be integrated in the MaaS platform/services to further improve the travel experience of people and expand to other, related service needs with their audience.

3.4.5. Financial impacts for end-users

Replacing car ownership by car use (using car or ride sharing schemes) provides current car owners an option for reducing travel costs, as they can save on the fixed car costs (e.g. purchase costs, assurance

costs, etc.). Particularly for travellers with relatively low annual mileage, travel spending could be reduced in this way. From a financial perspective, MaaS therefore seems to be particularly attractive for people who are willing to give up (or delay) car ownership. This could be particularly beneficial to elderly who travel relatively little but have similar fixed costs of car ownership. For regular public transport users, the financial benefits of MaaS are probably low or even lacking, as it is expected that the tariffs for MaaS services are not (much) lower as the current public transport tariffs (Decisio , 2017). MaaS systems could also make transportation costs much more apparent to consumers than they currently are. This could make travel decisions more rational and might have a larger influence in shaping decisions like where people live and work.

3.4.6. Synthesis

The implementation of MaaS schemes may increase travel comfort and convenience for travellers, while at the same time transport efficiency and profitability of transport operations could (at least theoretically) be improved (see Table 8). Furthermore, it may improve the accessibility of the transport system, particularly for vulnerable groups like older adults and the disabled. To what extent MaaS also will contribute to other societal goals, like reduction in emissions and congestion levels, is still uncertain. This will probably differ from case to case, depending on location specific factors (quality of the mobility services offered, modes prioritised, density of the city, etc.) and the design of the scheme.

As shown by the colour code in Table 8, the evidence on the direction and level of the impacts differ between the various indicators. Particularly on vehicle ownership, modal shift, environmental effects, traffic safety, and congestion, the available evidence is inconclusive on the direction and level of the expected impact.

Table 8: Summary of impacts MaaS

Indicator	Impact
Impacts on the transport sector	
Transport demand	Total transport demand will increase, among others by the fact that unmet travel demand is better served.
Vehicle ownership	Private car ownership is expected to decrease, but by what level is uncertain.
Transport efficiency	Transport efficiency is increased due to better use of existing transport services and resources.
Modal shift	Various modal shift effects may be expected, but to which mode and by what extent largely depends on local circumstances, design of the scheme and governmental incentives and policies.
Travel experience	Improved travel experience due to more flexibility, reliability and convenience.
Environmental impacts	
GHG and air pollutant emissions	Environmental impacts are uncertain and depend on local circumstances, design of the scheme and governmental incentives and policies.

Indicator	Impact
Social impacts	
Traffic safety	Impacts on traffic safety are uncertain, depending on the type of modal shift from cars to alternatives.
Congestion	Congestion impacts are uncertain and depend on local circumstances, design of the scheme, governmental incentives and policies.
Accessibility	MaaS will improve the accessibility of the transport systems, although impacts of social exclusion of certain groups should be carefully considered.
Economic impacts	
Impact on European industry	Business opportunities are provided to MaaS operators and transport operators, physical and digital infrastructure and service providers, data providers and data analytics providers.
Financial impacts for end-users	Particularly car-owners selling their cars benefit financially from MaaS.

Note: green indicates that assessment of impact is rather certain, while orange shows that assessment of impacts has a high level of uncertainty.

The impacts of MaaS, as discussed in this section, are more likely to be achieved on the medium (2025/2030) than short term (2020). For example, people are probably more willing to give up their private car once MaaS services have reached a critical mass and will provide a good alternative for owning a car. Furthermore, the introduction of automated vehicles is regarded by the interviewed experts a potential tipping point for MaaS, as this may further support the transition to a shared mobility system.

Box 5: MaaS and automated vehicles

In the case study on automated driving (see Annex D), it is showed that using automated vehicles and (shared) taxis on a large scale within a MaaS scheme, the number of parking spaces needed in the city centre decreases. The freed up space can benefit the quality of life in cities. However, part of the space will have to be used for locations where people can be picked up and dropped off. Parking income and income from vehicle taxes (as there may be less vehicles) will decrease. Under current policy, providers of mobility services do not pay for the extent to which they use publicly financed road capacity compared to private car owners. Therefore, a large-scale implementation of shared vehicles may provide challenges in the field of infrastructure funding. A possible option to address this challenge is by implementing road-charging schemes where road users have to pay according to road use.

Although MaaS schemes could be implemented at all spatial levels, current initiatives are mainly focused on the urban (or even metropolitan) area. Hence the evidence on the impacts, as presented in this section, refer mostly to these schemes applied in those environments. MaaS projects/pilots in more rural areas are currently very rare.

3.5. Self-organising logistics

Self-organising logistics are the next step from digitisation, automation and robotisation. Until now, relatively few concrete examples are present of full-scale self-organising logistic concepts. Digitisation in logistics has not reached maturity level yet (Kayikci, 2018), but many initiatives are ongoing and under development. This section highlights the main current developments and expected future prospects of this technology. Results per subsection are predominantly qualitative, because of the relative few data sources and results in the area of self-organising logistics.

3.5.1. Impacts on the transport sector

Transport efficiency

Self-organising logistics has the potential to improve the efficiency of logistical processes. Current system operators calculate the optimum route for freight and packages and can deliver track-and-trace systems, but widespread integration between supply chain partners is still hampered by security threads and privacy issues (Clausen, et al., 2016). Instead, distribution of cargo is often still planned centrally by a single logistics provider, using software to accelerate planning processes. However, a decentralised system where cargo can choose its own route and use of transport modes makes the logistical process more efficient (TNO, 2020b). The versatility and flexibility of choosing different options makes the system able to choose the most efficient path.

Cooperative actions through digitalisation in sharing warehousing and transport capacities has the potential to improve the efficiency and reliability of the logistics industry (Kayikci, 2018). Customers are connected to suppliers and also logistic partners to each other, providing opportunities to improve the efficiency of logistic processes. The logistical processes can be made more flexible to internal or external influences. This adaptiveness can allocate freight to other routes or other modes of transport, making the supply chain more agile and responsive, and therefore making it more reliable. Risks are reduced and end-to-end transportation and lead time are more robust against changes or threats to the supply chain.

Self-organising logistics can also be self-learning (using predictive analyses and machine learning), where processes are optimised through harvesting data from current and historical data. In doing so, the corrections are made to smoothen out logistical processes or find alternative routes or modes of transport.

Finally, with the use of digital platforms transport supply and transport demand can be matched automatically and autonomous vehicles can perform the matched orders. This process can be organised 24/7 without dependency on human planners. This will improve transport efficiency by decreasing personal cost and improving utilisation of assets.

Transport demand

A significant growth is expected in small and large-goods logistics activity in the future. Freight activity (in tonne kilometres) is expected to increase by as much as 250% by 2050 (EC, 2017e). An increase in efficiency and infrastructure is needed to facilitate this increasing demand of activity. As explained above, SoL may improve the efficiency of the logistical processes and hence may contribute to the facilitation of the autonomous increase in transport demand (EC, 2017e). It may even be the case that the larger capacity of the logistical system due to SoL may induce additional transport demand.

Fleet size and occupancy rate

As explained above, SoL have the potential to increase supply chain efficiency. With intelligent route planning freight can be better programmed and scheduled to optimise routes. A result of this is that more cargo can be loaded for the same route, thus increasing occupancy rates. Another subject here is that empty kilometres can potentially be reduced (ALICE, 2013), such as when digital models can assign shipments to vehicles that would previously return empty to depots or terminals.

Cooperative action through digitalisation, such as shared warehouse and transport capacities, has the potential to improve the efficiency and reliability of the logistics industry. Strategic alliances of several companies or partners that allow sharing of their physical assets can achieve utilisation of logistics service beyond their own region of operation (Kayikci, 2018). This will also result in higher occupancy rates. As mentioned by one of the interviewees, it may even provide opportunities for cross-fleet collaboration between different transport modes and different organisations. Companies may use smaller fleets because of optimisation through efficiency increase, or alternatively hire fleet vehicles from other organisations only when needed. To what extent this impact on fleet size will occur is still highly uncertain.

Modal shift

Incumbent logistical processes rely on predetermined transport supply chains. With SOL, the optimum route is chosen incorporating all available transport modes. With seamless shifting between transport modes, combinations of modes (road, rail, water, air) can be accomplished that could previously be unfeasible. As explained in the text box below, a modal shift to road transport is most likely. However, as mentioned by one of the interviewees, this heavily depends on the conditions that are set by the algorithms used in the SoL application. Therefore, the modal shift impact depends on the actual design of the scheme.

3.5.2. Environmental impacts

GHG emissions

As mentioned above, SoL will probably result in higher transport efficiency (higher occupancy rates, optimised routes, etc.). Therefore, less vehicles and vehicle kilometres are required for the same amount of cargo or goods. Furthermore, an efficiency increase in the chain from producer to receiver means fewer movements are needed to reach the same performance. Consequently, this will result in a reduction of energy demand, either in conventional fossil-based fuels or renewable energy sources. The entire chain will therefore have less CO_2 emissions. As said in transport demand, an increase in efficiency or capacity can attract more demand. This would partly counteract any emission reduction from transport efficiency.

Another potential rebound effect may result from a reversed modal shift (i.e. from rail and/or inland shipping to road transport). When supply chains algorithms search, for instance through AI, for the most optimal routes and transport modes, this could mean that modes that have higher emissions per tonne of cargo are chosen. A shift from rail and water towards road transportation can provide faster delivery times against higher emissions on the short term. However, as illustrated by Box 6, it is unclear whether a reversed modal split will result in additional emissions on the long term as well.

Box 6: Is a reversed modal shift desired?

The case study exploring the changing competitiveness of road, rail and inland waterways for freight transport at the EU level (see Annex F) explains how the competitiveness between the various modes might change in the future. Currently and for the short term, strong technological developments are expected: digitisation, automation and energy transition. Those developments together can limit the advance of rail and inland waterway over road transport. A reversed modal shift towards road transport might therefore be likely. To what extent this modal shift is a wanted or unwanted outcome depends on the combination of technological developments. In case road transport will shift to the night and in case the vehicle fleet decarbonises fast enough a reversed modal shift is likely to result in positive impacts. In case not all developments occur, impacts might be negative, contributing to more emissions, more noise disturbance and higher congestion levels during daytime.

Based on the arguments provided above, it can be concluded that SoL is expected to contribute to lower GHG emissions of freight transport, but that the size of this impact is rather uncertain (due to various potential rebound effects). The actual design of the scheme will heavily affect the final impact of SoL on GHG emissions. This conclusion was confirmed by some of the interviewees experienced on logistics.

Air pollution

With a decrease of movements needed because of efficiency increase and occupancy rates, less energy is needed to reach the same performance. In the case of non-zero-emission transport, this would mean lower emissions of air pollutants, such as nitrous oxides (NO_x) and particles (PM_{10}). However, as for climate change, these positive environmental impacts may be partly counterbalanced by rebound effects like additional transport demand.

3.5.3. Social impacts

Traffic safety and congestion

As previously mentioned, digitalisation can increase efficiency and occupancy rates of vehicles. This would mean that for the same amount of freight less vehicles would be necessary. Furthermore, dynamic routing can guide vehicles to certain time frames or routes, keeping vehicles away from schools runs and busy rush hours. A modal shift towards light transportation, such as a shift from trucks towards vans and bicycles, can also raise safety in urban areas (CE Delft; INFRAS; TRT, 2019). Routes can become more efficient, meaning less kilometres are needed per route. All these effects may contribute to a higher level of traffic safety, as was also mentioned by some of the interviewed stakeholders. However, no evidence is available on the size of this effect. The various transport efficiency effects may also result in lower congestion levels. This positive effect may be partly counterbalanced by the induced transport demand due to SOL.

Data gathered from freight shipments can also benefit road management organisations, as their data can be used to make more efficient policies and infrastructure investments. This may indirectly also lead to more traffic safety and less congestion.

3.5.4. Economic impacts

Impact on the European industry

An optimised utilisation of assets and supply chain processes can give organisations a better return on assets and working capital (ALICE, 2013). Also, risks can become lower, with less cargo lost to theft or

damage through remote sensoring and tracking of freight. Additionally, waiting time in terminals and lead times can become lower when the efficiency of supply chains is increased (ALICE, 2013). This can reduce risk factors within supply chain delivery times, creating a more robust and reliable logistical chain.

The European industry has to invest in new systems that can facilitate the shift towards SOL. As mentioned by one of the interviewed stakeholders, this can become difficult for smaller companies that do not have the resources to overhaul their supply chain systems. First mover advantages will likely be taken by companies that can make the leap towards digitalising their supply chains. Companies that are not able to take such actions may fall behind in the market.

In the end, it is expected that SoL will be beneficial for the European industry, i.e. the benefits are expected to outweigh the costs on the longer term. High investment cost may, however, be an important barrier, particularly for smaller companies.

Financial impacts for end-users

A more efficient supply chain will eventually lead to lower transport costs. Though, at first investments have to be made to update and digitalise supply chains and therefore lower transport costs are mainly expected on the longer run.

In addition to lower transport costs, an optimised supply chain may also result in lower lead times and total end-to-end delivery times. Furthermore, delivery can be made more reliable and dynamic, which benefits the end user as they can specify delivery to their needs. Supply chain visibility (e.g. due to real time tracking and dynamic estimated time of arrival) benefits end users as they can optimise their own schedules to adjust to unforeseen changes in the supply chain.

3.5.5. Synthesis

As illustrated by Table 9, SoL may result in a higher efficiency of logistical processes. This may also result in higher occupancy rates. Additionally, SoL may facilitate additional transport demand by providing additional capacity on the transport infrastructure. Modal shift effects may be possible as well, although the size and direction of this effect is uncertain. The increased logistical efficiency will, particularly in the longer run, provide benefits for the industry and end-users in the form of lower transport costs and more reliability. Finally, reduced emissions and improved traffic safety are important societal benefits of SoL. Evidence on the impacts of SoL are most uncertain for indicators like transport demand, fleet size and occupancy rate, modal shift, and congestion.

Table 9: Summary of impacts SoL

Indicator	Impact
Impacts on the transport sector	
Transport demand	SoL may facilitate the expected autonomous increase in freight transport demand. It may also induce some additional demand due to higher levels of transport efficiency.
Transport efficiency	Optimising supply chain will create higher efficiency.
Fleet size and occupancy rate	With an increase in efficiency, occupancy rate will increase. To what extend is unclear. Effects on fleet sizes depend on many variables, which are uncertain to this point.

Indicator	Impact
Modal shift	Potential for modal shift when logistical services are better connected. A modal shift from rail and inland waterways to road is most likely but depends on the design of the scheme.
Environmental impacts	
Climate change	Improved transport efficiency will result in lower CO_2 emissions per tonne. This effect may be partly counterbalanced by additional induced transport demand and a potential reversed modal shift (although the impact of the latter effect on GHG emissions is rather uncertain). A net decrease of CO_2 emissions is expected, although the level of this reduction is very uncertain and depends on the design of the scheme.
Air pollution	With improved efficiency, less vehicles are needed to transport the same amount of freight, resulting in less emissions. This positive impact may be partly counterbalanced by additional transport demand.
Social impacts	
Traffic safety	Dynamic routing and modal shift to lighter vehicles can potentially create higher levels of traffic safety.
Congestion	Dynamic routing and less vehicle kilometres due to increased transport efficiency may result in lower congestion levels. These effects may, however, be (partly) undone by additional transport demand.
Economic impacts	
Impact on European industry	Reduced risks and more efficiency in supply chains, which will probably outweigh on the long run the required investments. High investments may be a barrier for smaller organisations with limited resources.
Financial impacts for end-users	SoL may lead to lower transport costs (on the long run). Additionally, reduced risks and higher visibility in shipments and logistics are expected, which provide economic benefits to the end-user.

The impacts of SoL are expected to increase over time for two reasons. First of all, to fully benefit from the effects of SoL a critical mass of operators joining SoL schemes is required. Secondly, on the longer turn additional technologies (e.g. AI) could be used that will further increase the effectiveness of the various SoL applications.

Finally, the impacts of SoL are expected to be relevant for both urban and rural areas (motorways).

4. IMPACTS OF EMERGING TECHNOLOGIES ON TRANSPORT INFRASTRUCTURE

KEY FINDINGS

- Emerging technologies and the Smart Mobility applications using them are very dependent on the digital infrastructure. For the further development of Smart Mobility, the digital infrastructure is crucial. Not only a base condition for each individual application, but also to realise a robust, resilient, safe and secure system. The development, availability, security and governance need to be a key priority in Smart Mobility policies.
- It is paramount to have specific (but integrated) strategies for the physical, digital and operational infrastructure as they have different investment horizons, stakeholders and user requirements. By ensuring strong integration of these specific strategies, the fact that the different infrastructure levels are related and dependent of each-other can be taken into account. (Near) Real-time processes requiring continuous availability and management will become more prominent.
- As the responsibilities for the physical, digital and operational infrastructure lay with different stakeholders, the integration of these different levels of infrastructure requires more cooperation and maybe even other organisation models for the operation of transport infrastructure.

4.1. Introduction

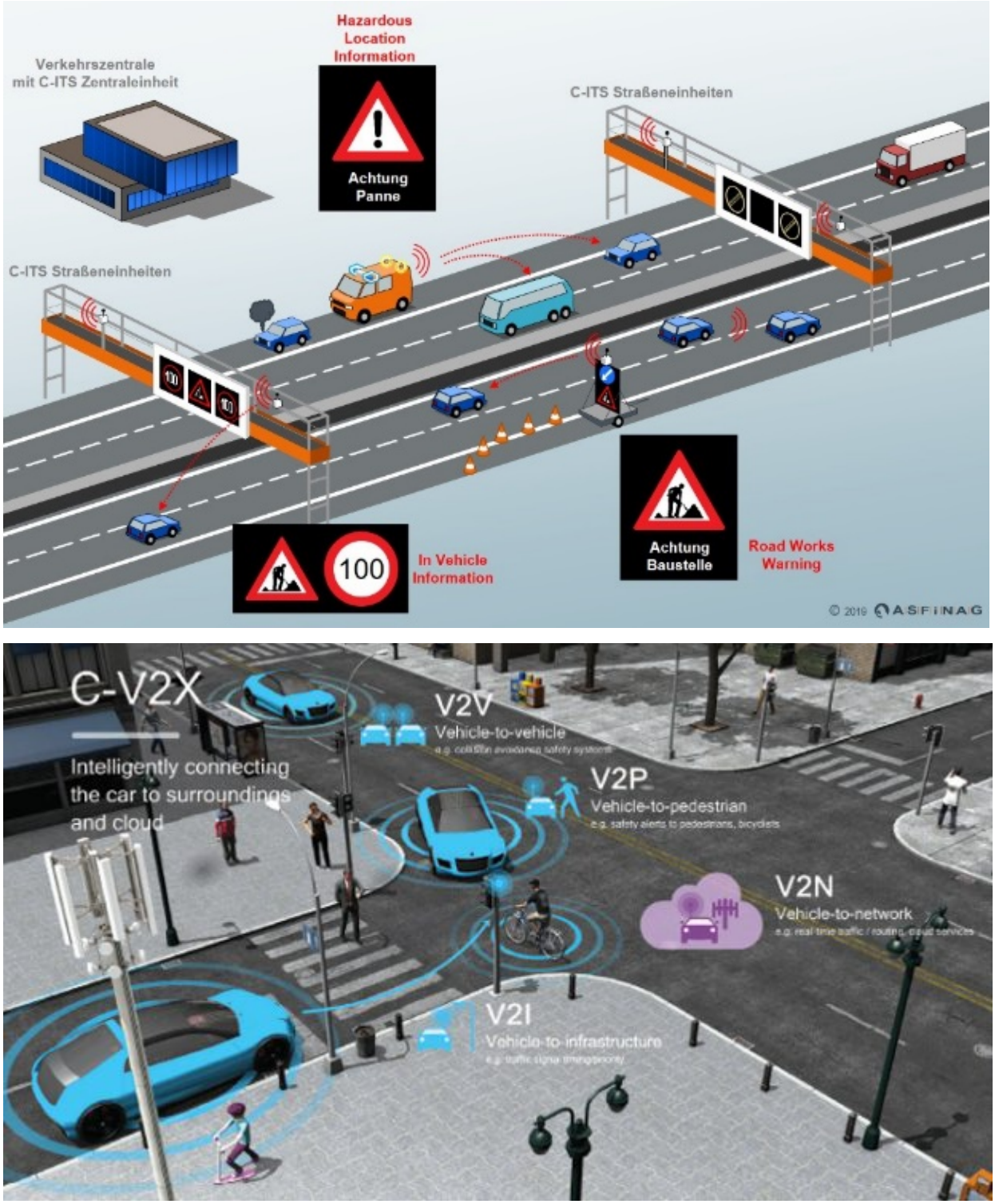
In the previous chapter, we discussed the impacts the various categories of Smart Mobility applications may have on the transport sector and the society. The impacts on transport infrastructure will be the topic of this chapter. In that respect we distinguish between physical, digital and operational infrastructure. These three levels of infrastructure will be defined in Section 4.2. The impacts of the four main categories of Smart Mobility applications on the various types of infrastructure are discussed in Section 4.3 to 4.5. Finally, in Section 4.6 some issues affecting several types of infrastructure together will be discussed.

4.2. Different levels of infrastructure

This section considers three levels of transport infrastructure: the physical infrastructure, the digital infrastructure and the operational infrastructure. These types of infrastructure are interrelated and together form the overall transport infrastructure.

In order to explain the various levels of infrastructure, we will use a C-ITS example for road transport on highways and in the urban context (see Figure 13). This example will be used to illustrate the various levels of infrastructure.

Figure 13: C-ITS deployment on highways and in the urban context



Sources: ASFINAG (2019) and Qualcomm (2020).

Physical infrastructure

Road infrastructure is traditionally seen as concrete and asphalt, road signs and traffic lights, bridges and tunnels, sidewalks and parking places, in other words physical infrastructure. Each mode has its own physical infrastructure. Trains, trams and subways use rail infrastructure also accompanied by

signs, lights, stations and platforms. Similarly, inland navigation has its own network of rivers, canals and (short) sea shipping connections accompanied by ports, docks, quays, signals and lights.

As illustrated by Figure 13, variable message signs (above or next to the road with for instance dynamic maximum speed) and road operator vehicles (with a sign on it indicating that a lane is temporarily closed due to a road works warning or an incident) can be used to send this information to the road users on the highway. Both elements of the C-ITS application are part of the physical infrastructure. In the urban context, traffic lights interacting with road users at an intersection is an example of an element belonging to the physical infrastructure.

Most of the physical infrastructure is (still) state-owned, operated and maintained. Most responsibilities with respect to the physical infrastructure lays with the infrastructure manager. This could change in the future, as some components of the physical infrastructure could also be owned by private parties (for instance the mentioned C-ITS equipment). This will be elaborated more in this chapter, as well as in Chapter 6.

Digital infrastructure

The physical infrastructure is nowadays complemented by digital infrastructure. This consists of several aspects including information exchanged by communication networks (short and long rang), data networks, cloud platforms, a PKI infrastructure (Public Key Infrastructure) and the static and dynamic digital representations of the physical world (like HD maps, traffic regulations, traffic light status).

Where the communication units sending and receiving the information in the C-ITS example are part of the physical infrastructure, the information sent itself is part of the digital infrastructure. The digital infrastructure comprises of different functionalities. Digital mapping and real-time traffic information for instance, for assisted and automated vehicles. Although these vehicles rely particularly on their own sensors (camera's, radar, lidar), they make also use of information from the transport infrastructure, other transport users/vehicles and real time information to enrich their world map. The physical equipment on which this information is collected, analysed and made available (computers, server, cloud platforms and fibres connecting them) is considered part of the digital infrastructure.

Ownership, operational aspects (including roles and responsibilities) as well as maintenance of the digital infrastructure is less straightforward. More and more stakeholders (OEMs, service providers) will get involved and will get part of the responsibilities. This will be elaborated in this chapter, as well as in Chapter 6.

Operational infrastructure

The purpose of the interaction between road users and traffic lights in the C-ITS example above is, among others, to guide the vehicles more efficient through a city. These traffic management possibilities are part of the operational infrastructure, which consist of traffic management control functions facilitating traffic flows by providing information or guidance to vehicles, service provider platforms, etc.

Traffic management is typically a responsibility of the road operator. The C-ITS example above illustrates that also this role is getting more complicated, as the road operator can and will be making use of the digital and physical infrastructure, which are no longer only owned by himself.

4.3. Impact on the physical infrastructure

4.3.1. C-ITS

Current infrastructure is already widely deployed with varying 'physical' traffic signs like traffic lights, variable message signs and fixed signs. These are used to regulate manually operated traffic and visually inform transport users about regulations. When this information needs to be provided in a digital manner to facilitate C-ITS, communication between the infrastructure and C-ITS equipped vehicles/vessels needs to be facilitated.

Current C-ITS architectures deployed within Europe provide this communication in a so-called hybrid way, meaning that both short-range direct communication between the infrastructure and the C-ITS equipped vehicles/vessels as well as long-range cellular communication are possible.

In order to facilitate short-range communication between the infrastructure and transport users, the infrastructure needs to be equipped with communication units. These units can facilitate communication via one of the two available direct communication technologies, i.e. ETSI ITS-G5 and/or 3GPP C-V2X (see Chapter 2 for more detailed explanation on connectivity technologies). These two connectivity technologies are not compatible with each other, which could result in vehicles equipped with ITS-G5 and other vehicles with C-V2X. If the transport operator would want to be able to exchange information with both vehicles through short range communication, both type of communication units should be available. This is not an ideal scenario for the infrastructure operator, as this will result in higher investment and operational costs. Moreover, both technologies could even disturb each other, which in the end could result in information not being send and/or received by the other, leading to potential risks.

For the long-range communication, C-ITS equipped vehicles are connected to cellular base stations via which they receive infrastructure communication.

As the C-ITS services are categorised into multiple categories, from less to more complex, the corresponding support from the physical infrastructure (if needed) can be categorised in the same manner influencing the requirements on the physical infrastructure. This is not one-way communication: the vehicles themselves also provide information to the infrastructure, acting as "moving sensors", communicating their time, position and if available more sensor information to the communication units and/or cloud. The digital infrastructure will make use of this data, while the operational infrastructure can use this information to optimise its traffic management.

4.3.2. CCAM

Transport users have to cope with various infrastructure elements such as traffic signs, delineators, bridges, tunnels, intersections, pavements, lighting, fences, etc. In the future, automated vehicles/vessels will be expected to deal with many of these elements as well.

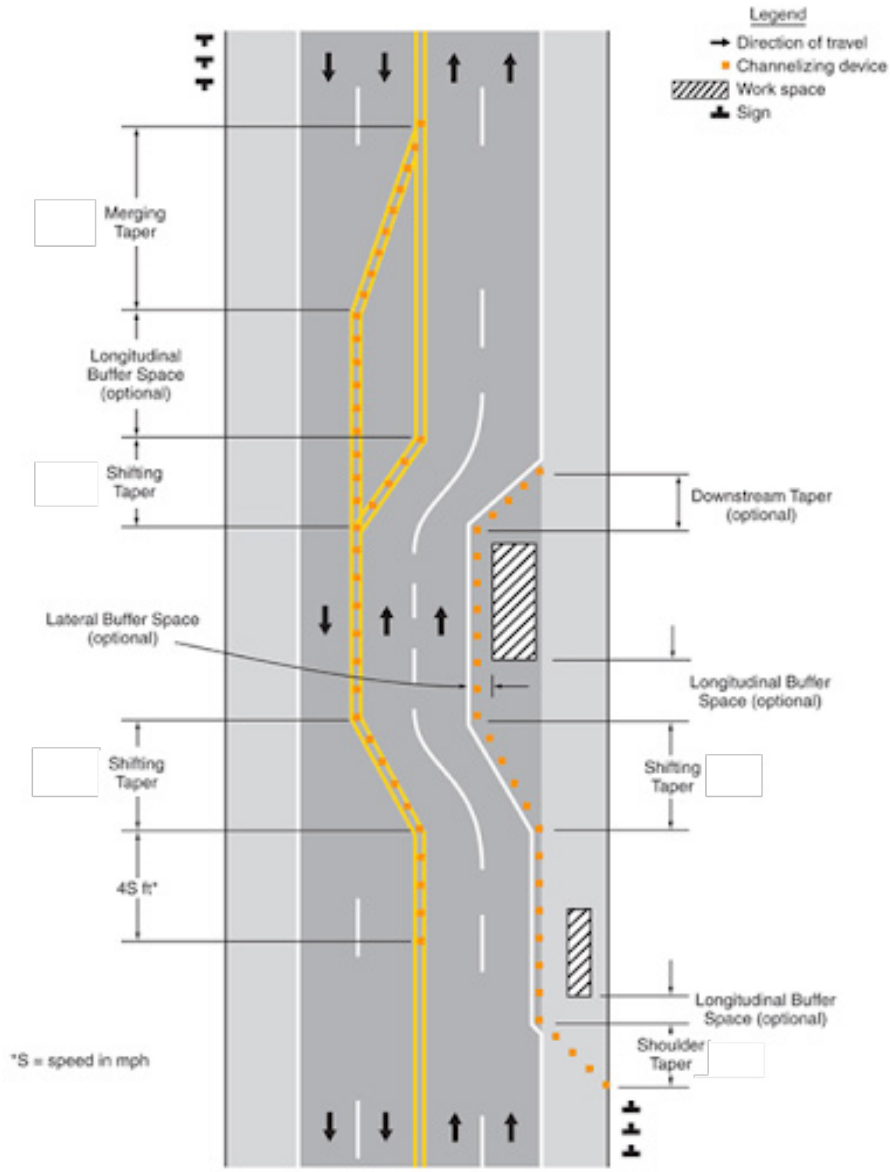
Particularly for road transport, adaptations on the physical infrastructure may be required to facilitate higher levels of automation. One has to think of the following topics (Coffeng, et al., 2018; ACEA, 2020a; CARTRE, 2018):

- Infrastructure design: particularly for road transport, changes to road design may be needed to facilitate higher levels of automated vehicles. In general, it is not expected that the road design rules will change soon, as the roads will be used by regular road users as well for many years to come. In lower vehicle automation levels (SAE 1-3), systems are expected to cope with the existing road infrastructure. The needs to adapt the existing

physical infrastructure and to deploy new digital infrastructure for automated driving and transport are likely to increase with higher (SAE) vehicle automation levels. However, there are some points of attention:

- Merging lanes, and especially merging tapers and rush-hour lanes, needs special attention, as the marking itself may be clear for human drivers but not (automatically) for automated vehicles.

Figure 14: An example with some different tapers which can be (temporarily) present on the road



- The length of on-ramps need attention, as automated driving vehicles may need more time to safely merge to the main road. One wants to avoid that automated vehicles will have to drive slowly or come to a stand-still before merging, not desired due to traffic safety and traffic efficiency. This length may also be important for regular vehicles, when merging while a platoon (with limited space between the platoon members) is on the main road.
- Curves with a desired speed less than the maximum allowed speed. For regular drivers this may be obvious, for automated vehicles this has to be absolutely clear.

- Rutting by vehicles, in particular trucks using the lane keeping system. They will typically drive in the exact same lateral position in a lane, thereby increasing the wear and tear on that exact locations. With (especially) truck platoons this will also result in changing load on bridges (more weight than foreseen, on the same repeated locations).
- Decent, consistent quality and visibility (reflection and contrast) of lane markings on motorways, national/regional roads, dual carriageways, key cross-border routes (TEN-T network) and in cities (facilitates lateral control). This should be consistent with the state-of-the-art of the sensor's expectations.
- Decent amount, clear visibility, good maintenance and harmonisation and standardisation of transport infrastructure signs for the vehicle sensors (standardised traffic signs, speed limit signs, conditional signs, etc.).
- Availability of existing and usable hard shoulders and intact fences to exploit the safety potential during automated emergency stops and to minimise risk regarding hazardous situations with animals.
- A communication infrastructure offering the connectivity needed to offer all required information.

4.3.3. MaaS

MaaS is expected to change the physical infrastructure needs. As MaaS consists of providing multi-modal transport services, it is relevant to take the needs of all modes into account: infrastructure for motorised vehicles (cars, vans, trucks), busses, rail/trams/subways, bicycles, micromobility and walking. MaaS can change the mobility choices of people resulting in different travel patterns, e.g. other activities and activity patterns (working from home, other recreational activities, additional taken trips), modal shift, use of different vehicles, travelling at other times and different routes. The magnitude of the changes in travel patterns will depend both on the specific policy goals for MaaS (for example the goal can be a modal shift from single occupancy car use to more sustainable modes as illustrated in the Finland case) and the way MaaS is deployed, the level of accompanying policies and the specific context in a country (for example whether or not there is a (high quality) public transportation system). Hence, MaaS can potentially affect all aspects related to the infrastructure of all modes. Below we provide some examples of MaaS issues related to the infrastructure.

As MaaS can lead to a demand for new modes and services and/ or a modal shift among the available modes, this can lead to the need for new infrastructure or changes in the existing capacity. It all starts with which new services are allowed to be used as part of the transportation system. In these discussions, often issues related to the physical infrastructure are involved. Examples include concerns about the safety impacts of the use of micromobility and the parking of micromobility and (shared) bicycles on sidewalks.

Sometimes completely new infrastructure will need to be built, sometimes the capacity of current infrastructure will be extended and sometimes the current space will be re-allocated. In some countries, there is limited infrastructure or active modes (cycling, micromobility and walking) and MaaS can lead to the need to build new infrastructure. In other countries, MaaS can lead to a higher demand for public transportation, leading to building more new lines, more connections and/or increasing the frequency of existing lines. Examples of the re-allocation of space in cities (where public space is mostly limited) are closing streets for motorised traffic giving more room for active modes, reducing car lanes to create dedicated lanes or space for (rail-based) public transportation, reducing the number of parking places to build bicycle lanes, etc. Finally, the trend towards more electric vehicles requires a charging

infrastructure. The direction of physical infrastructure needs (which modes will require more space, for instance) will largely depend on the priorities given to MaaS platforms and the incentive structures and policies that will help shape user choices.

With the introduction of a range of new transportation services, parking and curb management (the use of and access of the sidewalks) is a major topic. With the increase of modes and services, there is a higher demand for (often already) limited space on the curb. The increase in the use of taxi and Transportation Network Companies[26] services increases the demand for taxi stands, kiss-and-ride locations and pick-up and drop off points. Note that not only passenger transportation requires space, the rise in e-commerce also leads to the need for pick-up and drop-off space for deliveries. The increase of shared cars leads to allocating dedicated parking places for these vehicles. With the increase of vehicles such as (shared) bikes and e-scooters, the amount of parking space and where and how they are being parked and charged has become an issue. Cities around the world gained experience with this and have adopted different solutions (from dedicated parking places, regulating the number of vehicles to parking instructions and fines for users).

Increased desire to access the curb for multiple modes also points to the need to manage the roadway to avoid conflicts between vehicles and modes. The issues seen around competing needs of cyclists and public transport services – in access to and travel along the curb - will only become more heightened as more modes and more people in each mode have these needs. Vehicles blocking travel lanes as well as injuries related to mode interactions could become more common if this space is not well managed.

Another topic is the need for hubs. As MaaS is based on the ideas of a seamless chain of various transportations modes, the interchange between modes need to be facilitated as well. The idea of a hub at the border of a city (centre) where flows from different direction come together and are bundled, started in the field of logistics (see the section on logistics in this report). For passenger transport a hub is a physical location where passengers coming from various locations and modes can change mode. For example, a passenger could park their car and continue with public transportation or change from a train to a shared bicycle. Often, these types of areas not only require attention to the transportation services but also to the quality of the space, the flow between modes, and the amenities as well to make the use of hubs as attractive, inviting, and efficient as possible.

One of the underlying drivers of MaaS is the development from ownership to access. This not only holds for vehicles but also the physical infrastructure. With the introduction of private companies in the field of transportation, the infrastructure may no longer always be owned by the public authority. This development started decades ago with the privatisation of public entities in the field of public transportation. Also, for many years, road authorities have involved private companies in the Design Build Operate and Maintain process. MaaS is expected to accelerate the involvement of private companies in offering transportation services in all modes, which can also lead to more variations of public and private ownership of all types of infrastructure as well.

As it is expected that, in the future, (shared) automated vehicles will be part of MaaS as well, the impacts of automated driving on the physical infrastructure, as discussed in the previous section, will also become relevant.

[26] "Transportation Network Companies (TNCs) provide prearranged transportation services for compensation using an online-enabled application or platform (such as smart phone apps) to connect drivers using their personal vehicles with passengers." Source: CA.GOV : Transportation Network Companies

4.3.4. Self-organising logistics

The introduction of self-organising logistics may have an impact on the physical infrastructure as well. Connecting vehicles may require the use of communication units along transport infrastructure, as was discussed in Section 4.3.1). In case autonomous vehicles are part of SOL, changes to the infrastructure similar as discussed in Section 4.3.2 may be required. For example, for safe guidance of autonomous vehicles at 'difficult' parts of the infrastructure, sensors might be needed both in the vehicles and in the infrastructure to avoid collisions. Besides, for the first stages of autonomous vehicles at restricted areas at (air)ports and yards, separate lanes might be reserved or build (for instance the Container Exchange Route at the Port of Rotterdam). For the next stages of autonomous vehicles there will be mixed traffic on public roads which might require modifications in the infrastructure to separate manned and unmanned transport where needed.

Self-organising logistics will lead to much more bundling of goods on the long haul, which has to be distributed to different locations for the first/last mile. For this decoupling of the bundled goods on the long haul to dedicated flows on the first/last mile, central gates at (air)ports and hubs for city logistics have to be developed. These gates and hubs have to be developed and good accessibility to/from these locations has to be guaranteed.

Finally, self-organising transport is expected to lead to changes in the competitive position of the different modes of transport. Dependent on how this competitive position changes different shifts between the modes of transport are possible. This requires an adaptive approach to make decisions on large investments for new infrastructure of the modes of transport to make sure there is enough capacity available for the demand of transport.

4.4. Impact on the digital infrastructure

4.4.1. C-ITS

C-ITS applications make heavily use of information from the digital infrastructure, for instance information of intelligent traffic lights or information of the current traffic status (e.g. traffic jams, road works). The digital infrastructure should be able to make sense of all available data, provide this information to connected vehicles and receive in return information from these vehicles.

C-ITS is about exchanging information in a safe manner. A public key infrastructure (PKI), specifically designed for C-ITS, needs to be in place to be able to do this. This entity will be responsible for providing certificates to all C-ITS elements, making and distributing CTLs (certificate trust list) and CRLs (Certificate Revoke List). This will be done per Member State, but also Europe wide CTLs and CRLs will be exchanged.

The digital infrastructure could become critical in case they will replace existing services (like traffic management information in car instead of traditional physical signs, incident information, re-routing information). Currently C-ITS is mostly deployed in parallel with existing (physical) components, but when more and more vehicles will become equipped one could start thinking of substituting these components with the digital ones.

4.4.2. CCAM

There is debate over how much effort countries and jurisdictions should put into digital infrastructure for automated vehicles (AVs), including sensor networks, infrastructure equipment such as smart traffic lights that can inform AVs when to stop or go, and high-quality digital mapping. From a safety point of view, level 5 AVs should not need to rely on external infrastructure while moving. However their safety

is likely to come at the cost of efficiency, with a number of studies (e.g. (KPMG, 2019) (Arcadis ; TNO, 2018)) suggesting slower traffic speeds and worse congestion with AVs because they will drive more defensively and keeping more distance than humans. Connected automated vehicles will benefit from increased connectivity with other vehicles, the infrastructure and other road users. This will allow them to better coordinate their manoeuvres, making use of active infrastructure support and enabling smart traffic and fleet management for improved throughput and increased safety. CCAM solutions will ultimately be based on connected and highly automated vehicles with very high levels of robustness and reliability even in particularly challenging and complex traffic environments Digital infrastructure, allowing vehicle-to-infrastructure (V2I) communication, is potentially the solution to this. V2I systems use a centralized traffic management system to optimise the use of infrastructure by orchestrating how vehicles/vessels operate for the benefit of all users. Level four AVs, which are only capable of autonomy in certain conditions (within their own operational design domain (ODD)), may be 'geo-fenced', or geographically limited, to areas with adequate digital infrastructure (KPMG, 2019). For these higher levels of automation (see Chapter 2) information from the infrastructure can extend the ODD (operational design domain) of the CCAM vehicles, allowing them to move automatically instead of handing back control to the driver on more locations. It is important to notice that the situation seems to differ a bit between the different regions in the world. In Europe, connectivity in mobility is high on the agenda, for instance being discussed in the CCAM platform and 5GAA between vehicle manufactures, road operators and the telecom industry. In the USA, manufacturers of autonomous vehicles are still hesitant to make developments in their vehicle dependent on information from outside the vehicle (from other vehicles and/or the infrastructure). In Asia both approaches are seen. These varying approaches may slow down the introduction of certain CCAM functionality, as choices will have to be made in terms of what to develop first.

Often, the 5 ISAD (Infrastructure Support levels for Automated Driving) are used to describe the different levels of infrastructure support which can be offered to CCAM vehicles (ERTRAC, 2019).

Figure 15: Levels of the Infrastructure Support for Automated Driving (ISAD)

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicles movements, he infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow	X	X	X	X
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time	X	X	X	
	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs	X	X		
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs	X			
	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs				

The levels of infrastructure support ranges from level E (no support from digital infrastructure) to level A, in which the infrastructure is able to guide CCAM vehicles in order to optimise the overall traffic flow.

- These different levels of infrastructure support could include the following activities
- Provisioning of high-definition maps. Static data (basic map data) as well as semi-static (traffic regulations, road works, weather forecast)
- Provisioning of real-time traffic information like dynamic maximum speed, real-time traffic information like accidents and congestion, (semi-dynamic data)
- Sharing sensor data or merged sensor data ("Dynamic map data")
- Based on real-time traffic information the infrastructure could guide the CCAM vehicles in certain situation through complex traffic situations.

The infrastructure manager will need to have this real-time data available in digital form, according to the standards (see Chapter 2), in a secure and trustworthy manner. Connectivity also has to be available, as described in Chapter 2 and the previous section on the physical infrastructure as well. The higher levels of support (A and B) involve applications running at the infrastructure. For instance, cooperative merging, or shockwave damping[27], or dedicated lane advice or smart routing.

As indicated before, there is a clear need for common definitions and standards enabling wide adoption of the information exchanged. In order to be able to use this information (like static/dynamic traffic regulations), the data exchange has to be clearly specified. Three aspects have to be considered:

- Adopted data formats, contents and communication protocols;
- Quality and trust of the exchanged data;
- Accessibility to the information exchanged.

The main challenge for using external data when extending from L2 to L3/L4 vehicles, so to the levels in which the vehicles are able to drive (partly) automatically in certain locations, (see Figure 9 earlier in the report) is that the automated operation functionality has to rely on and trust external data, e.g. external sensor information, maps, positioning information, etc. If the integrity of this data is compromised or not provided with the expected quality, the building blocks of the automated operation functions (Sense – Plan – Act) will use incorrect data to the control the vehicle. Similarly, if data authenticity cannot be verified, the system cannot ensure accurate moving or fully correct operation. This will be detailed further in Section 4.5.

4.4.3. MaaS

MaaS is highly dependent on a digital infrastructure and data standards. The core of MaaS is considered to be a platform (or multiple platforms) that allow users to find, book and pay for an integrated transportation service. Hence, MaaS' dependency on the digital infrastructure results in requirements for the (further) development of the digital infrastructure in a country. In turn, the digital infrastructure (including underlying techniques such as AI) can boost the development of MaaS as well. Note that the

[27] Shockwave damping is a service that aims to smoothen traffic flow in dense traffic conditions by giving optimal speed recommendations and displaying these in a vehicle. In this way, an optimal usage of the capacity of the roads should be reached. The advices are based on a detection of a disturbance on the road, the advices are given to vehicles further upstream (~a few kilometres before the disturbance location is reached), so these vehicles can already slow down before seeing the disturbance, and by doing so allowing the disturbance more time to dissolve.

digital infrastructure can also affect the activity patterns of end-users directly, for example through teleworking, which in turn affects the travel demand and the use of (MaaS) transport services.

In general, the impact of MaaS on the digital infrastructure will increase as MaaS further develops. Below the impact of MaaS on several elements of the digital infrastructure is described.

- *Data:* The ideas behind MaaS is to have real time and integrated information on all modes of transportation. Different categories of information included are data on availability, timetables, routing, sensor information from connected vehicles or smart phones, capacity of a transport mode or service, (additional) services, costs and ticketing – for each mode of transportation and each specific service. This requires access to, standardisation, and integration of many different data sources from different stakeholders. The larger the scale of integration, the higher the dependency on the digital infrastructure.
- *Handling, analyzing and predicting data:* With the increase of the number of transportation modes, services and users adopting these services, the amount of data required for and generated by MaaS will rise exponentially. Hence, the dependency on data handling, analysis and prediction processes will increase with the further development of MaaS.
- *Storing, processing and exchanging data:* MaaS requires platform technology (to provide information, streamline processes, and integrate sensors to provide value-added services), cloud solutions and data communication technology supporting the integration of travel options and the communication of the information of the MaaS services. The development of MaaS will result in an increase of requirements for these parts of the digital infrastructure.
- *User interface:* MaaS services and information need to be presented to the intermediate and end users. This can be done via online systems and (mobile) websites or apps. As such, the level of digitalisation in a country (e.g. the percentage of people with internet access, with a fixed connection and cellular, e.g. the number of users with a smartphone) has an impact on the adoption of MaaS.

4.4.4. Self-organising logistics

Besides the required digital infrastructure, for connected (and automated) transport as described above, a digital infrastructure is required for the decentralised planning and control by transport units, loading units or the cargo itself.

Let us take an autonomous container[28] as an example in a SoL concept. First of all, a digital platform is required that matches transport demand and transport supply. The autonomous container can use this platform to check which transport orders are available and which of these orders is most interesting. Then the autonomous container needs an overview of all available transport alternatives in the multimodal network that are relevant for all modes of transport, all routes and all schedules. Besides, this overview of alternatives, the real-time status of these alternatives is required including expected performance and current or expected delays. Based on all this information, the autonomous container will decide what order to take and what alternative in the multimodal network to use based on a mix of performance indicators.

[28] Actually, with an autonomous container we mean a digital twin representing this container. This digital twin is a tiny application (software) that is able to store essential information, to interact with other digital twins and to make decisions.

This way of working means that many real-time data should be available to create visibility in the complete transport chains. Platforms and data spaces are required to make this data available in a safe and controlled way. On top of this, algorithms should be able to access this data in real-time, process the data, make data driven decisions and deliver actions to the autonomous container. These kinds of applications where digital twins represent the autonomous container should be developed within or on top of the data spaces.

4.5. Impact on the operational infrastructure

4.5.1. C-ITS

Traffic management can use the possibilities of C-ITS. Not only by giving warnings and advices to transport users, but also to include the C-ITS possibilities into their traffic management. It will become possible to guide and direct individual transport users/vehicles, or streams of users/vehicles. To be able to do so, available traffic management systems/traffic control centers and C-ITS platforms will have to be connected, and functionality will have to be coupled. For instance, when setting a traffic measure (avoid route A due to an accident, associated C-ITS warnings and advices have to be send out as well). Vehicles/vessels themselves can also play an active role: they constantly share the position, but are for instance (if allowed) also able to ask for priority at a specific part of the infrastructure (e.g., intersection, landing strip), hereby actively influencing traffic management.

4.5.2. CCAM

Traffic management centres have a crucial role in providing real time traffic information and detecting, guiding and optimising real-time traffic conditions. Interaction between vehicles, vehicles and infrastructure authorities (V2I, I2V) and the digital representation into the vehicle system of traffic rules and traffic elements such as road signs, speed, variable messaging is crucial. This interaction offers even direct traffic management possibilities, to directly "control" transport users. This can be done either with advices / warnings (as in C-ITS), so the vehicle can decide how to use this information, or with related information which can automatically be used by higher levels of CCAM vehicles (having its own safety systems still in place of course). One can think of smart routing (e.g. suggesting eco-routes distributing traffic over alternatives routes from A to B, when knowing the destination of the vehicle, etc.).

Traffic rules and regulations should also be digitalised as described in Section 4.4. The availability in real-time of correct information at a given location is as important as harmonisation. Traffic managers will therefore need to translate their traffic management policy, decisions and requests into a digitalised standardised language, so that it can be exchanged well in advance with automated vehicles. Cooperative incident management is hereto complementary.

4.5.3. MaaS

MaaS systems can be of great assistance to overall road traffic management and the operational management of various transportation modes. Because of its multimodal nature and the ability to impact the traffic and travel patterns of users as well as other transportation choices (e.g. type of activity, location, destination) the operational management of MaaS is often called mobility management. Examples of this include giving information, (near-real-time) advice and warnings to users. To be able to do this, the traffic management systems/traffic control centers for (all or the included) modes and services need to be connected to (parts of) the MaaS platforms and systems.

Besides information, advice and warnings, pricing and other incentives can also be used as part of a MaaS system to manage the behaviour of users. As MaaS schemes includes payment for the use of the service, including pricing incentives (both increases of prices and subsidies) to manage behaviour (at specific times, locations, user groups etc.) can become an option. When large amounts of data become available via MaaS, moreover, this might open up opportunities for on-demand asset and labour management (in order to optimise all available resources using real-time demand and supply information). As MaaS is still in development, it remains to be seen how the operational management of MaaS can and will be shaped in the future.

4.5.4. Self-organising logistics

Contrary to a control tower approach where a central organisation controls processes, SoL is an approach based on decentral organisation. Smart agents are optimising their performance based on local information and local intelligence. However, it is the question whether this approach will lead to optimal outcomes (in terms of for instance efficiency, accessibility or sustainability) in all situations on a system level. Therefore, an operational infrastructure might be required that can provide guidance or impose measures to improve the performance on a system level. This can be the case on a macro level (in a region) related to congestion on transport networks but also on a meso level (for all shipments of a company) related to for instance unsustainable solutions in the logistics chain. This way, SoL is based on decentral control in most situations, but a mix of central and decentral control may be required in specific cases to guarantee good performance at the system level.

4.6. Overall impact on the infrastructure

In the previous sections, we have described the impact of the selected applications on the physical, digital and operational infrastructure separately. However, as these different levels are interrelated, it is also relevant to consider the impacts on infrastructure on a more holistic way, considering all levels together.

4.6.1. Discrepancy in lifetime of the physical, digital and operational infrastructure

The lifetime of the physical infrastructure components is in general much longer than the digital and operational infrastructure. This means that for decisions on investments in physical elements of the infrastructure much longer periods have to be considered than for the digital infrastructure. Investment decisions for one level depend on the other levels as well. To decide, for instance, whether new VMS (variable message signs) need to be installed above the road one needs to know whether the coming years C-ITS could be used for this instead and in what timeframe one realistically can expect that this information for road users can be available through digital platforms, as this will make the investments in the physical infrastructure obsolete. In other words, investment decisions in transport infrastructure requires that all different levels of infrastructure are considered and hence that all stakeholders (or bodies representing them) owning/using parts of these infrastructure levels should be involved/consulted. Chapter 6 will describe in more detail the stakeholders involved. It means that the coming years investments will have to be done which will not serve all infrastructure users. It also means that for some functionality investments in more than one layer will have to be done, to be able to offer the service through both the physical and the digital infrastructure. For example, dynamic speed limits through VMS signs, visible above the road, but also by sending information to the road users through the digital infrastructure.

4.6.2. Domains (and responsibilities) are getting mixed

Most responsibilities with respect to transport infrastructure used to lay with the infrastructure manager, but by applying more and more digital approaches other stakeholders (OEMs, service providers) get involved and will get part of the responsibilities. These shared responsibilities may complicate issues and require other organisation models. Investments, which are likely to increase, may be slowed down or even postponed due to these shared responsibilities, because the different stakeholders wait for each other or have a different view on who is really responsible and should take action. Liability also plays an important role. Who is, in the end, responsible for the infrastructure and the safety on it? Or, in case of a shared responsibility, how can this be organised? An intensified cooperation of the key actors (OEMs, road operators, policy makers, service providers) will be necessary. Chapter 6 discusses in more detail the different stakeholders involved, the challenges they face as well as potential mitigation actions that could be taken by them. This will also illustrate the fact the roles and responsibilities are getting mixed and that this will have to be addressed in cooperation with each other.

4.6.3. The chicken/egg investment dilemma

Having the digital infrastructure in place is one challenge, to reach the road users with the available data is another challenge. The impact of C-ITS services, for regular vehicles as well as vehicles with a higher level of automation, depend on the penetration rate of vehicles/vessels which are actually reached with the information (and vice versa with the data these vehicles/vessels make available).

For road transport, we see that road operators are hesitating to invest heavily in the digitalisation of their infrastructure, waiting for the automotive industry to make their vehicles connected, while the automotive industry waits for the road operators to make the first move, postponing the addition of connectivity in their vehicles till the road infrastructure is digitalised. This is the classical chicken/egg investment dilemma. Although this dilemma is most profound for road transport, it is also relevant for other transport modes as there is often a split between ownership of infrastructure and vehicles/vessels as well.

4.6.4. Large dependency on the digital infrastructure

The various categories of Smart Mobility applications all use combinations of emerging technologies. As these emerging technologies are largely part of the digital infrastructure, the dependence on the digital infrastructure will become larger. Often, the digital infrastructure is a precondition for the further development of the applications. Also, the deployment of the applications will be accelerated by the further development of the digital infrastructure.

5. EU POLICIES AND STRATEGIES

KEY FINDINGS

- Smart Mobility solutions are expected to provide a significant contribution to the environmental, social and economic goals of the EU. These solutions are explicitly mentioned in many EU strategies to make the transport sector more sustainable, efficient and safer. Furthermore, Smart Mobility is expected to provide attractive economic opportunities for the European industry (e.g. automotive, telecommunications).
- To facilitate the deployment of the Smart Mobility applications the European Commission has worked over the last decade on a legal framework. Furthermore, several public-private partnerships have been initiated by the Commission to support the deployment of these applications (e.g., C-ITS Platform, C-Roads Platform, CCAM Platform). These initiatives have also provided input on specific issues used by the Commission as input for new legislation or strategies (e.g., European Strategy on C-ITS and the forthcoming Strategy for a Sustainable and Smart Mobility, see also Section 7.2).
- EU policies and initiatives in the field of Smart Mobility was initially focussed on C-ITS, e.g. by the initiation of the C-ITS and C-Roads Platforms. This also resulted in the adoption of an EU-wide Strategy on C-ITS in 2016. Over the last years, more attention has been paid to CCAM and, to a lesser extent, SoL. In 2018, an EU-wide strategy on connected and automated transport was adopted as well. For MaaS no EU-wide strategy on further development and deployment is available yet. For this application, mainly regulations facilitating the access to transport and travel data have been implemented and several EU-funded research and pilot projects have been launched.

5.1. Introduction

This chapter provides an overview of the main EU strategies and policies with respect to the Smart Mobility applications considered in this report. Policies and strategies on Smart Mobility are developed also at the national and regional/local level. However, it is out of the scope of this study to provide a complete overview of the policy framework in the various Member States.

In Section 5.2 we first show which role the European Commission have in mind for Smart Mobility in achieving social goals like reducing Greenhouse Gas and air pollutant emissions, improving traffic safety, reducing the level of congestion and boosting the EU economy. We do this by assessing what contribution is expected from Smart Mobility in some EU strategies on these issues.

In Section 5.3, we discuss the main EU policies, strategies and initiatives with respect to the four Smart Mobility applications considered in this report. This overview is limited to policies, strategies and initiatives that are directly addressing (Smart) Mobility. Policies on other domains, like the Digital Market or ICT, may indirectly also be relevant for Smart Mobility, but are out of the scope of this study.

5.2. The role of Smart Mobility in the EU transport strategy

Stimulating the uptake of Smart Mobility applications (facilitated by emerging technologies) is an important element of the European strategy to achieve a more efficient and sustainable transport system. Already in the EU Transport White Paper of 2011, these kind of applications (e.g. the European Rail Traffic Management System (ERTMS) and the air traffic management system of the future (SESAR))

are mentioned as an innovative way to improve transport efficiency, safety and the use of infrastructure towards a modern and user-friendly EU transport system (EC, 2011).

Also, in more recent strategic documents the important role of Smart Mobility applications in achieving various social goals (e.g., reduction of emissions, improving traffic safety) is highlighted.

Reducing environmental impacts

The recent European Green Deal (EC, 2019c) mentions that Smart Mobility options such as automated, connected and shared multimodal mobility will need to play a role in achieving a more sustainable transport system and realising a reduction of GHG emissions of 40% in 2030, compared to 1990 levels. For that purpose, the EU transport system and infrastructure should be made fit to support these innovative mobility services, like MaaS applications and smart traffic management. Funding instruments from the Commission (e.g. Cohesion funds, the proposed Recovery and Resilience Facility[29]) will be used to enable such mobility solutions in the EU transport system. In earlier EU strategies, also, the contribution Smart Mobility applications could have to reduce the environmental impact of EU transport is highlighted. For example, in the 'European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' Smart Mobility applications like connectivity and autonomous driving are expected to become an important element[30] in the decarbonisation of the transport sector (EC, 2018c). Additionally, these applications may also contribute to reducing other environmental problems, like air pollution and noise, particularly in the urban context.

Improving traffic safety

Smart mobility solutions are also seen as an option to improve safety on the EU transport infrastructure. The EU has ambitious goals in this field. In 2019, the Vision Zero (EC, 2019b) is adopted by the Commission in order to increase road safety on European roads. This guideline aims to move close to zero fatalities in road transport by 2050 and added that the same should be achieved for serious injuries. It also proposed new interim targets of reducing the number of road deaths by 50% for 2030 as well as reducing the number of serious injuries by 50% in the same period. The development of connected and automated vehicles was identified as a very promising option to reduce and eventually eliminating driver errors and hence traffic accidents in the European 'Road Safety Policy Framework 2021-2030', and therefore could provide significantly to the goals set by the Commission. However, at the same time, issues like cyber-security and interaction with 'traditional' vehicles were identified as potential risks for traffic safety.

Reducing congestion levels

As indicated by the 'European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' Smart Mobility applications, like smart traffic management and increasing automated mobility in all modes, could contribute to lower levels of congestion as well (EC, 2018c). As part of the program Europe on the Move, the objective to reduce congestion levels in urban areas by using Smart Mobility applications (e.g., automation, sharing economy and new forms or personal mobility) is mentioned as an objective as well.

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[29] The Facility is a central pillar of NextGenerationEU (proposed by the European Commission), a temporary recovery instrument to help repair the economic and social consequences of the COVID-19 pandemic, support economic recovery and build a better future for the next generation. The Facility provides loans and grants to Member States for investments in measures that may contribute to the achievement of EU's policy objectives, particularly the green and digital transitions (including Smart Mobility).

[30] In combination with decarbonised, decentralised and digitalised power, more efficient and sustainable batteries, and highly efficient electric powertrains.

Boosting the EU economy

The benefits Smart Mobility could have for the European economy is highlighted in several European strategies. The Third Mobility Package (EC, 2018b), for example, presents the goal to make Europa a world leader for fully automated and connected mobility systems. In the Commission's strategy for autonomous transport (EC, 2018e) it is anticipated that automated and connected mobility will provide significant revenues to the EU automotive industry and the EU electronic sector (and to other economic sectors as well), although it is mentioned that some other sectors (e.g. insurance, maintenance and repair) may be negatively affected. With respect to employment, it is expected that the development of new technologies and services may require new skills and highly paid (e.g. engineers) and medium skilled (e.g. mechanics) jobs. In order to meet the requirements for these new jobs, the Digital single market strategy (EC, 2017c) and the Skills Agenda for Europe (EC, 2020) is putting priority on digital skills at all levels. As part of the Skills Agenda, the Blueprint for Sectoral Cooperation on skills was launched, providing a framework for strategic cooperation between parties to prepare for digital transition. The automotive sector was selected as one of the pilots within this framework.

Providing adequate infrastructure

To achieve the various social benefits of Smart Mobility as mentioned above, the necessary infrastructure should be available. This is stimulated by deployment of smart features and supporting facilities on the TEN-T infrastructure. The EU has a vision of a new trans-European Network of Transport (TEN-T), which includes the deployment of EU-wide Smart Mobility applications, backed by the Connecting Europe Facility (CEF), a supporting financing instrument (EC, 2020c). The realisation of the European Railway Traffic Management System (ERTMS) is an example of such an EU-wide deployment of a Smart Mobility application. Milestones are the completion by 2030 of the core network, structured around nine multimodal core network corridors. The comprehensive network is planned for 2050, which facilitates accessibility to all European regions.

Achieving close cooperation between the public and private sector

Finally, the development, financing and operation of national transport systems require close collaboration between public and private sectors. These two sectors have to have a mutual understanding of their needs, and create a situation that is a win-win for both (EC, 2017e), or else there is little motivation for collaboration to take place. The public sector could have a facilitating role in the warehousing and the management of multimodal information. Furthermore, the public sector should create an EU broad harmonised regulatory framework and policy objectives, where national borders do not act as barriers for smart technologies. The private sector can engage in the market for data exchange, network and traffic management functions and service provision for the end user (EC, 2019a). The roles between the public and private sector have to evolve, where public interest and policy goals are balanced with profit and customer satisfaction. The EU could stimulate the process of public and private sector alignment by providing support to the development of multi-actor organisational and business models.

5.3. Relevant EU policies with respect to emerging technologies

Over the last decade, the European Commission has adopted several policies in order to provide a legal foundation facilitating the development and deployment of the Smart Mobility applications and their underlying technologies. Furthermore, several public-private initiatives have been initiated to stimulate the development and deployment of Smart Mobility in Europe. Below, the most important policies and initiatives are presented for each of the Smart Mobility applications.

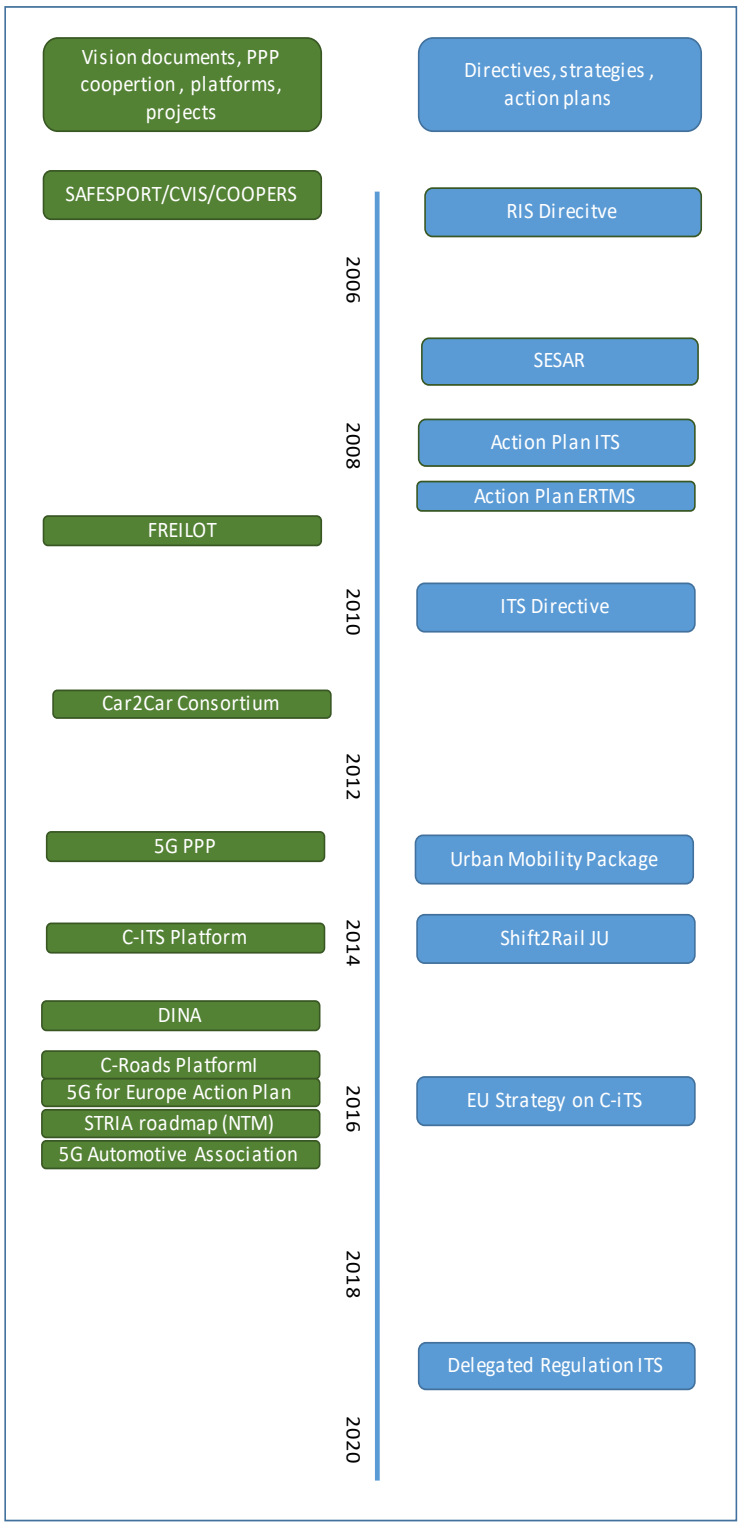
5.3.1. C-ITS

C-ITS has seen development in Europe for more than a decade. The ambition of the European Commission and EU Member States is to establish large scale deployment of C-ITS (Lu, et al., 2018). Since 2005 several projects have been launched targeting cooperative systems on traffic safety and efficiency such as **SAFESPORT**, **CVIS** and **COOPERS**, as are logistical applications such as **FREILOT**.

A gain in momentum in policy backing of C-ITS can be identified from 2008 onwards with the publication of the **ITS action plan** (EC, 2008), which is formed with the goal to speed up market penetration of rather mature ITS applications and services in Europe. This is followed up with the **ITS directive** in 2010 (EC, 2010), which provides the first EU-wide legal-framework to support the deployment of ITS in the road transport sector. An ex-post evaluation of the Directive (EC, 2019g) shows that the Directive had a positive impact on the deployment of ITS across Europe, particularly by addressing the lack of coordination in ITS deployment in Europe and the slow, risky and not cost-effective deployment of these systems.

In 2011, the **CAR2CAR Communication Consortium**[31] was launched, which is a joint initiative of EU vehicle manufacturers. The goal of this consortium was to start large-scale deployment of C-ITS by 2015. However, it became clear that such a deployment was only possible when all main stakeholders followed a common approach on both technical and non-technical aspects.

In December 2013, the Commission launched a public-private partnership (PPP) on 5G, the **5G PPP**[32], with the



Source: CE Delft

[31] Car 2 Car: Communication Consortium

[32] The 5G Infrastructure Public Private Partnership (5G PPP)

objective to prepare the next generation communication networks based on this technology. A 5G Action Plan was published in 2016, providing a deployment timeline indicating an early roll-out in major cities in the member states in 2020 and a coverage of all urban areas and major transport corridors in 2025. Transport was mentioned an interesting field to develop new C-ITS and automated services based on this new communication technology infrastructure.

In 2013, the **Urban Mobility Package** was presented by the European Commission, reinforcing the supporting measures in the area of urban transport (EC, 2013). A central element of this Package were the **Sustainable Urban Mobility Plans (SUMPs)**, which are strategic plans designed to satisfy the mobility needs of people and businesses in cities for a better quality of life. Some basic characteristics of SUMPs are a participatory approach in developing them, a balanced and integrated development of all transport modes and a long-term vision and clear implementation plan. C-ITS applications (and also the other Smart Mobility applications considered in this study) may be key measures to be integrated into these SUMPs as they can provide a significant contribution to a more sustainable and efficient urban mobility system. At the same time, the SUMPs may cover supporting measures that ensures that the C-ITS applications (and other Smart Mobility applications) effectively contribute to the achievement of social goals.

In 2014, the European Commission launched a **C-ITS Deployment Platform** in order to work on such a harmonised approach. This platform is joined by national authorities, C-ITS stakeholders and the Commission in order to develop a shared vision on the interoperable deployment of C-ITS in the EU. The platform was expected to provide recommendations for the development of a roadmap and a deployment strategy for C-ITS in the EU. Furthermore, some critical issues for the deployment of C-ITS in Europe (e.g. privacy, data security, hybrid communication) were investigated by the platform and possible solutions were formulated. The results of the platform were summarised in the final report 1 for phase I (2014-2016) (C-ITS Platform, 2016) and phase II (2016-2017) (EC, 2017b).

The **C-Roads Platform**[33] was launched in 2016 and is a joined initiative of Member States, road operators and the European Commission to implement pilots on market-ready C-ITS applications (C-Roads Platform, 2020). Its main goal is to support the development and sharing of technical specifications and to test cross-border interoperability. In accordance with the C-ITS strategy, the use of hybrid communication (combination of ETSI ITS-G5 and existing cellular networks) are supported by the C-Roads Platform. Relevant (international) pilot projects on C-ITS deployment are NordicWay[34] (Scandinavia), InterCor[35] (Netherlands, Germany and Austria) and Scoop[36] (France). Based on cooperation between C-Roads and the CAR2CAR consortium progress has been made in the various pilots on harmonising V2V and V2I messages and systems throughout Europe.

In 2016, automotive and telecommunication companies launched together the **5G Automotive Association**[37] on technology for connected and automated mobility including for C-ITS. This association is a strong advocate of the direct cellular C-V2X standard instead of the (up to then) more common ITS-G5. This resulted in a situation where two short-range communication technologies exist that are not interoperable and have different levels of maturity.

The results of the C-ITS platform (phase I) was a key input for the development of the **European strategy on C-ITS** (EC, 2016b). This strategy aimed to define and support common priorities at the EU

[33] C-Roads - The Platform of harmonised C-its deployment in europe
[34] NordicWay website
[35] InterCor (Interoperable Corridors) European project
[36] Project Scoop website
[37] The 5G Automotive Association (5GAA) website

level in order to avoid fragmented investments and regulatory frameworks. This harmonised approach should facilitate the deployment of market ready (safety-related) C-ITS services by 2019. Furthermore, the strategy recommends the use of hybrid communication combining complementary and available communication technologies in order to maximise the information that could be received by vehicles across Europe. The strategy also addressed the issue of security and data protection issues (by including the development of a common EU security policy for C-ITS), proposes specific actions to safeguard transport users to have full control for what purposes their data are being used (privacy and data protection) and proposes the development of a common security and certificate policy for the deployment and operation of C-ITS in Europe.

In addition to the issues above, the European strategy on C-ITS also identified the need for a common legal framework for the deployment of C-ITS in Europe. Therefore, the European Commission adopted in 2019 a **Delegated Regulation** supplementing the ITS Directive from 2010 to provide minimal legal requirements for interoperability for C-ITS (EC, 2019h). Specifications and standards for interoperable 'day 1' services are set as well as a common security solution. The Delegated regulation did not join into force due to an objection by the Council of the European Union. The reason for this rejection was that a specific communication technology (i.e. ITS-G5) was defined instead of favouring a technology-neutral strategy. Currently, the Commission is working on a modified Delegated Regulation.

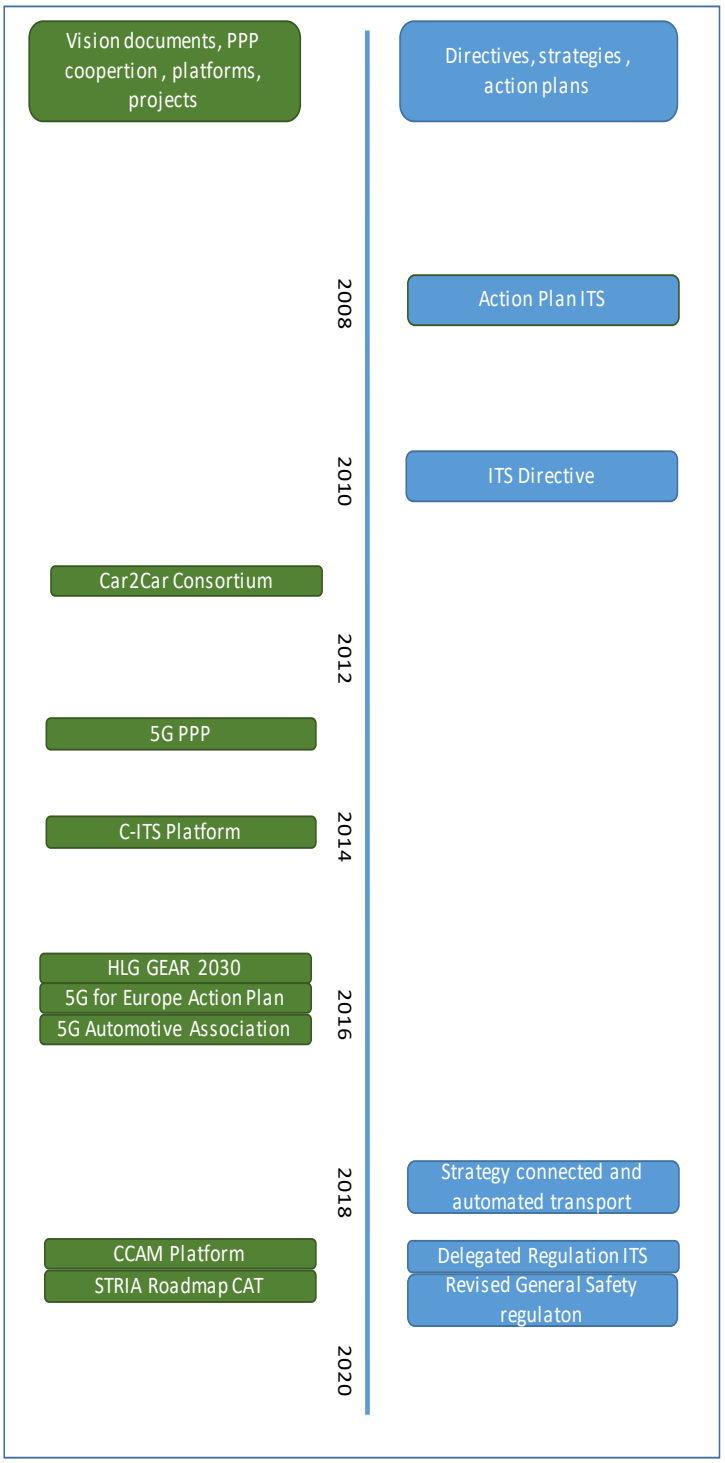
Specific actions for non-road modes

Although the scope of policies discussed above sometimes cover non-road modes as well, the focus is mainly on road transport. This can be explained by the fact that C-ITS services are more intensively deployed in road transport than in any of the other modes. There are, however, some specific policy actions in the field of (C-)ITS for non-road modes that are relevant to be mentioned here:

- *Rail transport*: in 2009, the Commission adopted a **European deployment plan for ERTMS** (EC, 2017b), which provides a progressive deployment of ERTMS along the main European rail routes. Additionally, technical standards (**TSI – technical specifications for interoperability**) are implemented by the Commission, to define the exchange of harmonised data within the rail sector (i.e. between rail infrastructure managers, railway undertakings and other stakeholders). Finally, the **Shift2Rail** program was launched (as a H2020 initiative) to support research and innovation to accelerate the deployment of innovative technologies (including C-ITS) into innovative rail product solutions.
- *Shipping*: in 2005, the Commission adopted Directive 2005/44/EC on harmonised River Information Services (**RIS**) on inland waterways of the Community, providing minimum requirements to enable cross-border compatibility on nation systems. are also a cornerstone of the **Digital Inland Waterways Area (DINA)** initiative, that has been launched by the European Commission in 2015. For more information on RIS and DINA, see Section 2.3.1.
- *Aviation*: in 2007, the European Commission launched the research program **SESAR** (Single European Sky ATM Research), aiming to improve Air Traffic Management (ATM) performance by modernising and harmonising ATM systems in Europe. In 2014, an agreement was reached between the Commission and major ATM stakeholders on a € 3 billion funding for the implementation of common projects and ATM infrastructure to modernise Europe's ATM system.

European technology Platforms

In addition to the C-ITS related policies discussed above, European Technology Platforms (ETPs) are relevant for the deployment of C-ITS (and CCAM and SOL) as well. These Platforms were initiated by the European Commission in 2013 in order to bring technological know-how of the industry, regulators (including the European Commission) and financial institutions together to develop a strategic agenda for leading technologies. These platforms develop short to long-term research and innovation agendas and roadmaps for action at EU and national level to be supported by both private and public funding. Relevant ETPs with respect to C-ITS are ERTRAC[38] (road transport), EARPA[39] (automotive R&D organisations), ERRAC[40] (rail transport), Waterborne TP[41] (shipping) and ACARE[42] (aviation).



Source: CE Delft

5.3.2. CCAM

European CCAM policies are built on (a large part of) the policy framework in place for C-ITS. Most of the policies and initiatives (including the ETPs) discussed for C-ITS are therefore relevant for CCAM as well. In addition, some other policies and initiatives are relevant as well.

First of all, the **High Level Group GEAR 2030** was launched in 2016 as a public-private partnership supporting the deployment of emerging technologies and Smart Mobility applications in the automotive sector. This group,

38 (ERTRAC) European Road Transport Research Advisory Council website
39 (EARPA) association of automotive R&D organisations website
40 (ERRAC) Teh European Rail Research Advisory Council website
41 The European research and innovation platform for waterborne industries
42 (ACARE) Advisory Council for Aviation Research and Innovation in Europe

consisting of stakeholders representing the automotive, telecoms, IT and insurance industries, is initiated by the Commission to ensure a coherent EU policy on vehicles. Within GEAR 2030, a specific work group on 'highly automated and connected vehicles' has been set up, with as overall aim to identify possible actions at the EU level that could accelerate the implementation of automated vehicles. In 2017, GEAR 2030 presented their first recommendations (EC, 2017b), which has been taken over by the Commission as part of its strategy for connected and automated vehicles.

The **Strategy for connected and automated vehicles** (EC, 2018e) was presented by the Commission in 2018 as part of the 3rd Mobility Package. The strategy provides a set of measures intended to:

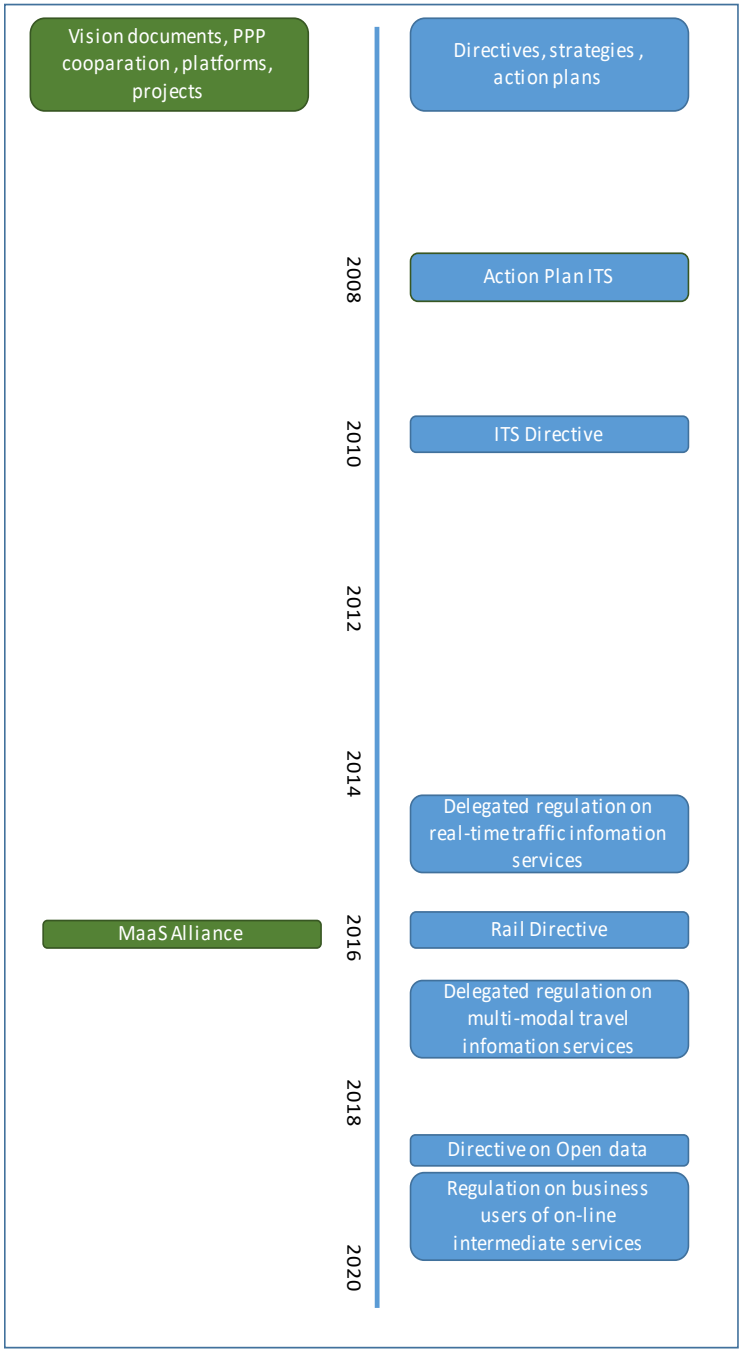
- *Develop the required technologies and infrastructure in Europe*. For this purpose, the Commission is making € 450 million available under CEF to support digitisation in transport in support to automation. Examples of other actions proposed in this respect are the encouragement of Member States and regions to make use of EU funding for research, innovation and deployment, and the development (together with Member States) of a priority list of large-scale pilots.
- *Ensuring the safe-take up of automated vehicles*. For this purpose the Commission will, amongst others, work on new vehicle type-approval rules, proposals on safety requirements for driver assistance systems and autonomous vehicles as well as road infrastructure, a proposal on a mandatory black box in automated vehicles, adoption of rules to ensure secured communication, data protection and interoperability and guidelines on a liability framework.
- *Cope with impacts of automated vehicles on society and economy*. In this respect, the Commission will assess the medium and long term socio-economic and environmental impacts, support the reskilling of the workforce, set up an EU forum on ethical aspects of autonomous vehicles, and develop ethical guidelines on the development of AI.

As announced in the Strategy for connected and automated vehicles, a **revised General Safety Regulation** (EC, 2019i) has been applied in 2019. This revised regulation includes rules that will require, for instance, that cars are equipped with advanced safety features (e.g. advanced driver distraction warning and lane-keeping systems) as well as event data recorders. In addition, autonomous vehicles also have to be equipped with features like systems to replace the driver's control of the vehicle, harmonised format for the exchange of data, instance for multi-brand vehicle platooning and systems to provide safety information to other road users.

Another initiative announced in the Strategy for connected and automated vehicles was the composition of a single EU wide platform for all relevant stakeholders to coordinate open road testing and pre-deployment activities. Therefore, in 2019 the **Cooperative, Connected, Automated and Autonomous Mobility (CCAM) Single Platform** was launched, consisting of both private and public stakeholders. This platform will contribute to the coordination of CCAM research, piloting, testing and

deployment activities. Furthermore, the group will address various issues relevant for CCAM, like communication technology, data access and exchange, cybersecurity and road safety.

As mentioned by the Strategy for connected and automated vehicles as well as the by the recommendations of GEAR2030, a coordinated approach and priority setting for research and innovation in the field of CCAM in Europe is required. For that purpose, the Commission initiated the development of a **Strategic Transport Research and Innovation Agenda (STRIA) for connected and automated transport** (EC, 2019a). A roadmap for short, medium and long-term research and innovation initiatives and actions has been developed, separately distinguishing road, rail and waterborne transport. In this roadmap challenges like lack of user acceptance, no business cases, the existence of hybrid systems during transition and lack of a complete and consistent legal framework were identified. Furthermore, measures are defined referring to technological innovations needed, but also to actions like assessing user acceptance and organising demonstration projects.



Source: CE Delft

5.3.3. MaaS

In contrast to C-ITS or CCAM, no EU-wide strategy for MaaS has been developed by the European Commission yet.

However, stakeholders expect that the EU will impose concrete standards to MaaS in the future, gradually replacing any national or local regulations. For now, EU policies relevant for MaaS are mainly related to the access to traffic and travel data and to integrated ticketing systems.

In the **ITS Action Plan** and the **ITS Directive,** the provision of EU-wide multimodal travel information services and real-time traffic information services were identified as priority actions. These actions were further operationalised by the **Delegated Regulation concerning provision of EU-wide real-time**

traffic information services (EC, 2015) from 2015 and the **Delegated Regulation concerning the provision of EU-wide multimodal travel information services** (EC, 2017c) from 2017. These delegated regulations provide specifications to ensure that EU-wide multimodal travel information services and real-time traffic information services are accurate and available to ITS users across borders. For example, the delegated regulation on multimodal travel information services makes it mandatory for Member States to install National Access Points, at least including static travel and traffic data of different modes. Furthermore, it is left open to Member States whether or not dynamic data should be provided as well. The accessibility, exchange and reuse of data is regulated by the Regulation as well. Finally, standards and technical specifications are provided for each of the transport modes.

Specifically for rail transport, the **Rail Directive** provides Member States the option to require railway undertakings operating domestic passenger services to participate in a common information and integrated ticketing scheme or give the power to authorities to establish such a scheme (EC, 2016b). This may facilitate the deployment of integrated ticketing systems as part of MaaS schemes.

Sharing of data between various parties joining a MaaS scheme is key for a successful deployment of that scheme. The **European Directive on open data** (EC, 2019j), adopted in 2019, is relevant in that respect. This Directive provides common legal framework for a European market for open data and the re-use of public sector information, mitigating various barriers that hamper the use of these types of data. Furthermore, the Directive is replacing earlier Directives in order to bring the legislative framework up to date with advances in digital technologies. Finally, it also stimulates digital innovation, particularly with regard to AI.

In 2019, the EU adopted a **Regulation on promoting fairness and transparency for business users of On-line Intermediate Services** (EC, 2019k). This regulation provides requirements to online intermediaries on the services they provide for business users. These requirements provide principles on issues like access to personal data, ranking parameters used, implementing changes to terms and conditions and any preferential treatment of a platform's or search engine's own products and services. These issues may all be relevant for the services provided by the MaaS operator to other members joining the MaaS scheme.

In the field of MaaS, also, public private partnerships have been launched over the last decade. For example, in 2016 the **MaaS Alliance** was founded, aiming to facilitate a single, open market and full deployment of MaaS services. As part of the MaaS Alliance workgroups have been initiated on issues related to user needs, regulatory challenges, governance and business models, technology and standardisation.

Finally, the European Commission has funded several research and pilot projects on MaaS, many of them under the H2020 research program. Some of these projects are MaaSiFiE, IMove, MaaS4EU and Pro-MaaS project.

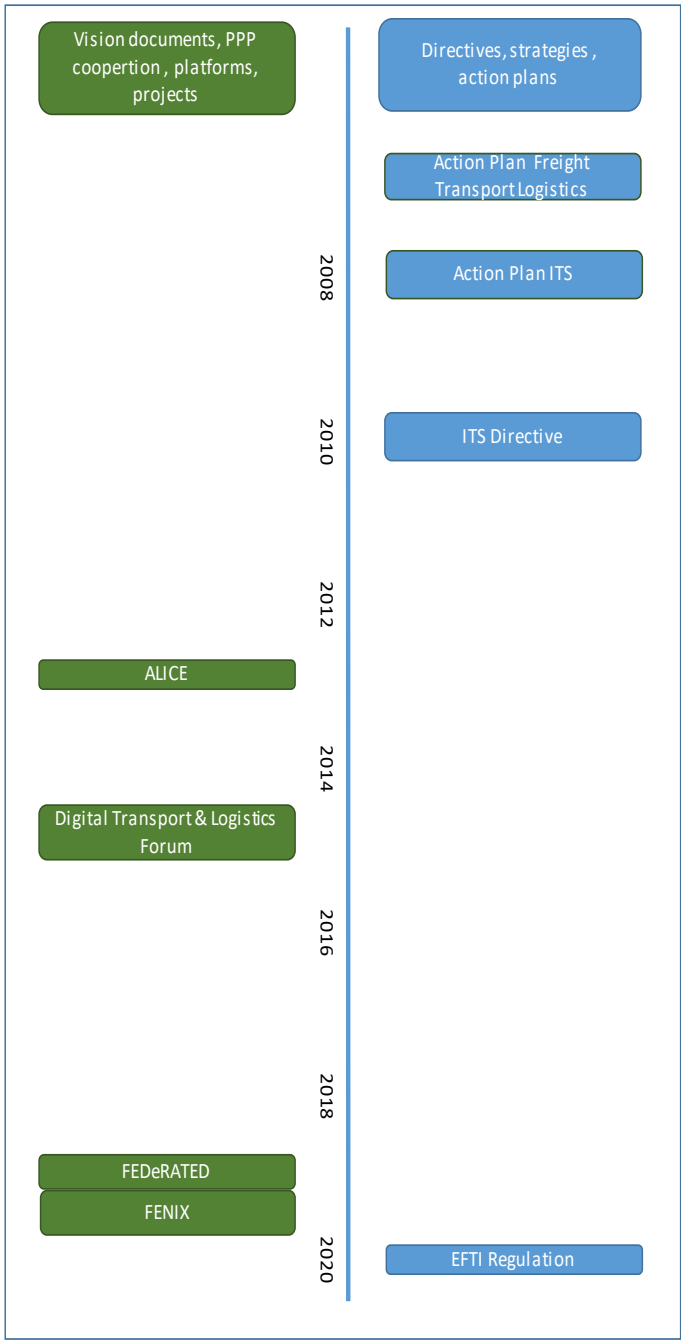
5.3.4. Self-organising logistics

As SoL makes use of the same kind of applications as C-ITS and CCAM, many of the policies discussed for these two Smart Mobility applications are relevant for SoL as well. Logistics is covered by regulations like the ITS Directive and initiatives like the C-ITS Platform. However, the focus in most of these policies and initiatives is on passenger transport.

There are, however, also some policies and initiatives specifically targeting smart freight transport and logistics. To start with the **EU Action Plan for Freight Transport Logistics** (EC, 2007) from 2007 which

promotes the use of ITS and other services facilitated by technologies like satellite services and radio frequency identification to improve the efficiency of freight logistics.

In 2013, The European Technology Platform **ALICE**[43] (Alliance for Logistics Innovation through Collaboration in Europe) has been set-up to develop a comprehensive strategy for research, innovation and market deployment of logistics and supply chain management innovation in Europe. The platform supports and assists the implementation of Horizon 2020 projects on this topic. The ALICE program has the mission to contribute to 30% improvement of end-to-end logistics performance by 2030 (ALICE, 2013). This is, among others, pursued by digitalisation and operational interconnectivity.



Source: CE Delft

In 2015, the European Commission initiated the **Digital Transport and Logistics Forum** (DTLF). It is a group of experts in the field of transport and logistics, consisting of Member States and relevant stakeholders from the sector. The general objective of the DTLF is to improve digital interoperability in logistics and freight transport in Europe. To this purpose, it assists the Commission in identifying challenges and areas where common action in Europe is required, provides recommendations and supports the implementation of these recommendations where needed. During its first mandate (2015-2018) the DTLF provided recommendations and preparatory work for the regulation on electronic freight transport information (EFTI), and a concept for digital corridor information systems. The latter resulted in the EU funded projects **FEDeRATED** and **FENIX**. Both projects aim to develop an interoperable infrastructure for data sharing within the European logistics community.

The **Regulation on electronic freight transport information (EFTI)** (EC, 2020b) mentioned above was adopted in 2020. It obliges Member State authorities to accept electronic freight information in order to reduce administrative costs, improve enforcement, and enhance the efficiency and

[43] (ETP-Alice) The European Technology Platform ALICE

sustainability of transport. Furthermore, it specifies the electronic format in which the electronic transport information should be made available and asks the Commission to provide common data sets and procedures to process the information.

Finally, under the EU research programs FP7 and Horizon2020 several projects relevant for SoL were started, including FREIGHTWISE, LOGSEC, CASSANDRA and CORE.

6. SOLUTIONS TO ACCOMMODATE THE TECHNOLOGIES

KEY FINDINGS

- The Smart Mobility applications considered in this study are innovative concepts and there are still many challenges related to their development and deployment.
- Challenges that are relevant for most Smart Mobility applications include improving user and public acceptance, developing a viable business case, sharing and protecting of (private) data, and ensuring interoperability between countries/regions and modes. Furthermore, a right balance should be sought between private and social benefits by minimising any rebound effect(s).
- An overarching strategy towards Smart Mobility is required because of the common challenges to the various Smart Mobility applications, the fact that they make use of the same technology base, and the increasing integration of the various applications in the future. The European Commission is currently working on a strategy for a Sustainable and Smart Mobility which could provide such an overarching strategy.
- The strategy should outline how Smart Mobility contributes to the societal goals. Furthermore, it should include at least a clear and consistent legal framework (e.g., on data access and security, liability, etc.), institutionalised cooperation between all relevant stakeholders including end-users (e.g., by using platforms like the CCAM platform), large-scale pilots (that are carefully evaluated), and a good balance between public, public-private and private financing.
- The actions to address the challenges related to the development and deployment of Smart Mobility applications should be joined by all stakeholders and not only by the EU and/or Member States.

6.1. Introduction

After the identification of emerging technologies and innovative applications in Chapter 2, an assessment of their impacts on the transport sector and society in Chapter 3 and the transport network in Chapter 4, an overview of the current EU policies and strategies in Chapter 5, this chapter analyses which measures can be taken in the future to facilitate the implementation of the various categories of Smart Mobility applications. All applications and underlying technologies face challenges which might hinder the deployment of these applications and consequently the potential benefits as well. Besides challenges to benefit from the positive impacts, challenges also exist in relation to minimising the risks and preventing negative impacts.

This analysis is performed by exploring the relations between the new developments and the action perspective of different stakeholder groups per category. Each section starts with an overview of relevant stakeholders followed by an analysis of the main challenges and potential mitigation actions.

A draft of this chapter has been shared with a group of experts (stakeholders from industry and consultants) to check whether relevant stakeholder groups, challenges and mitigation actions were missing in the initial analysis. Based on the input received from these experts, the final version of this chapter has been produced.

6.2. C-ITS

6.2.1. Overview of relevant stakeholders

The main stakeholders with respect to C-ITS services are:

- **Infrastructure managers** could have several roles with respect to C-ITS. They could act as communication provider, being responsible for providing a communication platform for the exchange of messages, but they could also use a third parties communication infrastructure (from a communication provider). At the same time, infrastructure managers could also act as service provider, supplying and receiving C-ITS services to and from transport users, provided by a communication provider and/or vehicle manufacturer (including the security layer).
- **Communication providers** are responsible for providing a communication platform for the exchange of messages. This can be both short-range and long-range communication. Communication providers can deliver communication as a bit-pipe, just as normal Internet traffic, but they can also take a more active role (e.g., by offering C-ITS services themselves, taking the role as infrastructure provider and/or service provider).
- **Dedicated service provider** supplying C-ITS services to customers (both other organisations and end-users).
- **Vehicle manufacturers** are equipping vehicles with connectivity technologies: adequate on-board units which are able to communicate with infrastructure (V2I), other vehicles (V2V) and/or the network (V2N).
- **Transport operators** could act as end-user (e.g., using the C-ITS services provided by a service provider), but may also be a service provider offering services to their clients.
- **Public authorities** (at different levels) could provide a policy framework for the appliance of C-ITS services and may support the deployment of these services (e.g., by granting subsidies).
- **Research institutions** could contribute to technical improvements of C-ITS, the development of innovative business models, assessing requirements for user acceptance or the provision of more evidence on the impacts of C-ITS.

6.2.2. Main challenges and potential mitigation actions

Table 10 provides an overview of some important challenges for deploying C-ITS services as well as potential mitigation actions that could be taken by the various stakeholders. All challenges and potential mitigation actions are discussed in more detail below.

Table 10: Overview of challenges and potential mitigation actions for C-ITS

Challenge	Potential mitigation actions	Infrastructure manager	Communication provider	Dedicated service provider	Vehicle manufacturers	Transport operators	Public authorities	Research institutions
Ensure high levels of interoperability and (cross-border) service continuity	Standardisation of technologies and procedures		✓		✓		✓	✓
	Establish mechanisms to ensure interoperability of ITS services in cross-border or multiple operator scenarios, including compliance assessment	✓	✓	✓	✓	✓	✓	
Develop a financially viable business case	Assessing (new) business models for C-ITS applications, make roles and associated responsibilities clear	✓	✓	✓	✓	✓	✓	✓
	Assess the potential private and social impacts of C-ITS and disseminate the results of these assessments to users, infrastructure managers and public authorities			✓	✓			✓
Ensuring a C-ITS ready infrastructure	Develop public or public-private financial arrangements to invest in the required modifications to the infrastructure, including the communication and PKI infrastructure		✓	✓		✓	✓	
	Make investments in C-ITS ready infrastructure (partly) mandatory	✓					✓	
Security	Further elaborate the current EU security procedures and legislation for C-ITS	✓	✓	✓	✓	✓	✓	
Data sharing vs data privacy and protection	Further specify legislation for data privacy and protection						✓	
	Further development of technical systems ensuring data privacy and protection (privacy by design)			✓	✓			✓
	Inform C-ITS users on the ability to manage their personal data and on the benefits of sharing data			✓	✓		✓	

Challenge	Potential mitigation actions	Infrastructure manager	Communication provider	Dedicated service provider	Vehicle manufacturers	Transport operators	Public authorities	Research institutions
User acceptance	Improve evidence on the impacts and concerns of C-ITS, involve end-users in the development and deployment of C-ITS services			✓	✓		✓	✓

Ensure high levels of interoperability

High levels of interoperability of C-ITS systems at the EU level are important to ensure that the advantages of the internal market can be achieved. A sufficient market penetration of C-ITS services is required to fully meet the potential of these systems ('network effects'). Therefore, avoiding regional/national incompatibility of the connectivity technologies, ensuring spectrum allocation and operational procedures applied is a key issue for a successful deployment of C-ITS services. Additionally, a lack of common procedures for security, testing and performance requirements is considered to negatively affect the interoperability of C-ITS services.

Public authorities should ensure standardisation and harmonisation (i.e., the actual profiling how the standards should be used in practise). The standards alone still leave room for interpretation and different usage (do we use this optional field or not? And if so, how?). This should be done at the EU level in order to guarantee interoperability. Currently, the European Telecommunications Standards Institute (ETSI) and the European Committee for Standardisation (CEN) have already developed common standards for the deployment of C-ITS services, and harmonisation (profiling) is taken place in C-Roads and the Car2Car Communication Consortium. This standardisation and harmonisation work will need to be continued, also to integrate other, new technologies (like C-V2X), with continued support from the Commission. Standardisation of connectivity technologies to be used will be covered by a modified version of a delegated act to the ITS Directive. An important discussion point in the preparation of this delegated act (DA) is whether a specific type of connectivity technology could be mandated (prioritising the currently most mature technology) or that a more technological neutral approach should (if possible) be applied. As a result of the rejection of the DA, an investigation on if - and if so how - the two non-interoperable direct communication technologies (ITS-G5 and C-V2X) could coexist should be carried out. The result of this investigation should be used in the modified version of the DA. This issue should be discussed openly between the ***public authorities***, ***C-ITS industry***, ***infrastructure managers*** and ***vehicle manufacturers***. The absence of a DA presents a challenge to ones wanting to deploy C-ITS using short range communication. Waiting for an updated DA is a suboptimal option, so deployment without central guidance could take place, with a possible undesired or at least not optimal outcome (not compatible short range communication technologies deployed, different services, lack of cross-border interoperability). Delivering services using long range communication is also taken place (either alone or (planned) in combination with short range). For several (I2V) C-ITS services this is fine, but for (future) other services (both I2V and V2V) this is not optimal.

In addition to interoperability on paper, stakeholders should establish mechanisms to ensure interoperability of ITS services in cross-border or multiple operator scenarios, including compliance assessment. ***Research institutions*** could contribute to the level of interoperability by assessing, validating and dissemination of results of pilot projects.

Develop a financially viable business case

In order to have all required stakeholders on board for the deployment of C-ITS applications and the necessary infrastructure, a sound and convincing business case for all the actors involved is required. From a social perspective, the benefits of C-ITS deployment seem to outweigh its costs (Ricardo ; TRT, 2016). However, these benefits will only materialise over time, while a large share of the costs are upfront, resulting in rather high (perceived) business risks (EC, 2019a)). Furthermore, a large part of the benefits goes to users or the society at large, while the costs are borne upfront by infrastructure operators and vehicle manufacturers (EC, 2017b)[44]. A viable business case, feasible and acceptable to all stakeholders, is still unclear at this moment (Ricardo & TRT, 2016). In a longer term, as services will go beyond information only and vehicles could also act taking into account information from their environment, the potential for a viable business case is far better. Another complicating factor mentioned by some of the interviewees is the relatively limited knowledge (or belief) of users, infrastructure operators and public authorities on the potential (social) benefits of C-ITS, hindering their willingness to contribute to the required investments in C-ITS applications.

As input for the development of viable business cases, more detailed evidence on the impacts of C-ITS (on users and the society at large) should be gathered by systematically evaluating C-ITS deployment projects and pilots (EC, 2017c). This could be done by the ***C-ITS industry*** or ***research institutions***. The evidence found by these exercises should be shared with (long-term) infrastructure planners, using targeted methods and tools, in order to increase their willingness to contribute in the upfront investment costs. It should be realised that current (and past) C-ITS projects and pilots all implement only a small subset of the services which are possible. Once large number of vehicles are connected new possible services arise, and also implemented services will have larger effects with more equipped vehicles. In addition to increasing knowledge levels, ***all stakeholders*** should work together in exploring new business models for C-ITS applications. According to several interviewed stakeholders, end-users (consumers and businesses) should get a more prominent place within these discussions on business models, as knowledge on user needs and willingness to pay are key in developing these business models. More in general, the involvement of end-users in the development of (innovative) products or services, which is known as co-creation, may contribute to the successful development and deployment of these products/services by providing the opportunity to learn from their perceptions, needs, and ideas (O'Hern & Rindfleisch, 2008).

Ensuring a C-ITS ready infrastructure

To apply C-ITS services, the transport infrastructure should be ready to accommodate these services. However, without a viable business case, there will be no commercial incentive to invest in this infrastructure. Moreover, without any certainty on the demand for C-ITS services, infrastructure managers will be reluctant to make these investments. This could be classified as the classical chicken or the egg causality dilemma, as demand for C-ITS services heavily depend on the availability of the

[44] Most of the services targeted for deployment on short notice fall under the scope of the Delegated Regulation 886/2013 on safety related traffic information, which demands the free use of these services (i.e. at no costs at the point of use). End-users 'pay' for these services with their vehicle data (position, time, etc.), but the actual financial costs are borne by infrastructure operators and/or vehicle manufacturers.

required infrastructure. So, next to a viable business case also a solution for this chicken or the egg causality dilemma should be found in order to ensure a C-ITS ready infrastructure.

Box 7: Willingness to pay and need for business case

From the evaluation results described in the C-ITS use case study (see Annex D) it can be said that users liked the services offered and indicated they would use them. However, users do not generally want to directly pay for discrete services. This attitude did not change from the acceptability survey taken before the pilots began. These evaluation results stress again the importance of having a clear business case, not only a value case.

Several potential mitigation actions could be considered to address this challenge. First, ***public authorities*** could provide subsidies to transport operators to invest in the required infrastructural devices. At the European level, funding from the Cohesion fund or the proposed Recovery and Resilience Facility could be used for that purpose. In this respect, it could also be investigated whether public-private partnerships could be developed to ensure the required investments. ***Dedicated service providers*** or ***transport operators*** may be interested in such constructions as the expected rate of return on their investments is sufficient (which depends on the business model that will be applied). Another option is that ***public authorities*** mandates the provision of (some level of) C-ITS ready infrastructure (in a similar way as was done by the Alternative Fuel Infrastructure Directive which requires Member States to provide a certain amount of infrastructure for alternative fuels). This action would preferably be taken at the European level, in order to avoid fragmentation at the EU market. Further research on this policy option could be done.

Security

The information shared within C-ITS is used for various purposes: purely informative, for safety related applications or even (in the future) to directly affecting vehicles' behaviour (CODECS, 2016). Securing the communication channels used is important to ensure a trustworthy and interoperable system. Based on assessments made by the security workgroup of the C-ITS platform, EU Member States and industry representatives agreed on the definition of an European Union C-ITS Security Credential Management System, providing a set of technical and organisational requirements (C-ITS Platform, 2016).

Public authorities together with the ***C-ITS industry*** should further implement the security of the C-ITS ecosystem. The standards are available, and first implementations based on this become available. These are encouraging first steps, but for large scale implementations all stakeholders should be involved. Translating the standards into specifications usable for all need attention.

Data privacy and protection

C-ITS equipped vehicles making use of certain C-ITS services are continuously broadcasting data, including e.g. their speed and location. As indicated by several interviewed stakeholders, the broadcasting of these types of data raises potential concerns on data privacy and protection. C-ITS Platform (2016) concludes that these data should be considered 'personal data'. This implies that for these data the provisions provided by the European General Data Protection Regulation applies, meaning that the driver will have to give consent to make use of the data. There are only a few exceptions to this situation, i.e. cases where the use of the data is of vital interest to the driver himself or the public in general.

Public authorities should further specify legislation for data privacy and protection. This should include legislation on how drivers can grant third parties' consent to use their data, which is complicated as there is no peer-to-peer communication between the driver and the party who will use the data. Furthermore, European legislation should be developed indicating where processing data is necessary for a task carried out in the public interest. The ***C-ITS industry*** and, ***vehicle manufacturers*** should develop systems flexible enough to guarantee full control of personal data by the driver (privacy by design) and providing a 'no tracking' function. Finally, the ***C-ITS industry***, ***vehicle manufacturers*** and ***public authorities*** should actively inform users of C-ITS applications on the negative consequences of disabling the broadcast (e.g., reduced traffic safety), but at the same time their ability to manage their personal data should be pointed out.

User acceptance

As mentioned by many of the interviewed stakeholders, acceptance of the C-ITS services by its users is key, as these services can only be effective as users are willing to apply them. Perceived safety and security issues, high costs, lack of personal benefits and/or poor understanding of the overall benefits of the services may negatively affect user acceptance (C-ITS Platform, 2016). These issues may not only hamper the uptake of C-ITS services by individual transport users, but also by businesses (like transport companies or infrastructure operators) involved in all transport markets (road, rail, aviation, shipping).

As recommended by C-ITS Platform (2016), users should be better informed using two types of messages: on the one hand, they should be informed on the benefits on C-ITS deployment and how it can contribute to a safer, more sustainable and more efficient transport system. On the other hand, factual information should be provided on concerns related to these innovative services (like privacy and safety). The ***C-ITS industry***, ***public authorities*** and ***research institutions*** could all play a role in this action and preferably they would do it together (e.g. via the C-Roads Platform). Also, EuroNCAP can play an important role here for road transport. They have played a crucial role in incentivising road safety. The star ratings provide neutral information to users (consumers and businesses) on the safety aspects of their vehicles. By integrating the road safety possibilities of C-ITS in this rating, it may inform users on the safety benefits of C-ITS. Furthermore, more evidence has to be collected on the various impacts and concerns with respect to C-ITS, preferably based on actual applications of these services in pilot projects. Finally, as proposed by several interviewees, dialogues with end-users (consumers and businesses) should be organised to better understand their needs and concerns with respect to these kinds of services. As mentioned before, end-users may also be actively involved in the development and testing of C-ITS services (co-creation) to learn from them on their needs, perceptions and ideas.

6.3. Connected Cooperative Automated transport (CCAM)

6.3.1. Overview of relevant stakeholders

A large range of stakeholders is involved in the development and deployment of CCAM. The main ones are:

- **Vehicle manufacturers** are working on the advancement of the required technology and the deployment of connected and automated vehicles on the market. This includes both the OEMs themselves as their direct suppliers, who are building and providing much of the technologies and products necessary for CCAM.
- **ITS industry** (including telecom providers) provides the digital infrastructure required for the deployment of CCAM.

- **Infrastructure managers** are required to support the deployment of CCAM by providing adequate transport infrastructure facilitating the use of CCAM.
- **Transport operators** may offer services with connected and automated vehicles (starting with pilots).
- **Public authorities** (at different levels) could provide a policy framework for the successful deployment of connected and automated vehicles and may support the development and deployment of these vehicles (e.g. by funding pilots).
- **Research institutions** may support the technological development of CCAM and may contribute to the evidence base on impacts and challenges of CCAM.

6.3.2. Main challenges and potential mitigation actions

An overview of some relevant challenges for deploying CCAM as well as potential mitigation actions that could be taken by the various stakeholders is given in Table 11. All challenges and potential mitigation actions are discussed in more detail below.

Table 11: Overview of challenges and potential mitigation actions for CCAM

Challenge	Potential mitigation actions	Vehicle manufacturers	ITS industry	Infrastructure managers	Transport operators	Public authorities	Research institutions
Social accept-ability	Carry out detailed studies on a better understanding of user requirements, expectations and concerns related to CCAM						✓
	Organising of and participating in workshops or debates amongst different stakeholders	✓	✓	✓	✓	✓	✓
	Pilots with CCAM	✓	✓	✓		✓	
Coordinated financing and funding approach	Assessing (new) business models for CCAM, especially at the start	✓	✓	✓	✓	✓	✓
	Assess the potential private and social impacts of CCAM and disseminate the results of these assessments to users, infrastructure managers and public authorities	✓			✓		✓
	Providing subsidies, e.g. for necessary investments in infrastructure, pilots or technological development					✓	
Interoperability	Support the standardisation and harmonisation of solutions and development of functional specifications for interoperability	✓		✓		✓	✓

Challenge	Potential mitigation actions	Vehicle manufacturers	ITS industry	Infrastructure managers	Transport operators	Public authorities	Research institutions
	Further development and continuous discussion involving multiple stakeholders	✓	✓	✓	✓	✓	✓
	Coordination of pilot projects and development of a long-term framework to foster development activities (e.g. research or pre-deployment programmes on CCAM)					✓	✓
Liability	Monitoring whether revisions to Directives or new legislation are necessary to facilitate CCAM					✓	✓
(Cyber)security	Assessing the robustness of vehicles function related to different types of attacks	✓	✓		✓		
	Detection and prevention of malicious activities	✓	✓		✓		
	Optimisation of the security of all different components of the vehicle and develop advanced redundancy measures to ensure the safety of the entire CCAM system in case of failures in some subsystems or components	✓	✓		✓		
Data privacy and protection	Further specify legislation for data privacy and protection					✓	✓
	Further development of technical systems ensuring data privacy and protection (privacy by design)		✓	✓			
	Inform C-ITS users on the ability to manage their personal data and on the benefits of sharing data.		✓	✓		✓	
Enhanced type approval and compliance testing procedure	Develop a standardised test framework, setting the requirements to be met by the test procedures					✓	
	Operationalisation of test procedures						✓

Social acceptability

EC (2020b) shows that a majority of the people would not feel comfortable travelling in an automated vehicle. In case of remote supervision of a human operator, about 61% of the people felt uncomfortable, while even 76% of the people would feel uncomfortable without any human supervision. The same study also shows that the majority of the people do not feel comfortable when automated vehicles are present on the road, even if they are not travelling by those vehicles. These results are in line with evidence collected from other studies (e.g. (EC, 2019e)) and the interviews, where doubts on traffic safety (next to personal security and privacy) were mentioned as an important barrier for the deployment of CCAM. Also, the fact that people would like to be in control may slow down the deployment of higher levels of automation (EC, 2019a). Trust in using AI could potentially lower trust in CCAM as well. AI will be introduced to make the system safer, being able to anticipate to scenarios not foreseen, but this does not mean it will also feel safer. Not knowing or understanding what a vehicle does at a certain moment could (at first) be uncomfortable, even if second later the reason becomes clear why the action was taken. Here acceptance comes with (good) experience. ADAS systems sometimes (as intended) also act before a driver can. If this is the correct behaviour, the driver will get used to it and appreciate it. It does mean that thorough testing, and robust implementations, are necessary ("Trust is hard to gain but easy to lose"). (Bezai, et al., 2020) study shows that about 50% of the respondents are not willing to pay to get level 3 and 4 automation.

This lack of user acceptance is not only an issue for road transport. As mentioned by (EC, 2019a), also in rail and waterborne passenger transport, user acceptance of fully automated vehicles/vessels is very uncertain. As mentioned by (Powell, et al., 2016) and (DNV-GL, 2018), not the fact that the train or vessel is controlled automatically seems the main long-term issue, but personal security because of unstaffed trains or vessels. In parallel with the lack of user acceptance for (particularly higher levels of) CCAM, acceptance at the political level is also fragmented. According to (ERTRAC, 2020) a lack of knowledge on the potential implications and impacts (e.g. on traffic safety or the environment) contributes to this lack of social acceptance.

In order to improve social acceptance of CCAM, a better understanding of user requirements, expectations and concerns related to CCAM is key (EC , 2020b). Therefore, ***research institutions*** should carry out detailed studies on these issues. Furthermore, the impacts of CCAM could be assessed by organising workshops or debates amongst ***different stakeholders***. As was mentioned by several interviewees, the participation of end-users to these workshops/debates is key. One step further is to actively involve the end-users in the entire development and deployment process of CCAM (co-creation), in order to continuously learn from their perceptions, needs and ideas. Pilots (of Living Labs) with CCAM (which could be organised by ***public authorities***, ***vehicle manufacturers***, ***ITS industry*** and/or ***infrastructure managers***) could also help to improve the knowledge and expectations of users on new automated driving technologies in real life and the impacts on society (EC, 2019a).

Coordinated financing and funding approach

Higher cost of CCAM hamper the large-scale production and mass consumer availability of automated cars (as mentioned by several interviewed stakeholders), while potential benefits mostly require a large penetration rate of those vehicles. Some of the benefits are at the user level, while many other benefits occur at the social level, such as a decrease in fatal accidents and a potential reduction of congestion. These benefits will result in lower cost for society, while individual users pay the higher vehicle cost. In addition, some of the cost reductions for users will occur after the investment have been made (such as a fuel cost reduction and lower insurance cost). Autonomous vehicles might not be affordable for all vehicle owners. Licensing constructions and MaaS concepts might help to overcome these higher

purchase cost. Like with most other innovative products (e.g. electric vehicles), purchase cost for autonomous vehicles are likely to drop in the future as result of upscaling and learning effects, but manufacturers and other stakeholders have to overcome the higher technology cost first and have to invest heavily in testing. Like with C-ITS there is the chicken-and-egg problem where car manufacturers would like to see infrastructure managers to investments in infrastructure and vice versa.

The actions for stakeholders are more or less the same as for C-ITS and should focus on the development of viable business cases and more insight in specific impacts and cost associated with these impacts (see Section 6.2.2). Furthermore, financial support could be provided by ***public authorities***, e.g. for necessary investments in infrastructure or pilots. At the European level, Horizon Europe (and the CCAM partnership) and Connecting Europe Facility (CEF 2 Digital) can both play an important role here.

Interoperability

Many aspects relevant to interoperability of C-ITS systems at the EU level are also valid for CCAM and closely linked to each other. Especially a lack of common procedures for security, testing and performance requirements and lack of coordination already in the development phase of these procedures and standards is a risk for interoperability on the long term. Interoperability is not only linked to infrastructure, but also to the data formats and data handling, because of the large amounts of data produced by the sensors of connected and automated vehicles, as well as by infrastructure sensors, mobile phones etc. (EC, 2019a). Here, differences between vehicle brands and even between vehicle type of the same brand occur: they use different sensors, will use different data and will expect different data from other vehicles and infrastructure. Harmonisation will be necessary to get to a common view of what information is necessary under what circumstances.

Although connectivity is considered to be necessary to reach higher levels of automation, vehicle manufactures are not all on the same page on what kind of connectivity should be included in the vehicle. Long range communication will most probably be present in all new vehicles the coming years, even in "autonomous" vehicles, but the implementation of short-range communication in vehicles is not yet beyond doubt. There are also different competing technologies available. Both facts can result in low percentages of vehicles able to "talk" directly to each other, preventing an optimal connected traffic to exist.

Besides the type of connectivity, there is also a role to play for ***public authorities*** to potentially demand connectivity as a precondition to access roads, for instance to be able to act upon warnings (an emergency vehicle intending to cross an intersection through red light or approaching from a not well visible direction) and mandatory speed limits. Road access is now granted to vehicles at the national level but might also require EU action.

Public authorities should also support the standardisation and harmonisation of solutions to assure interoperability among the different operational environments, infrastructures and vehicles (EC, 2019a).This is especially valid for transboundary transport, both for road transport and network bound transport modes such as rail transport. Diversity of existing technical standard and differences in operational principles per country can be seen as main challenges for a high level of interoperability. The requirements for CCAM are clear for first applications but need further development and requires a continuous discussion involving multiple stakeholders, including ***vehicle manufacturers*** and ***infrastructure managers***. Special attention should be paid to traffic management of mixed environments with automated and non-automated vehicles, requiring cooperation of ***vehicle manufacturers***, ***fleet operators*** and ***road operators***.

Public authorities should also ensure making available traffic information all over Europe for all vehicles (especially for automated ones but also for conventional ones) to smoothen the traffic and making it safer. By making this available in the cloud, a large number of vehicles can be reached with long range communication.

Both ***public authorities*** as well as ***research institutions*** can coordinate Living Labs for CCAM to foster harmonisation and interoperability to guarantee cross-border functionality all over Europe. Participation by different ***vehicle manufacturers*** is desired to ensure all (different) data requirements are taken into account. End-users could be involved as well to learn from their ideas and perceptions.

In general, the European Commission should develop an EU agenda for testing and should establish a partnership to develop a long-term framework to foster development activities, such as research and pre-deployment programs on CCAM. This partnership could also develop functional specifications for interoperability, which ensure investments at the various levels are complementary (EC, 2019a). Finally, ***research institutions*** could contribute to the level of interoperability by validating results of pilot projects.

Liability

As driver's tasks are taken over by automated vehicles, it will become more difficult to assign liability in case of accidents (hindering the payment of compensation to victims in accidents with automated vehicles). As indicated in the literature (e.g. (Taeihagh & Si Min Lim, 2019) and by various interviewed stakeholders, this may be an important barrier for CCAM. For that reason the European Commission has proposed the use of data recorders for automated vehicles to establish a clear understanding of who is driving the vehicle: the machine or the driver (EC, 2018e) (EC, 2017b) concluded that the European motor insurance directive is currently sufficient to address issues with CCAM, while the application of the Product Liability Directive on CCAM is currently explored (EC, 2019e).

Public authorities (particularly at the European level), supported by ***research institutions***, should keep monitoring whether revisions to the Motor Insurance Directive and Product Liability Directive are needed (e.g. adding a definition of a new service) or that new legislation should be implemented to address future developments in technology or jurisprudence.

(Cyber)security

Secure communication is, like for C-ITS, crucial for CCAM. Similar challenges and mitigation actions as for C-ITS are relevant. On this issue, we therefore refer to Section 6.2.2. Cybersecurity threats may be an additional issue for CCAM, particularly at higher levels of automation (Taeihagh & Si Min Lim, 2019). Hackers can use the connectivity interfaces to tamper with the vehicle, potentially generating safety hazards (EC, 2019e). These cyberattacks can be directed at the vehicle itself, but also at the infrastructure. In the latter case, infrastructure can be manipulated to send false information to the vehicle. Cybersecurity is an important issue for all transport modes, i.e. road, rail, aviation and shipping (EC, 2017a).

The ***ITS industry***, ***vehicle manufacturers*** and/or ***infrastructure operators*** could further improve cybersecurity by assessing the robustness of vehicles functions to different types of attacks, address the detection and prevention of malicious activities (e.g. by plausibility checks of the security system throughout the lifetime of the vehicle), optimising the security of all different components of the vehicle and develop advanced redundancy measures to ensure the safety of the entire CCAM system in case of failures in some subsystems or components (EC , 2020b).

Data privacy and protection

With respect to data privacy and protection, the same challenges and potential mitigation actions as for C-ITS services are relevant for CCAM. For a discussion on these challenges and actions, we refer to Section 6.2.2.

Enhanced type approval and compliance testing procedure

At higher levels of automation, enhanced type approval and compliance testing procedures are required to ensure safety (EC , 2020b). Particularly for mixed traffic situations, which will be the case for many years, more scenario-based verification of the vehicle and its operation is required. But also in less complex environments (as is often the case for non-road modes), additional tests of functional safety, reliability and security of the vehicle are required. As connectivity will be part of the vehicle, the safe interaction with other vehicles and the infrastructure, based on information exchanged, will have to be assessed. Artificial Intelligence will be part of the vehicle platform. Numerous scenarios can occur (included false information, intended or not), which cannot all be included in testing procedures. Therefore, a robust and sound selection of scenarios should be made. Testing should also cover situations where information sources contradict or provide false information. False information provision can happen unintendedly but is also related to cyber security issues. Furthermore, dynamic verification and validation is required, as the functionality of the vehicle will change during its lifetime due to software updates (EC, 2019e). These new requirements to the type approval and compliance testing requires a combination of virtual, physical and hybrid test approaches (EC , 2020b).

Public authorities (at the European level) should develop a standardised test framework, setting the requirements to be met by the test procedures. These procedures could be operationalised together with ***research institutions*** by developing a standardised virtual simulation environment, dedicated hardware and physical infrastructure for testing (EC , 2020b). These new test procedures could become part of the European type-approval concept, by extending the scope of this regulation from pre-market testing to testing including used-vehicles. In this way, vehicle changes over the lifecycle can be tracked and main differences in testing at the national level could be avoided (EC, 2017b).

6.4. Mobility as a Service/ shared mobility

6.4.1. Overview of relevant stakeholders

The MaaS ecosystem covers a wide range of stakeholders, depending on the scope and maturity of the MaaS scheme considered (Kamargianni & Matyas, 2017). Some core stakeholders include:

- **MaaS operator** who owns and provides the MaaS services. It is an intermediate between transportation providers and users, integrating the services of the supply side and offers these as MaaS products to the users through a single interface. Different actors could take the role of the MaaS operator, e.g. public transport companies, any other transport service provider, a MaaS company, a tech firm, etc.
- **Transport operators**, such as public transport companies, car- or bike-sharing companies and ride-hail organisations, provide vehicles and services to move people. In the context of MaaS, they offer their mobility capacity to MaaS operators and provide access to their data via secure interfaces.
- **Digital infrastructure and service providers** act as service suppliers to the MaaS operator, transport operators, and/or government entities offering services including the

data platforms, ticketing/payment processing systems, the user interface and the journey planning service.

- **Data providers** (other than transport operators) providing interoperable data to the MaaS operator. This may include actors as infrastructure operators and mobile phone data providers.
- **Data analytics providers** providing public authorities with relevant information to manage MaaS. These providers (which can be private companies, research institutes or agencies part of the public authorities) focus on translating all the data on the use of MaaS and the transport services being part of the MaaS system into valuable information using dashboard and reporting tools to manage MaaS (if possible near real-time). Examples include the contribution of MaaS operators to societal goals, the compliance of MaaS operators to the operating requirements set by the public authorities and the business intelligence included in the data that can be used to further accommodate the user needs.
- **Public authorities** (at EU, national, regional or local level) provide policies and regulation to ensure issues like fair competition, passenger rights, privacy, social inclusion, optimal social benefits, etc. In addition, they might get anonymised and clustered route-usage data in return (feedback loop) for planning issues (e.g., scaling the public transport offer).
- **End-users** need to adopt the new services and include them in their daily routines.
- **Research institutions** who study issues like business models, business cases and value cases for MaaS.

In addition to these actors, other stakeholders could be involved in (more evolved) MaaS schemes as well, such as investors, media and advertising firms, retailers, insurance companies, etc. In this study, however, we will focus on the core actors listed above. End-users have a large impact by using or not using services and can create powerful lobbies via consumer associations. However, they can take limited actions to overcome the main challenges around MaaS and are therefore excluded from the overview below.

6.4.2. Main challenges and potential mitigation actions

An overview of some main challenges for deploying MaaS as well as potential actions that could be taken by the various stakeholders is given in Table 12. All challenges and associated actions are discussed in more detail below.

Table 12: Overview of challenges and potential mitigation actions for MaaS

Challenge	Potential mitigation actions	MaaS Operator	Transport operator	Digital infrastructure and service providers	Data providers	Data analytics	Public authorities	Research institutions
Define the roles for the various stakeholders involved	Set-up of pilots to test various market models	✓	✓				✓	✓
	Open dialogue of mutual expectations and responsibilities, resulting in contractual arrangements. Check whether current cooperation bodies sufficiently facilitate such dialogue	✓	✓				✓	
	Develop procurement processes and contractual arrangements to define role of public transport operators					✓	✓	
Trust between main stakeholders	Improve transparency (e.g. through contractual arrangements) and open communication	✓	✓			✓		
	Develop clear legal framework for MaaS schemes						✓	
Develop a financially attractive business case	Test potential business models that could be used for MaaS schemes	✓	✓	✓	✓	✓	✓	
	Providing objective evidence on the impacts of MaaS on travel behaviour	✓	✓					✓
	Remove regulative barriers to integrate public transport subsidies into MaaS schemes						✓	
Overcome market entry barriers	Removal of regulatory inconsistencies hampering MaaS concepts						✓	
	Identifying and discussing options for harmonisation of regulatory, operational and technical issues to improve scalability	✓	✓		✓		✓	
Access to required data	Developing legislation to set general principles of data sharing, including requirements on quality, format and accessibility						✓	
	Starting a mutual exchange of relevant data according to a defined format and procedure	✓	✓	✓	✓			
Realise integrated payment and booking systems	Provide a general framework for integrating payment and booking systems						✓	
	Open discussion on options to arrange integrated ticketing.	✓	✓					
	Develop technical systems for integrating payment and booking systems	✓	✓	✓				

Challenge	Potential mitigation actions	MaaS Operator	Transport operator	Digital infrastructure and service providers	Data providers	Data analytics	Public authorities	Research institutions
Combine a personalised approach with social benefits	Arrange effective public sector oversight on the MaaS schemes	✓	✓			✓	✓	
	Discourage private car use and encourage alternatives						✓	

Define the roles for the various stakeholders involved

MaaS requires the participation from multiple stakeholders, both from the private and public sector. The allocation of roles of these various stakeholders is still under debate (Araghi, et al., 2020), particularly with respect to role of the MaaS operator (UITP, 2019). Both private and public agents could take this role, each option having their own advantages and disadvantages. For example, it is often claimed that a private operator would be better able to provide a customer-oriented and innovative scheme, while a public operator (i.e. public transport agency) would probably pay more attention to the broader social benefits of MaaS (e.g. social inclusivity) (UITP, 2019). More generally, the role of the public transport authorities in MaaS is often discussed. On the one hand, it is argued that they could be reluctant to offer their services under a MaaS provider, because of the risk of losing their identity, fear for the potential change of their business models, the failure to see the benefits a MaaS scheme could bring to public transport operators, and the fear that the costs of participating in MaaS and the potential for lost revenue are too high for these companies (IET, 2019). On the other hand, it is feared that the large public transport operators will create entry barriers for new start-ups or competitors to join the MaaS scheme, as they might be afraid of losing segments of their market (Araghi, et al., 2020).

In order to get a better understanding of the (dis)advantages of different MaaS models of roles and responsibilities for public and private parties (e.g. private operator, public operator), pilots should be organised by ***public authorities***, ***MaaS operators*** and/or ***public transport operators*** (and evaluated by ***research institutions***). Additionally, ***private MaaS operators*** and ***public transport operators*** should organise an open dialogue on mutual expectations and responsibilities. ***European public authorities*** could check whether current platforms related to MaaS in the context of Horizon Europe are adequately cover this issue or that new forms of cooperation have to be initiated. ***Private MaaS operators*** and ***public transport operators*** should also develop contractual arrangements to define their roles and cooperation which can be monitored by ***data analytics providers***. Finally, ***public authorities*** (both national and local) should define the role of public transport operators in the procurement process and contracting arrangements (IET, 2019).

Trust between main stakeholders

In addition to a clear definition of the roles and responsibilities of the various stakeholders involved in MaaS schemes, mutual trust between the stakeholders is essential as well (MaaS Alliance, 2019) This lack of trust between various parties was also identified as barrier in the case study on MaaS in Finland (see Annex E). Critically, this not only includes trust between the public and private sector, but also trust between different areas within the private sector – including MaaS platform providers and the various

transportation service providers. As activities from various stakeholders are integrated by the MaaS operator into one product, all participants should, for example, trust that their services are offered in a fair way on the MaaS platform (i.e. they have to trust that fair algorithms are used by the MaaS operator on its platform).

MaaS operators and ***transport companies*** should try to maximise transparency through contractual agreements, well-defined liabilities and open communication (MaaS Alliance, 2019). By developing a clear legal framework, presenting the rights and obligations of all parties involved, **public authorities** could contribute to more trust between the various stakeholders. As shown by the case study on MaaS (see Annex E), this was one of the pillars of the approach followed in Finland, where the government created legal frame conditions while they let the market fill in the type of services that are offered. Additionally, public authorities should be clear and consistent in their enforcement of standards and requirements. If enforcement and penalties are not regularly maintained, it creates a situation where bad actions can lead to beneficial business conditions. This leads to an uncomfortable situation where private sector companies have to choose between complying with regulations and being competitive.

Develop a financially attractive business case

As illustrated by the case study for MaaS in Finland (see Annex E), another important challenge is to define a business model that is financially viable and attractive to the various players involved. It is not clear yet whether there would be a financially attractive business case for private MaaS operators and other stakeholders joining the MaaS scheme (Araghi, et al., 2020) (Polis, 2017). Relevant issues (which are still unclear) in this respect are whether travellers are willing to pay a premium for the services provided by the MaaS scheme and to what extent cost savings could be realised by the various participants to the MaaS scheme. Some possible business models that are considered in literature are (UITP, 2019):

- Agency model: pre-paid bulk purchase of transport services by the MaaS operator with a volume discount, which are resold at higher prices by the operator to travellers.
- Merchant model: transport operators are paying commissions to the MaaS operator for selling their services.
- Transactional model: the transport operator pay fees per click, per settlement, per invoice, etc.
- Contribution of the end user: travellers paying a premium for the added value of the services provided by the MaaS scheme.

Another relevant aspect with respect to the development of a business case for MaaS is the way current public transport subsidies will be incorporated in the MaaS scheme. These subsidies will probably be required to ensure the provision of transport services – beyond only traditional transit options -in areas or at times that are not profitable. However, at the same time subsidising private MaaS providers can raise competition regulation issues (IET, 2019).

Pilots testing various types of business models should be set up by ***MaaS operators*** or ***public authorities*** and joined by ***all other stakeholders***. These pilots should provide more evidence on which business models may be interesting for all stakeholders being involved and should have a clear focus on scalability. Furthermore, ***MaaS operators*** and ***transport companies*** should study, supported by ***research institutions***, the expected impact MaaS will have on transport behaviour of travellers, as this will provide a better understanding of the market potential of several MaaS services. Finally, ***public***

authorities should investigate how public transport subsidies could be integrated in MaaS schemes[45], using the data from practice provided by the ***data analytics providers***.

Overcome market entry barriers

Current legislation and practice may prevent new mobility providers from initiating new markets and entering existing markets. For example, current procurement rules may hamper the introduction of innovative mobility schemes, as they only allow traditional public transport services to be procured (IET, 2019) (Polis, 2017). Additionally, there may be safety issues with new mobility technologies, providing an entry barrier for certain mobility services to the MaaS scheme (Araghi, et al., 2020). There may also be protectionary regulations that try to limit markets in favour of incumbent operators or modes. This is widely seen throughout Europe in regard to the taxi industry Finally, there may be significant regulatory differences between cities/countries, hindering the scalability and integration of MaaS concepts (MaaS Alliance, 2019).

Public authorities (at the local, national and EU level) should improve level playing field by removing regulatory barriers for the various types of mobility services to enter MaaS schemes (MaaS Alliance, 2019). At the European level, public authorities should identify (and address) the main barriers related to fragmentation of regulation between regions or between transport modes. Furthermore, discussions between ***MaaS operators***, ***transport operators***, ***data providers*** and ***public authorities*** on harmonising regulatory, operational and technological issues should be initiated in order to remove entry barriers between local markets and hence improve the scalability of MaaS concepts. For this purpose, (international) pilots or partnerships could contribute to better understanding the issues that should be further harmonised.

Access to required data

Delivering an integrated multi-modal mobility service through MaaS requires access to multiple data sources owned by different agents. However, data is not always freely available, often of low quality, fragmented, or lacks a common structure or format (Araghi, et al., 2020) (IET, 2019). Also, data privacy and security are relevant issues in this respect, as was indicated in some of the stakeholder interviews. Several reasons can be distinguished for transport operators to be reluctant to (fully) share their data, including disclosing their own business model to present competitors, the fear that the MaaS operator will become the gatekeeper of all demand and usage data, fear of problems with privacy protection and the fear that algorithms are used by the MaaS operator that will not prioritise their preferred options (UITP, 2019). On the other hand, the transport operators can also expect data back, to improve their mobility system. If this data is of usable quality, they can use it to improve their own services.

In order to ensure the availability of open, complete and high-quality data, ***national governments*** should develop legislation setting general principles of data sharing, including requirements on the quality, format and accessibility of the data. Additionally, the ***European authorities*** should provide a legal framework that supports such national legislation. Amongst others, necessary modifications on the General Data Protection Regulation (GDPR) should be considered. For example, the way personal data is treated by data processors in MaaS schemes may be in conflict with the restrictions set by the GDPR[46] (Costantini, et al., 2019). ***Transport operators*** and ***data providers*** should share the data in the right format with the MaaS operator. At the same time, the **MaaS operator** should provide back any

[45] An option mentioned by (IET, 2019) is to replace subsidising specific routes by subsidising journeys for individuals.

[46] For example, based on the data collected for MaaS services, it may be (theoretically) possible to find a pattern in user's movements to healthcare facilities, and so correlate certain travel data to illnesses.

relevant data to the transport operators that could be used to further enhance the efficiency of their operations. Finally, the ***digital infrastructure and service providers*** should assist this process from a technical perspective by developing common data standards, platforms and application programming interfaces (APIs)[47].

Realise integrated payment and booking systems

Delivering a single user account and an integrated payment system requires that MaaS operators should be able to integrate the payment and booking systems of the various transport service providers (IET, 2019) (MaaS Alliance, 2019). Integration of these schemes is not straightforward, as there are differences between companies, cities and countries. Allowing third parties to (re)sell tickets also represents a paradigm shift at (public) transport companies and public authorities (e.g. with respect to affordability, guaranteed service levels to users, etc.).

The potential actions that could be taken to mitigate this challenge are highly similar as the actions with respect to data sharing. First, ***public authorities*** could provide framework conditions for payment and booking systems to enhance the possibilities for integration (MaaS Alliance, 2019). Furthermore, any legislation hindering ticket selling by third parties could be removed. ***MaaS operators*** and ***transport service operators*** could discuss options to arrange integrated ticketing, including alternative pricing and tariff systems (e.g. pay for usage, dynamic pricing) which may better facilitate the integration of payment. Furthermore, these stakeholders (supported by ***digital infrastructure and service providers***) may develop a clear framework system for integrating payment and booking systems (MaaS Alliance, 2019).

Combine a personalised approach with social benefits

As discussed in Section 3.4, the personalised approach of MaaS provides the opportunity to better respond to individual needs. However, it cannot be taken for granted that this personalised approach will also result in social benefits, like less emissions and congestion, as well. Therefore, it is important to design the MaaS ecosystem in such a way that these social benefits of MaaS are achieved as well.

The ***public authority*** should organise an effective control/oversight of the MaaS scheme(s), independently of the market model applied. At the European level, legislation ensuring good market conditions (e.g. avoiding barriers to entry and monopolies) and safeguarding passenger rights should be considered. For example, passenger rights in the EU are currently defined for each relevant transport mode (i.e. bus/coach, rail, maritime, aviation) separately and hence may hamper the realisation of actual multimodal transport (MaaS Alliance, 2018). For example, passengers may be confused on what their rights are when disruptions at one leg of the multimodal trip causes a delay at another leg of that same trip. Furthermore, impracticalities and legal uncertainties may arise for MaaS schemes because of the Package Travel Directive (MaaS Alliance, 2018). For example, in some cases the mobility services offered by the MaaS operator may be (legally) considered a package that has to meet the obligations set by this Directive. This may result in an excessive burden for the MaaS operators, hampering the development of a viable business case.

At the national and local level, environmental and social issues could be regulated where necessary (e.g. to avoid social exclusion). Additionally, ***public authorities*** could implement measures to discourage private car use (e.g. by parking policies, pricing policies like congestion charging, etc.) in order to maximise the environmental and social benefits of MaaS. This would best be done by including MaaS and supporting policy measures within Sustainable Urban Mobility Plans (SUMPs), ensuring that

[47] An API is a software intermediary that enables the communication between two different applications.

these measures are integrated in the entire policy package used by the city to achieve sustainable and efficient urban mobility. The effects of the policies can be monitored by ***data analytics providers***.

6.5. Self-organising logistics

6.5.1. Overview of relevant stakeholders

The following stakeholders are relevant for the development of self-organising logistics:

- **Transport operators and logistics service providers** nowadays plan and monitor the transport. With self-organising logistics, they become less dependent on planners and more dependent on algorithms. Given expected benefits – lower costs, 24/7 operation and optimal choices in the complete multimodal transport network – this is a very interesting development for these organisations.
- **Shippers** are the clients of the transport operators and logistics service providers. They want their goods to be transported. In consultation with the transport operators and the logistics service providers, they determine the requirements of the transport and what kind of freedom they give for the planning of the transport (based on the preferences of the consumers). Shippers have to adapt their logistic process in order to integrate SoL.
- **Data providers** (other than transport operators) providing interoperable data about the real-time status of all kind of assets along the logistics chain. For instance, about the expected time of arrival of a transport unit or the available capacity of a transport unit.
- **Digital infrastructure and service providers** act as service suppliers to the transport operator and/or logistics service provider, offering services including the data platforms for easy and reliable access to the data.
- **Data analytics providers** developing tools for processing lots of data, analysing the current status of assets in the logistics chain and predicting future situations. On top of that, they develop and deliver autonomous algorithms for autonomous data driven decision making by smart agents in the logistics chain.
- **Public authorities** (at EU, national, regional or local level) could provide policies and regulations to prevent that autonomous algorithms will produce undesired outcomes from a societal perspective.
- **End-users** such as planners, drivers, and management of transport companies need to understand and adopt the new services and include them in their daily routines.
- **Research institutions** could study issues like awareness, acceptance, business models, business cases and value cases for self-organising logistics.

In addition to these actors, other stakeholders could be involved in (more evolved) self-organising logistics developments as well, like OEMs, investors and insurance companies, etc. In this study, however, we will focus on the core actors listed above.

6.5.2. Main challenges and potential mitigation actions

An overview of some main challenges for deploying self-organising logistics as well as potential actions that could be taken by the various stakeholders is given in Table 13. All challenges and associated actions are discussed in more detail below.

Table 13: Overview of challenges and potential mitigation actions for self-organising logistics

Challenge	Potential mitigation actions	Transport Operator	Shipper	Data provider	Digital infra provider	Data analytics	Public authorities	End-users	Research institutions
Trust to share required data	Agree on what data will be shared with whom and limit the amount of data sharing as much as possible	✓	✓	✓	✓	✓		✓	
	Make use of data space: a digital virtual environment which facilitates finding and controlled sharing of (potentially) sensitive data	✓	✓	✓	✓	✓		✓	✓
High level data infrastructure	Develop and test a reference data architecture/infrastructure			✓	✓				✓
Control of autonomous algorithms	Test behaviour of autonomous algorithms under a large set of different situations and understand the way the algorithm works	✓				✓		✓	✓
	Prepare escalation levels and roles of stakeholders in case the algorithm will not perform	✓				✓		✓	✓
Prevent undesired results at societal level	Test behaviour of autonomous algorithms under a large set of different situations and understand the way the algorithm works	✓				✓	✓	✓	✓
	Identify problematic outcomes and take measures to avoid them	✓				✓	✓	✓	✓
Awareness and acceptance for involved companies and people	Show how the concepts work and what the advantages are in pilots	✓	✓				✓	✓	✓
	Elaborate impact on skills of people and value cases of companies	✓	✓					✓	✓
	Develop a shared understanding on the transition to SoL	✓	✓	✓	✓	✓	✓	✓	✓
High investment costs	Develop public or public-private financial arrangements to invest in the required modifications to the infrastructure	✓	✓		✓		✓		
	Make investments in SoL ready infrastructure (partly) mandatory	✓					✓		

Trust to share required data

To implement self-organising logistics, local data is required on the real-time status of assets such as vehicles, loading units or packages. As mentioned by some of the interviewed stakeholders, agents in the logistics chain are not very willing to share lots of data with other (un)known stakeholders for several reasons. One of the benefits of self-organisation logistics is that not all data has to be shared with everyone or with a control tower, but as limited data as possible only has to be shared with a limited set of stakeholders for which this data is relevant at that moment in time.

To gain trust and to make sure that the required data will be shared, ***transport operators, shippers*** and ***data providers*** have to agree what data will be shared with whom. The ***digital infrastructure and services provider*** should develop a digital platform for controlled sharing of this data that will be trusted by ***all involved stakeholders***. A data space (such as International Data Sharing Association, IDSA) could be used for this. IDSA, consisting of more than 101 companies and institutions of various industries and sizes from 20 countries, aims to guarantee data sovereignty by designing an open, vendor-independent architecture for a peer-to-peer network which provides usage control of data from all domains, among which the transport sector.

High-level data infrastructure

An important condition to successfully deploy self-organising logistics is a high-level data infrastructure with sufficient capacity to facilitate SoL. The infrastructure should be able to collect and process all data required to deploy SoL services at a large scale. How to design such a data infrastructure is an important challenge.

An option to address this challenge is by developing a reference data architecture/infrastructure that could be used by stakeholders to develop real-world SoL implementations. This reference data architecture/infrastructure should be tested and evaluated in various pilot studies. ***Research institutions*** with the help of ***data providers*** and ***digital infrastructure providers*** could develop such a reference data architecture.

Control of autonomous algorithms

One of the characteristics of self-organising logistics is that there is no central control. Individual agents will take autonomous decisions. In theory this can lead to chaos. Therefore, different situations have to be tested in many scenarios to find out under what circumstances decentralised coordination works. And if it does not work, it is the question of what kind of escalation is required and which stakeholder takes what role in such situations. This means that for specific circumstances a mix of centralised and decentralised control is required.

Since this is a rather new development, ***research institutes*** have to study on the behaviour of the autonomous algorithms together with the ***transport operators, the data analytics providers*** and ***the end-users***. Agreements on escalation and roles of stakeholders have to be discussed between the same groups of stakeholders.

Prevent undesired results at societal level

In the autonomous algorithms that are developed and applied for self-organising logistics, several rules are included amongst others concerning what mix of indicators to optimise. Especially in cases where the algorithms have self-learning elements, the outcome might become very beneficial for the transport operator (low operational costs), but undesired from societal perspective (congestion, emissions) while the algorithms itself becomes a black box. Also, a reversed modal shift (from

rail/inland waterways to road) might occur, as was explained in Section 3.5.1. Some policy implications of such a reversed modal shift are discussed in Box 8.

To avoid this situation, ***research institutes*** should analyse these possible outcomes in a way that public authorities get an understanding how these algorithms work and together with ***transport operators***, ***data analytics providers*** and ***end-users'*** measures can be prepared.

Box 8: A 'classical' modal shift vs a reversed modal shift: policy implications

The case study on the competitiveness of various transport modes (see Annex F) provides a more detailed analysis of policy implications of a reversed modal shift. Current policies are aiming at a 'classic' modal shift while the elaborated transition path shows that a combination of technological developments might lead to a reversed modal shift. Crucial questions are: when will be the turning point from 'classic' modal shift to reversed modal shift; what triggers can be used as a warning signal this development is about to take place; and how should governments deal with this possible future situation?

The speed of these kind of developments is uncertain, but there are examples it can go very fast. Therefore, it is very important that governments are prepared. Relevant questions are: is a reversed modal shift with substantial volumes of road freight transport by night a wanted or an unwanted situation; can the government influence these developments; and what kind of (policy) measures should be taken?

In the result of the transition path leading to a wanted situation, it has to be decided when to stop with large investments and stimulating the use of the other modes of transport (rail and barge). Besides, this transition path can be stimulated by applying reduced road charges for driving at night. If the result of the transition path leads to an unwanted situation, it has to be investigated whether the development of automation in rail and barge can be stimulated to keep up with the pace of innovation in road freight transport. Besides, it has to be decided what measures can be taken to avoid and/or slow down this development in road freight transport.

Awareness and acceptance for involved companies and people

Self-organising logistics is a rather new and complex concept in logistics. For the successful implementation of this innovation, it is important to take – next to technological aspects – also into account the organisational and human behavioural aspects to create awareness and acceptance. But maybe even more important, a shared understanding on how the transition from the current logistic chain to SoL should be made is required.

Research institutes should work together with ***transport operators***, ***shippers*** and ***end-users*** on pilots to show how the concepts work and to showcase the benefits and the efforts that have to be taken to implement it. ***Public authorities*** could stimulate or facilitate such pilots. For companies, it is especially interesting to see the impact on their value case. For the ***end-users such as planners and drivers***, it is especially interesting to get a better understanding of the concept and the way it will have an impact on their available skills or the skills they have to develop. Additionally, ***the various stakeholders*** should develop together a shared understanding/vision on how the transition to SoL could be made, e.g. within a specific platform/workgroup at the national/European level. It should be checked whether current platforms existing under Horizon Europe are adequately cover these kinds of issues or that the initiation of another platform is required.

High investment costs

High initial investment costs to implement self-organising logistics may hamper its deployment, as was mentioned by several interviewed stakeholders. Again, the chicken or egg causality dilemma is relevant here, as infrastructure operators are probably not willing to invest in required adaptations of the infrastructure without any certainty that it will be used by transport operators, and vice versa. The fact that the investments (in infrastructure) have to be made prior to the benefits to be achieved contributes to the challenge to finance the initial deployment of SoL.

Public authorities may provide subsidies to infrastructure operators to make the required investments in the physical/digital infrastructure. Possibilities for public-private partnerships (involving ***transport operators*** or ***large shippers***) may be investigated as well. Another option would be that ***public authorities*** mandates the provision of (some level of) SoL ready infrastructure (similar to the Alternative Fuel Infrastructure Directive). This action would preferably be taken at the European level to avoid fragmentation at the EU market.

6.6. Summary of potential policy actions to be taken by the EU

In the previous sections a large number of actions that could be taken by the various actors to address the relevant challenges for the development and deployment of Smart Mobility applications have been discussed. The main potential actions identified for the European authorities are summarised in Table 14. Possible actions that the EU could take are implementing or modifying legislation, stimulating and facilitating public-private partnerships, providing funding (mainly for investments in digital infrastructure), facilitating/funding (large-scale) pilots or contribute to communication on the effects and requirement of the Smart Mobility applications.

Table 14: Summary of potential policy actions that could be taken by the EU

Application	Type of action	Description of actions
C-ITS	Legislation	• Development of a modified version of a Delegated act on the standardisation of connectivity technology. • Study the option to develop a regulation to mandate the provision of (some level of) C-ITS ready infrastructure. • Develop/modify legislation on data privacy and protection (e.g., on issues like how drivers can grant third parties' consent to use their data).
	Public-private cooperation	• Stimulate and organise (broader) public-private cooperation within the C-Roads Platform (or within the CCAM Platform).
	Funding	• Funding investments in adequate digital infrastructure (e.g. by the Cohesion fund).
	Piloting	• Facilitate (large-scale) pilots, with clear paths to deployment afterwards, amongst others to collect evidence on the impacts, to address interoperability (also towards other Smart Mobility applications) and concerns on C-ITS services. Also, business models should be an integral part of the pilots.
	Communication	• Contribute to the communication to end-users on the benefits and concerns about C-ITS services (e.g. privacy related issues). This could, for example, be done by developing, operating or funding communication programs.

Application	Type of action	Description of actions
CCAM	Legislation	• All legislative actions mentioned for C-ITS are relevant for CCAM as well. • Monitoring whether revisions to the Motor Insurance Directive and Product Liability Directive are required or that new legislation should be implemented to deal with liability issues. • Study whether additional or modified legislation is required with respect to standardisation and interoperability. • Development of new standardised test frameworks for the approval of new vehicles to the European market, that incorporates the specific characteristics of automated vehicles.
	Public-private cooperation	• Stimulate and organise (broader) public private cooperation within the CCAM Platform to share knowledge on issues like the impacts of CCAM and business models.
	Funding	• Funding investments in digital infrastructure (e.g. by Horizon Europe or CEF2Digital).
	Piloting	• Facilitate (large-scale) pilots or Living Labs to show new automated driving technologies in real life to improve social acceptance, improve and test technical knowledge (e.g. on interoperability) and test business models.
MaaS	Legislation	• Develop a legal framework to support and harmonise national legislation on data collection and sharing. In this respect, necessary modifications to the General Data Protection Regulation should be considered. • Modify European legislation on passenger rights to better cover the specificities of multimodal trips. • Modify the Package Travel Directive to remove any impracticalities for MaaS schemes. • Assess potential legal barriers leading to fragmentation of regulation between regions or transport modes, and where necessary implement required modifications.
	Public-private cooperation	• Check whether existing platforms bringing MaaS partners together in the context of Horizon Europe adequately address cooperation on the relevant issues for MaaS. If not, the development of a new platform/working group may be initiated.
	Piloting	• Facilitate/support the organisation of pilot project, amongst others to learn on different MaaS models, develop and test business models.
SoL	Legislation	• Many of the legislative actions mentioned for the other Smart Mobility applications are relevant for SoL as well (e.g. on data sharing, standardisation, etc.).

Application	Type of action	Description of actions
	Public-private cooperation	• Facilitate/stimulate public-private cooperation to develop a shared understanding /vision on how the transition to SoL could be made. For this purpose, a specific platform/workgroup could be launched (after checking whether this topic could not be covered by an existing platform/working group).
	Funding	• Funding for the required investments in physical and/or digital infrastructure (e.g. by CEF2Digital).
	Piloting	• Stimulate/facilitate pilots to show how the concepts work and to showcase the benefits and the efforts that have to be taken to implement it.

7. MAIN CONCLUSIONS AND POLICY RECOMMENDATIONS

7.1. Main conclusions

Development in Smart Mobility through emerging technologies

Mobility is in transition. The combined development of different emerging technologies (e.g. smart sensors, connectivity, blockchain, big data, digital platforms, artificial intelligence) boost innovations in Smart Mobility. This development is expected to accelerate in the coming decade as the various technologies become more mature, providing new and more advanced opportunities to be applied in Smart Mobility applications. These developments will not only be driven by the opportunities arising from emerging technologies but also by the increasing pressure on achieving the societal goals within the transport sector (e.g. reduction of GHG emissions, improving traffic safety, reducing congestion levels). The applications with the highest expected impact on the transport sector and society are Cooperative Intelligent Transport Systems (C-ITS), Connected Cooperative Automated Mobility (CCAM), Mobility as a Service (MaaS), and Self-organising Logistics (SoL).

Uncertain impacts on transport and society

Each application has the potential to be disruptive and their individual positive impacts on the transport sector and society can be large. Smart Mobility applications are expected by the European Commission to provide a positive contribution to the environmental, social and economic goals of the EU. In several EU strategies, these applications are explicitly mentioned as key solutions contributing to a more sustainable, efficient and safer transport system.

The assessments carried out in this study show that Smart Mobility applications are expected to provide benefits for transport users, particularly by increasing transport efficiency (e.g., more flexibility, lower user costs) and improving travel experience (e.g., a higher feeling of comfort and safety). Furthermore, Smart Mobility options indeed have the potential to significantly contribute to higher levels of traffic safety, less congestion and less emissions. To what extent this potential will be materialised depends on the design, implementation and management by public authorities (with (packages of) actions such as legislation, funding, piloting and public-private cooperation). If not managed well, Smart Mobility applications will not or only to a limited extend be applied and can also lead to a range of negative impacts.

Furthermore, the evidence on the impacts of Smart Mobility applications is only available from small-scale pilots, scenario studies and stated preferences studies. Therefore, the uncertainty in these findings are high and they should be considered carefully.

Because of the potential of Smart Mobility to contribute to solutions for the increasing challenges the transport sector is facing, continuation (and maybe even expansion) of the investments in Smart Mobility seems to be justified, even although the actual impacts are still highly uncertain. This should, however, be accompanied by intensified research for which societal goals, whether and under which conditions the anticipated benefits of Smart Mobility applications could be achieved. Note that Smart Mobility applications should not be evaluated standalone, but always in comparison to the societal cost and benefits of the current solution (e.g. MaaS might not have a positive business case in rural areas, yet the same is true for most public transportation solutions as they are subsidised). Hence, the societal value case of the current solution and the alternative (in this example public transport and MaaS solutions) should be compared.

Smart Mobility requires integrated management of various infrastructure levels

The deployment of Smart Mobility applications requires a well-developed digital infrastructure. Further development of the digital transport infrastructure in Europe is therefore key. As the lifetime and user-requirements of the digital (and operational) infrastructure differs widely from the physical infrastructure and the development of the infrastructures are not congruent, specific (but integrated) strategies for the various levels of transport infrastructure are required, that are aligned as part of an integrated Smart Mobility strategy (see also the section on policies below). This asks for a close cooperation between different stakeholders, as the various infrastructure levels are managed by different parties.

Wide range of challenges

To facilitate and accelerate the deployment of Smart Mobility applications in order to achieve their individual and social benefits, many challenges have to be overcome. Although each application has its own challenges, some general challenges were identified that hamper the development and deployment of Smart Mobility. These are technical, as well as economic and social and all seems to be equally important. Improving user and public acceptance, developing viable business cases, guaranteeing data privacy, providing a harmonised and secure data sharing infrastructure and ensure interoperability between countries/regions and modes are some of the main challenges to further develop and deploy Smart Mobility applications at large scale.

Policies

To overcome the various challenges, actions at different levels are needed. Not only by European policy makers, but also by a range of other stakeholders (e.g. Member States, regions and cities, vehicle manufacturers, transport infrastructure managers, transport operators, etc.). These actions should be aligned and coordinated which calls for more intensified public private partnerships. Each Smart Mobility application is in a different stage of development and the same is true for the emerging technologies underlying these applications. Therefore, a targeted set of actions is required for each application.

These targeted sets of policies should be part of an overarching strategy towards Smart Mobility. The European Commission is currently working on a strategy for a Sustainable and Smart Mobility, which could provide such an overarching strategy. All Smart Mobility applications make use of a similar technology base and hence the pace of their technology development is interrelated. Also, as applications mature, the borders between the applications become more blurred and more complex implementation and deployment interactions arise. This is already acknowledged by initiatives such as the European Interoperability Framework. Only with an integral overarching strategy these issues could be adequately addressed. Building such an overarching strategy is not something that can be done overnight but is expected to require a step-by-step process towards more integration (of applications, domains, department, etc.).

7.2. Policy recommendations

Based on the main conclusions presented in the previous section and the policy recommendations for each individual Smart Mobility application in Chapter 6, the following overall policy recommendations for the European policy makers could be made:

- Develop an overarching strategy for Smart Mobility; as mentioned above, an overall EU strategy for Smart Mobility is required to coordinate effectively all initiatives on the various types of Smart Mobility applications. Key elements to such a strategy are:

  - The developments automation, connectivity, electrification, and sharing (ACES) combined gear the mobility transition. Although sustainable developments (including electrification) were outside the scope of this report, note that they will have an impact on the development of Smart Mobility. For example, many new shared mobility concepts are electric. Hence, all developments should be taken into account in defining the strategy.
  - Within the transport sector the approach towards passenger and freight transport as well as road, rail, inland navigation based transport options (including the new mobility options that arise) and expertise from other domains relevant for transport (such as build environment and ICT) can be approached in a more integral way to avoid suboptimal solutions and investments.
  - Keep in mind that the impact of Smart Mobility is not limited to the transport sector yet also include, amongst others, effects on the economy, spatial planning, the energy domain and has social impacts. Cross-sector cooperation is recommended (e.g., to manage the spatial impacts of autonomous cars in cities). There are many ways to shape cross-sector cooperation. Examples include organising knowledge exchange around a specific application with explicit attention to cross-sector effects (i.e., MaaS and its effect on the transport sector, economy and labour); organise pilots or projects that address multiple policy goals (e.g., mobility and spatial planning) with a specific regional focus and consisting of a multi-disciplinary team; and funding the realisation of (parts of) the digital infrastructure (such as digital twins, real-time traffic information, connectivity) that benefits multiple sectors.
  - As many stakeholders are involved with each their own interests and contributions, it is recommended to balance the needs of users (of both passenger and freight transport), companies and governments in order to achieve societal goals, e.g. a sustainable, efficient and safer transport system. This requires insight in the core interests of each group (i.e., privacy and safety protections for users, a good business case for companies and contribution of Smart Mobility towards societal goals for governments), determine the roles and responsibilities (i.e., public and private roles), the base conditions to protect these core interests (i.e., stakeholders processes with a sufficient level of trust, safety legislation for new mobility options), a monitoring process to continuously check the balance (i.e., a policy dashboard) and having the appropriate tools for steering in place to adjust the course of action when needed (i.e., pricing policies).

- Create base conditions that allow for Smart Mobility. In order to be able to reach large scale deployment and user adoption of Smart Mobility – and through this the positive contributions towards societal goals – further investments in the base conditions are needed. Examples include the development of the digital infrastructure, data standards, data sharing requirements, privacy and security solutions, removing barriers to enter markets, harmonisation and legislative support actions.
- Define targeted policy packages for each Smart Mobility application. As each application requires a broad set of policy actions, we recommend assessing in detail which categories of policy measures are currently deployed and where opportunities lie to further steer the development of the applications. In this study, we found that are variety of stakeholders need to take action. Hence, the targeted policy package should also aim to stimulate and facilitate the actions needed from all stakeholders. Examples include a clear and consistent

legal framework (e.g. on data access and security, liability, etc.), institutionalised public-private cooperation and discussion interactions between all relevant stakeholders including end-users (e.g. by using platforms like the CCAM platform), large-scale (and transboundary) pilots (that are carefully evaluated) designed towards achieving societal goals, and a good balance between public, public-private and private financing.

- Ensure that policies are proactive, flexible and adaptive to be able to steer towards societal goals; as the Smart Mobility applications (and underlying emerging technologies) are very innovative, their future development is difficult to predict. Therefore, it is important to develop policies in such a way that they can be quickly adapted when new technological concepts become available, societal developments change or user preferences are different than anticipated. Periodic foresight studies to keep track of the state-of-the-art technology developments can support this as well as monitoring the progress on the societal goals to be able to take action when needed.
- Improve the knowledge base on Smart Mobility applications; increased knowledge on the (user) requirements, technical requirements, expectations and concerns related to Smart Mobility applications, potential business cases and the impacts these applications could have on the transport sector and society is required to further develop the various applications and to gain social acceptance for them. For this purpose, (large-scale) pilots should be designed, initiated and their results should be monitored, evaluated and disseminated. To support this, data, (new) transport models capable of including emerging technologies and Smart Mobility applications and a common evidenced-based assessment and evaluation method are key. Last, the dissemination of state of the art knowledge from pilots, project and research programs, the translation of knowledge into concise, easy to understand information that can serve as an introduction and starting point to all the stakeholders, and meta-analyses that integrate the findings for all studies are important building blocks in establishing a knowledge base on Smart Mobility applications.
- Organise cooperation between all relevant stakeholders; the development and deployment of innovative Smart Mobility applications, starting with creating the base conditions, require a close involvement of all relevant stakeholders in order to ensure that actions taken are consistent and aligned. Furthermore, close cooperation may enlarge the innovative capacity of the sector, accelerating the development of emerging technologies and/or Smart Mobility applications. It is crucial that a representative selection of (the categories of) stakeholders are included. This requires stakeholder management to ensure that stakeholders not (well) represented are actively invited and if necessary (financially) supported to ensure that not only large but also smaller interest are brought to the table. Specific attention is needed to include end-users to be part of these initiatives that facilitate cooperation, as a clear understanding of their needs is required to develop applications that will be taken up by the market. Therefore, cooperation and consultation bodies (like the CCAM platform) should be organised and/or prolonged and/or extended on the various aspects of Smart Mobility. Examples include the continuation of the C-Roads platform on C-ITS, the CCAM platform, and checking for MaaS and SoI whether the other platforms that bring partners together in the context of Horizon Europe adequately address cooperation on the topics listed in this study.

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ANNEX A. OVERVIEW INTERVIEWEES

Organisation	Name	Function
5GAA	Velimira Bakalova	Coordinator- EU Affairs/Security and Privacy
Dinalog	Bas van Bree	Program manager
EPF	Delphine Grandsarts	Research officer
ERTICO	Johanna Tzanidaki & Nikoleas Tsampieris	Innovation & deployment director/senior manager
ERTRAC	Xavier Aertsens	Director
Fundación Valenciaport (Port of Valencia)	Salvador Furió Pruñonosa	Director of innovation and port cluster development
ITS Finland	Laura Eiro	Program director
MaaS Global	Sami Sahala	Chief advisor
ProRail	Jeroen Klinkers	Program manager system integration
TU Delft	Bert van Wee	Professor in Transport policy

ANNEX B. CASE STUDY SELECTION

Case study selection

The following selection criteria were considered:

- Smart Mobility solutions: C-ITS, CCAM, MaaS, SoL.
- Geographical spread: one country, several countries, EU level.
- Focus areas: emerging technologies, policy, governance, services, impacts.
- Development phase: ongoing, emerging development, future-oriented study.

Table 15: Case study characteristics

	Case 1 Connectivity of automated driving	**Case 2 Regional impacts of automated driving**	**Case 3 MaaS in Finland**	**Case 4 Changing competitiveness of road, rail and inland waterways for freight transport**
Smart Mobility solutions	C-ITS, CCAM	CCAM, MaaS	MaaS	SoL, CCAM
Geographical spread	Developments in several EU countries, including Czech Republic	Regional and local impacts; Province of North-Holland / larger Amsterdam region, The Netherlands	Nation-wide approach	Developments at EU-level
Focus areas	Emerging technologies, services	Impacts, emerging technologies, policy	Governance (legislation), policy	Emerging technologies, policy, impacts
Development phase	Ongoing projects	Future-oriented study	Ongoing program	Emerging developments; Future-oriented analysis of competitiveness of multiple transport sectors

Case study descriptions

Case 1 Connectivity of automated driving

C-ITS is being piloted all over Europe. In this specific case study, we will focus on the C-ITS deployment in the Czech Republic. This is a unique pilot site within C-Roads. C-roads is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability. The Czech Republic pilot is specifically devoted to the verification of C-ITS use cases for railway level crossings. Achievements of the pilot project are being demonstrated by field tests recorded and assessed according to the developed procedures, at the deployment sites in the Czech Republic as well as in other Member States, in order to achieve an interoperable cooperative system harmonised at the European level. The testing consists of vehicle-to-vehicle communication technologies. Short range communication technologies will be compared to long range technologies. As the results of the Czech pilot are not yet available the results of the InterCor project are presented to learn on the impacts.

Case 2 Regional impacts of automated driving

This case study explores the mobility impacts of connected and automated driving and shared mobility. In a future oriented study, four extreme scenarios were explored in which 100% of the vehicles have high levels ((level 3-4) or a very high level (level 5)) of vehicle automation and people have a low or high willingness to share. A new transport model was developed and applied in order to provide insights in the impacts of emerging technologies. The model was applied in a case study, in which the potential impacts of automated and shared vehicles in the Dutch Province of North-Holland and the larger Amsterdam region were examined. In this case study a wide range of new mobility concepts are included - automated vehicles, automated (shared) taxis, automated shared vans and new parking concepts - as well as the way in which they affect mobility choices and traffic conditions. The study provides insights into the impact mechanisms and the direct and indirect mobility impacts. The results show that if automated vehicles and sharing are accepted, it is likely that there will be considerable changes in mobility patterns and traffic performance, with both positive and problematic effects.

Case 3 MaaS in Finland

This case study explores Mobility-as-a-Service in Finland. Finland is often considered as one of the front running countries in Europe in this field. This case study explores the MaaS ecosystem, the policy goals, the roles and responsibilities of stakeholders, the relation between new mobility concepts (e.g. bike sharing, MaaS apps/platforms) and traditional transport options and the policies to manage this development (e.g. laws and regulation, support actions such as changes in transport code and open data rules, support actions such as investments/funding/PPP). This case study discusses the advantages and disadvantages of the policy approach and governance, its implications for both public and private parties and how to manage the transition in the mobility system.

Case 4 Changing competitiveness of road, rail and inland waterways for freight transport

This case study explores the changing competitiveness of road, rail and inland waterways for freight transport at the EU level. Currently, transport policy for freight transport is often aimed at achieving a modal shift from road to rail and inland navigation in order to reduce the pressure on road infrastructure and contribute to policy goals such a accessibility, safety and sustainability. In this case study combinations of development in freight transport are analysed such as: connected automated driving, electric driving, use of platforms and driving at night. The case study shows that these developments are take place faster in road transport than in rail and inland navigation. As a result, the competitive position (e.g. costs, flexibility, speed, etc.) of road transport is expected to strongly improve

in the near future compared to rail and inland navigation. Without policy measures, this could lead to a reversed modal shift from rail and inland navigation back to road transportation. This case study explains the relevance of the interactions between developments, explores various policy directions and discusses how to deal with uncertain developments of emerging technologies.

ANNEX C. CASE STUDY I: CONNECTIVITY OF AUTOMATED DRIVING

Description of the case

C-ITS is being piloted all over Europe. The figure below gives an impression of the different pilot locations as can be found on the C-Roads platform website. Both Urban deployments and corridors/ trajectories on highways are tested.

Source: www.c-roads.eu

The C-Roads Platform is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability.

There are even more C-ITS sites. The InterCor website for instance illustrates pilot operation in the 4 member states involved in this project (UK, FR, BE, NL), with even more C-ITS deployments (although these member states are also part of C-Roads, not all pilots are illustrated on that website)

Involved stakeholders in these pilots are road operators from the different member states, deploying C-ITS on their roads, and by doing so involving more stakeholders like C-ITS service providers, OEMs (car industry), research institutes and automotive industry, among others.

C-ITS services implemented are primarily DAY1 applications (see Chapter 2) like traffic safety applications (e.g., road works warning, traffic jam ahead warning, intersection safety), traffic efficiency

applications (e.g., GLOSA and traffic signal priority requests, shockwave damping), traffic information (e.g. In-vehicle speed limits and probe vehicle data).

Some services combine goals (like GLOSA having traffic efficiency goals but also target environmental gains by reducing emissions).

Detailed description of the case

In this specific case study we will focus on the C-ITS deployment in the Czech Republic.

One of the main goals of the C-Roads Czech Republic is to verify coexistence, reliability, security and functioning of the mutual linking between ITS-G5 (short range) and LTE (long range) communication technologies, commonly referred to as a ´hybrid cooperative system´ (see chapter 2), which mainly reduces deployment costs and increases reliability of the system. LTE-V2X technology (alternative short-range communication) is being tested as well. Considerable effort is being devoted to the security of the hybrid communication which is paramount of importance.

A unique pilot site within C-Roads Czech Republic is devoted to the verification of C-ITS use cases for railway level crossings. The aim is to evaluate possibilities of C-ITS services to prevent collisions of trains with road vehicles.

Achievements of the pilot project are being demonstrated by field tests recorded and assessed according to the developed procedures, at the deployment sites in the Czech Republic as well as in other Member States, in order to achieve an interoperable cooperative system harmonised at the European level.

The Czech C-Roads pilot sites are located on the Rhine-Danube Core Network Corridor in the section München/Nurnberg – Praha, on the Orient-East Med Core Network Corridor in the section Praha – Brno, and on the urban nodes Plzen, Brno and Ostrava. Plzen and Ostrava are situated on the Rhine-Danube Core Network Corridor. Ostrava and Brno are situated on the Baltic-Adriatic Core Network Corridor. Cooperative systems are being deployed on more than 200 km of Core Network Corridors and municipalities network belonging to these motorways (Brno, Plzen).

The services will be implemented by Individual C-Roads Czech Republic project partners:

Implementation of C-ITS services via ITS G5:

- Road and motorway Directorate (RSD) of the Czech Republic
- City of Brno (via. Brněnské komunikace)
- Správa železnic, state organisation (SŽDC)
- City of Ostrava and Plzeň (via. their public transport companies)
- AŽD Praha.

Implementation of hybrid C-ITS system based on ITS G5 and current LTE technologies:

- O2 CZ
- INTENS Corporation
- T-Mobile CZ.

Implementation of new cellular technologies (LTE-V):

- T-Mobile CZ
- Evaluation and Assessment of implemented systems:
- Czech Technical University in Prague, Faculty of Transportation Sciences (CTU).

Barriers and enablers for the deployment of the various applications

The testing of the existing V2V technologies (ITS-G5) as well as the newest ones (LTE-V2X) constitutes important aspect of the Czech project. The short-range communication technologies ITS-G5 and LTE-V2X are not compatible with each other, in fact they interfere with each other. T-Mobile CZ is involved in both the hybrid ITS-G5 +LTE and LTE-V2X deployment and will be in a good position to evaluate both technologies, as well as compare it to long range LTE-Uu.

C-ITS systems will be deployed not only on the D1, D5 and D11 motorways but also in the cities, public transport systems and on level railway crossings.

The C-ITS deployment is supposed to bring many improvements in road safety in Europe and lays foundations for using cooperative ITS systems and highly automated driving systems, including the autonomous vehicles. The Czech pilot also intends to provide input for this.

The results of the pilots are expected to become available in 2020.

Learning on the Impacts (of the initiative and potential when scaled up)

Impacts on the transport sector

As the results of the Czech pilot are not yet available, we will use the results of the InterCor project for the learning on the impacts.

In InterCor extensive evaluation has taken place, evaluating the (potential) life benefits of C-ITS applications by reports on using technical evaluation, impact assessment, user acceptance and exploitation. Results of the 4 member states involved have been reported over Q1 2020.

The results are publicly available at: InterCor Library

The technical evaluation involved (cross-border) interoperability, communication performance as well as application and services interoperability. Many evaluations have been done; many conclusions have

been drawn. An interesting observation (both barrier and driver): "Hybrid communications, using both ITS-G5 and Cellular communication channels was very effective but more complex to implement".

User acceptance and impact assessment was done based on the evaluation framework, also available as deliverable and used in C-Roads.

In-vehicle signage, road works warning, GLOSA, PVD and the logistics use cases truck parking, Multi-modal cargo transport optimisation and tunnel logistics were implemented and evaluated in two or more of the four member states.

Users liked the services offered and indicated they would use them. There was encouraging potential indicated to positively influence their behaviour. However, users do not generally want to directly pay for discrete services. This attitude did not change from the acceptability survey taken before the pilots began. This stresses again the importance of having a clear business case, not only a value case. (see section 5 of this report).

For piloting, an important lesson can be drawn from the impact assessment conclusions: "Impact Assessment was difficult due to the scale and duration of the projects. We feel that to obtain more significant results they should ideally be longer, larger pilots planned on 'naked roads' where there is not existing ITS gantry or roadside mounted message signs. This will make getting a true driver reaction to the services easier using the control/treatment method outlined in the InterCor Detailed Evaluation Methodology".

Data logging (common or not) is key to good evaluation results but data processing & analysis overhead was onerous so should be carefully considered and scope allowed to be refined at the data validation and verification stage. Also, the sharing of best practice across project partners with respect to data storage structures, data processing and development and use of common analysis tools is recommended.

Lessons learned for the EU

As mentioned before, the importance of having a clear business case for C-ITS , for all involved stakeholders, and not only having a value case for C-ITS, is crucial. Therefore, for C-ITS to be successful one needs to go beyond (successful) piloting in the different countries. A uniform roadmap for deployment would be very helpful, guidance to individual member states based on an overall (European or even broader) approach is needed. Now individual member states are determining their own approach for C-ITS, and although it is encouraging that they see the potential it is important to realise that the largest effect will be obtained with a uniform approach.

ANNEX D. CASE STUDY II: REGIONAL IMPACTS OF AUTOMATED DRIVING

Description of the case

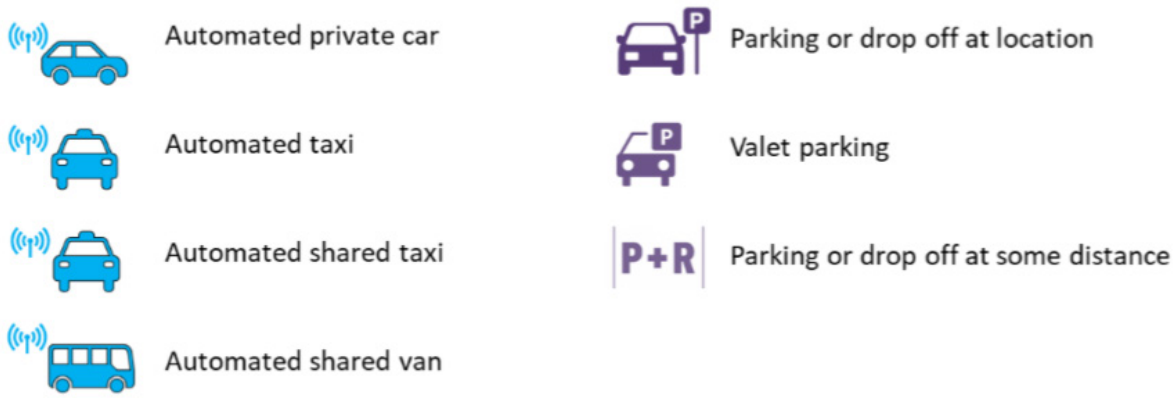
This case study explores the mobility impacts of connected and automated driving and shared mobility. The focus of this case study is on learning about the impacts of automated driving and shared mobility and the policies and policy recommendations affecting it. In a future oriented study, four extreme scenarios were explored in which 100% of the vehicles have high levels of vehicle automation and people have a low or high willingness to share. A new transport model was developed and applied in order to provide insights on the impacts of emerging technologies. The model was applied in a case study, in which the potential impacts of automated and shared vehicles in the Dutch Province of North-Holland and the larger Amsterdam region were examined. In this case study a wide range of new mobility concepts are included - automated vehicles, automated (shared) taxis, automated shared vans and new parking concepts (see Figure 16) - as well as the way in which they affect mobility choices and traffic conditions. The study provides insights into the impact mechanisms and the direct and indirect mobility impacts. The results show that if automated vehicles and sharing are accepted, it is likely that there will be considerable changes in mobility patterns and traffic performance, with both positive and problematic effects.

Geographical location

The case study focuses on the Province of North-Holland in the Netherlands. The largest city in this province is Amsterdam. Figure 17 shows the province of North-Holland and its region types.

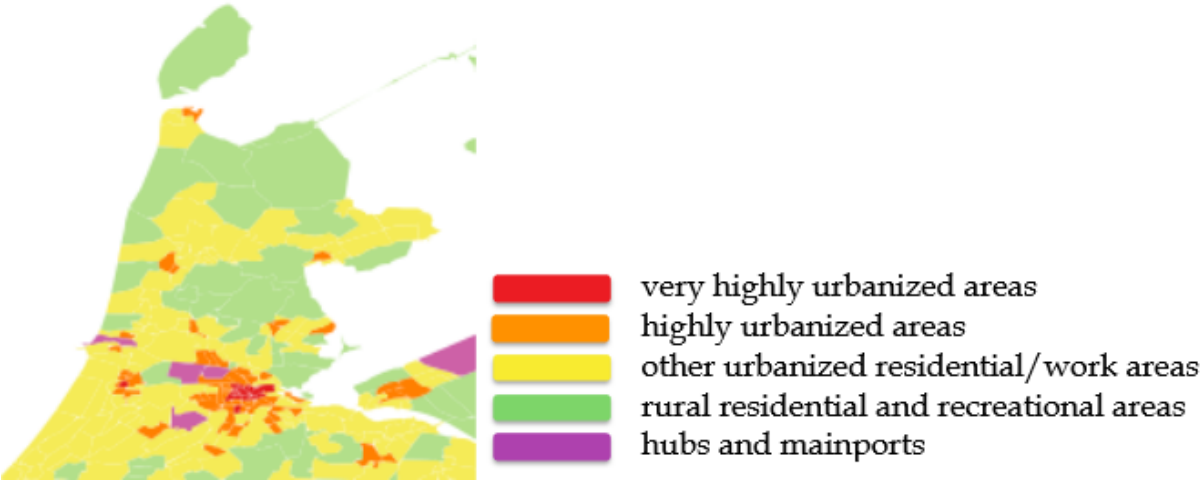
Smart Mobility application

Figure 16: New modes and parking concepts included in the study



Source: Wilmink et al. (2019).

Figure 17: The Province of North-Holland and its region types



Source: Arcadis & TNO (2018).

Stakeholders

This case study is based on the study done by Arcadis & TNO (2018) in the period November 2017-2018, commissioned by the Dutch Province of North-Holland and the Amsterdam Transport Region.

Objectives of the study

The study concerned an impact analysis into mobility impacts of connected and automated driving and shared mobility. The study also provided insight into the possible interventions (action perspectives) for the involved public authorities in their role as road authority and public transport concessionaire.

References

This case study is based on the study done by Arcadis & TNO (2018) and the various conference papers and the journal paper that was based on this work. Furthermore, the relevance of this work is explained in the TNO whitepaper on the Mobility transition (TNO, forthcoming). A complete list of references is included at the end of the case study.

Detailed description of the case

Established and new players are investing in the development of automated cars and in car- and ridesharing systems. For example, Waymo recently raised $2.25 billion in investments [17] and Uber's turnover grew by 37% to $4 billion in 2019 (Emerge, 2020). However, the industry's automated driving timelines are not being met year after year [17]. In Europe, investments are being made in 'connected' and cooperative automated driving based on the conviction that this is safer and leads to a more efficient traffic system than autonomous driving (Aittoniemi, et al., 2018; Lieshout, et al., 2019). TNO has explored transition paths combining the arrival of automated cars in urban areas with the arrival of new taxi and pooled taxi systems such as Lyft, UberPop, UberPool, etc.

In the current situation, the number of partially automated vehicles is gradually increasing [22]. This also applies to the use of shared cars in which people drive themselves [23]. Two important milestones that will lead to major changes in the mobility system are the arrival of automated vehicles in which the driver no longer needs to be able to intervene within seconds [24] and allowing non-professional drivers in cabs. With level 4 and 5 automated driving, the capacity of the road can increase by 10%-30%

(Snelder, et al., 2015) provided that communication takes place between vehicles and between vehicles and the infrastructure. At the same time, it becomes much more attractive to choose an automated car instead of public transport, walking or cycling because the time in a vehicle can be spent differently. It is expected that the number of rides with ride-hailing services (such as Uber and Lyft where you will be taken to your destination by a driver and where you can book and pay for the ride very easily via an app) will increase strongly as is happening in the USA when nonprofessional drivers will also be allowed to perform rides. This is due to a strong increase in supply and a decrease in costs. A distinction can be made between private taxis and pooled taxis that you can share with multiple strangers.

Automated driving and sharing systems can develop independently of each other. Automated driving can also stimulate the use of (shared) taxi services when no driver is needed anymore, and the costs decrease. However, this will only be possible on a large scale with full automation (level 5) and that moment seems far away. The exact timing and order in which a strong increase in the use of automated vehicles and (shared) taxis will take place is still very uncertain. Governments themselves can steer towards a situation that best fits their safety, liveability and accessibility goals" (TNO, forthcoming).

Methodology

A new transport model – the New Mobility Modeller – was developed and applied by TNO in order to provide insights in the impacts of emerging technologies and to analyse different future scenarios. "The New Mobility Modeller is a unique tool, that can give cities or regions specific insights into the effects of new mobility concepts. This includes estimation of quantitative impacts in terms of costs, travel demand, road capacity and travel times, and the possibility to explore interactively a large number of scenarios in a short time. The New Mobility Modeller is the first model (to the best of the authors' knowledge) that combines a network fundamental diagram with choice models." (Wilmink, et al., 2019). The model focuses on mode choice and travel times (via a network fundament diagram) and takes destination choice into account via elasticities. Location choice (spatial effects) and car ownership effects are exogenous inputs to the model. Table 16 describes the model segmentation (Snelder, et al., 2019).

Table 16: Model segmentation

Input	Explanation
12 transport modes (m)	Modes included are car driver (level 0/1/2), car passenger, train, bus/tram/metro, bicycle, walking, trucks (level 0/1/2), automated private car (level 3/4 or 5), automated taxi, automated shared taxi, automated shared van, automated trucks (level 3/4 or 5). Automated private cars are privately owned vehicles with level 3/4 or 5 automated driving functions. Distinctions between the levels can be made by selecting the road types on which the vehicles are allowed to drive automatically, and by changing the cost and time parameters. Automated shared taxis offer a ride sharing service. The same holds for automated shared vans (or buses) but with a higher capacity. In level 3 and 4 a driver is still required for automated taxis (and shared taxis and vans/buses). Automated trucks are level 3/4 or 5 trucks. Finally, with level 5 automation, there is no difference between car driver and car passenger. The car passenger option thus becomes superfluous in level 5 scenarios and is hence removed. Members of the same household can still travel together in an automated private car. Non-automated (shared) taxis/vans are excluded because they have a very low share in the Netherlands.

Input	Explanation
Level of communication	Share of the fleet that is capable of vehicle-to-vehicle (V2V) communication.
4 road types (s)	Through roads (freeways and highways), distributor roads with separate roadways, distributor roads with mixed traffic, access roads (district and neighbourhood arteries, residential streets).
5 region types (r)	Very highly urbanised areas, highly urbanised areas, other urbanised residential/work areas, rural residential and recreational areas, hubs and mainports.
4 user groups (u)	Car owners with a household income >30000 euro (1) or a household income ≤ 30,000 euro (2), no private car available and household income >30,000 euro (3) or a household income ≤30,000 euro (4).
4 age classes (a)	0-17, 18-35, 36-75, >75 years.
3 parking options (p)	Parking or drop off at location (in case of level 5 automation), valet parking, and parking or drop off at some distance (e.g. park-and-ride locations or centrally located car parks).
3 time periods (t)	Morning peak, evening peak, off-peak period.

Impact

Highlights

"In the most unfavourable situation, in which automated vehicles are allowed in unlimited numbers, cities will face major negative consequences on the quality of life and accessibility. In an extreme situation where 100% of vehicles are fully automated, despite the increase in capacity, the number of vehicle kilometres may increase by 74% and congestion in cities may more than triple (Snelder, et al., 2019; Arcadis ; TNO, 2018). The dominant position of the car puts pressure on the profitability of public transport, with all its consequences. It also leads to less walking and cycling (Snelder, et al., 2019; Arcadis ; TNO, 2018). If the use of taxi services is stimulated and the use of private cars is strongly discouraged, this increase may level off somewhat. Only if the use of private cabs is also discouraged and ride sharing is strongly stimulated the number of vehicle kilometres can decrease. In an extreme situation where private use of vehicles is no longer allowed at all, the number of vehicle kilometres decreases by 88%. If automated vehicles and (shared) taxis are used on a large scale, the number of parking spaces needed in the city centre decreases. The freed up space can benefit the quality of life in cities. However, part of the space will have to be used for locations where people can be picked up and dropped off. Parking income and income from motorcycle tax will decrease. Under current policy, providers of mobility services do not pay for the extent to which they use publicly financed road capacity compared to private car owners. This is an important argument for paying according to use (TNO, 2017; TNO, forthcoming)."

Results for each impact area

"In order to gain insight into which scenarios more or less meet the policy objectives of the Province of North-Holland (PNH) and the Transportation Region Amsterdam, an overview of relevant policy objectives has been drawn up on the basis of various policy documents, policy visions, etc. The most relevant policy objectives concern economic and social development, traffic throughput (accessibility), traffic safety, quality of the living environment and sustainability/liveability. The results of the analyses with limited policies included show that major changes in mobility choices can take place through the introduction of self-driving vehicles, especially in the two Level 5 scenarios (high and low willingness of people to share vehicles). This has significant consequences for mobility, (public) space and also affects social aspects.

Linked to the policy objectives of the PNH and the Transport Region, this means the following:

- Accessibility. All scenarios involve a higher number of vehicle kilometres. This increase in mobility has a positive effect on the accessibility of jobs, among other things. The downside is that the increase in vehicle kilometres has a negative impact on traffic throughput, especially in urban areas (the increase in vehicle hours lost in congestion takes place mainly in urban areas). In most cases, this increase is not compensated by the assumed (substantial) increase in the capacity of the road network (as a result of cooperative automated driving). In conclusion, this study shows that self-driving vehicles have a positive influence on accessibility in rural and less urban areas and a negative influence on accessibility in the more urban areas.
- Traffic safety. In all scenarios there are more vehicle kilometres. Normally this results in a higher expected number of accidents and more material and immaterial damage. This risk seems to be higher in urban areas because there is a greater interaction between fast and slow traffic. On the other hand, experts assume that further technological developments in vehicle safety will (perhaps more than) compensate for the possible additional risks. In conclusion, this study assumes that self-driving vehicles have a neutral or possibly positive influence on traffic safety.
- Liveability and/or sustainability. In all scenarios, there are more vehicle kilometres, which in principle, at the current level of electrification, results in more emissions of CO_2 and harmful substances. In addition, a higher noise impact occurs. However, it is also expected that vehicles will be increasingly electrified (based on renewable energy sources) and produced more circularly, which is expected to reduce emissions of CO_2 and harmful substances. The noise nuisance caused by tires will continue to exist. The development of both self-driving and electric vehicles does not necessarily have to go hand in hand. If self-driving vehicles are also to a large extent electric in the future, it is expected that the negative effects as a result of the increase in vehicle kilometres will be compensated, so that a neutral impact on liveability and sustainability can be expected. If, however, there is no electrification of the vehicle fleet, the expected impact is negative. Finally, the replacement of sustainable transport alternatives such as public transport, cycling and walking by self- driving vehicles is a point of attention in all areas and the loss of share of the 'healthy modalities' is a point of attention for public health.
- Economic development. Economic development (of an area) benefits from good accessibility. In all scenarios, there is an increase in the number of vehicle kilometres, but in urban areas in particular, this also results in an increase in the number of vehicle hours lost in congestion. Increased mobility makes more jobs accessible to more people.

Although it becomes busier, the economic core areas remain accessible because there are often several alternatives available (the point to be considered is whether this also applies to the centre of Amsterdam and the Zuidas to a sufficient extent). The increase in mobility also offers opportunities for mainports in particular. It can be concluded that self-driving vehicles have a neutral influence on the economic (social) development of the PNH and the Transportation Region in general. Another component concerns the financial operations of the PNH and the Transport Region. In scenarios in which sharing concepts are used, much can change in the number of vehicles needed and also in the locations where vehicles park (short stay). If the number of vehicles required decreases, the tax revenue from the provincial surcharges, among other things, also decreases. In both Level 5 scenarios there will also be a shift in the labour market as a result of the far-reaching automation (certain professional groups will become superfluous; others will emerge). And although the PNH and the Transportation Region itself do not own any parking garages/areas, the income from parking will also fall substantially when sharing concepts are used. More vehicle kilometres also mean more frequent management and maintenance of the infrastructure. As a result, self-driving vehicles will have a neutral to negative impact on business operations.

- Social development (accessibility and use of transport). The introduction of self-driving vehicles provides better and cheaper transport alternatives, which in principle allows a larger part of the population to access and use transport. The share of conventional public transport (bus/tram/metro/train) decreases in all scenarios, although this decrease is smaller in both Level 3/4 scenarios than in both Level 5 scenarios. Assuming that sharing concepts can be operated at less costs, it is assumed that this development can have a positive effect for areas with low (population) density. As a result, cheaper sharing concepts can replace the current thinner public transport lines. The sharing concepts will be less likely to be at the expense of high-frequency and/or fast public transport connections. There will also be a shift in the labour market, with certain professional groups (professional drivers and driving instructors) disappearing and others emerging due to the arrival of autonomous vehicles. In conclusion, this study assumes that self-driving vehicles have a positive or possibly neutral influence on social development.
- Spatial development (functional use of space and distribution). A small part of the population is expected to settle elsewhere as a result of the introduction of self-driving vehicles. After all, travel time will become part of working time and therefore more effective. Moreover, more facilities can be achieved with more comfort. At the same time, many factors play a role in the choice of location, including the level of facilities in the region versus in urban areas. In the sharing concepts and for the Level 5 scenarios, the need for (long term) parking will be greatly reduced, particularly in urban areas where, if necessary at all, cheaper parking facilities will be sought on the outskirts of cities. In addition, the need for Kiss+Ride strips at junctions will increase. All in all, it is expected that the arrival of autonomous vehicles will contribute neutrally (to a limited extent positively) to spatial developments.

For the transition phase, an adaptive policy will be needed to respond to changes. There will still be mixed traffic ('smart' and 'stupid' vehicles) and 'smart' vehicles that are not yet able to perceive everything (by themselves), making interaction with the infrastructure and roadside systems necessary. In the transition phase, there will be relatively more accidents involving self-driving vehicles, which are due to the not yet fully developed technology. This requires a controlled transition strategy. In the

strategy, the final goals must always be the main focus, in which self-driving vehicles will eventually provide more traffic safety and/or a higher level of safety. In any case, the transition phase means that different systems/functions must be maintained; for both conventional and self-driving vehicles. Depending on the pace of advancement of the (fully) self-driving vehicle, a gradual start can be made to reduce parking space." (Arcadis ; TNO, 2018)

Policies and policy recommendations

In this study a range of policy measures, called interventions, were explored (as shown in the following table):

Table 17: Categories and specific policy interventions

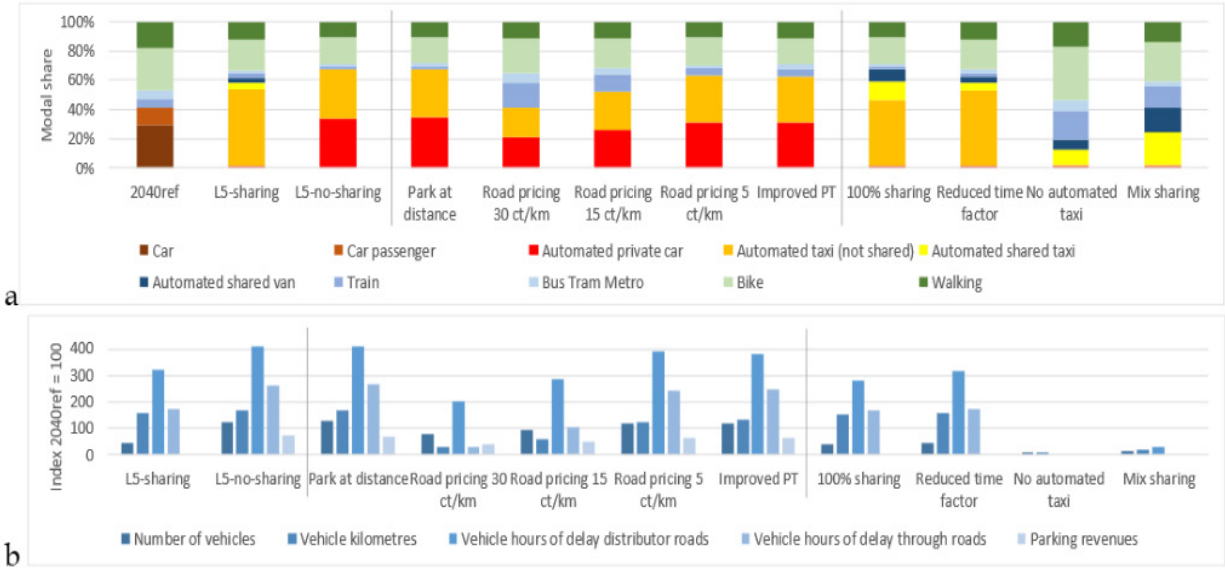
Category	Policy intervention
Spatial interventions	Discourage parking near the location in metropolitan downtown area.
Public Transport contract interventions and the stimulation of sharing	Stimulating car sharing through subsidies, reducing the cost of ride sharing or increasing the percentage of people willing to share (e.g. by pooled rides in vans). Promotion of ride sharing with more than one person by discouraging private cars and self-driving private taxis in certain area types (metropolitan). Increase frequency/capacity of Public Transport.
Pricing incentives	Pricing incentives to reduce the number of vehicle hours lost in congestion. The revenues of pricing can partly compensate for missed parking revenues (by municipalities) and lower revenues from vehicle ownership and registration taxes.
Infrastructure adjustments (both the physical and digital infrastructure)	Exert influence on local and/or network flows from traffic control centres, expressed in % of vehicles communicating.

Source: (Arcadis ; TNO, 2018).

"Governmental interventions can, on the one hand, accelerate a transition to a self- driving future. On the other hand, public authorities (in the study the Province and the Amsterdam Transport Region) can intervene to mitigate potential negative impacts (e.g., expected severe congestion in (very) high urbanised areas), in their role as road authority and public transport concession provider. In the case study, the model is further applied to explore the effect of interventions.

By means of example, Figure 18 shows the modal split results and traffic effects for a selection of policy measures that are relevant in L5-no-sharing (Level 5 automation and no sharing; column 4-8) and that are relevant in L5-sharing (Level 5 automation and sharing; (column 9-12). The three columns on the left are the modal split effects without policy measures. They are included to make comparisons easier.

Figure 18: Modal split effects (a) and traffic effects and parking revenues (b) interventions



Interventions L5-no-sharing

'Park at distance' refers to a scenario in which parking or drop/off at location is forbidden in highly urbanised areas. 'Road pricing <30/15/5> ct/km' refer to road pricing scenarios and 'improved public transport' refers to a scenario where the frequencies of train, bus, tram and metro are increased with a reduction of about 20% of travel time as a result. The figure shows that in L5-no-sharing only high road pricing charges (15 and 30 cent/ kilometre) can keep the number of car related trips, the number of vehicle kilometres and the vehicle hours of delay more or less at the same level as in the reference scenario. The number of bicycle and walking trips increases with all interventions, but the level of the reference scenario will not be reached. For the traditional public transport modes (train, bus, tram and metro) high road pricing charges are needed to reach the level of the reference scenario. The impact of 'Park at distance' is close to zero when all area types are considered. In very highly urbanised areas, the impact is larger (e.g. 9% reduction in automated private car trips).

Interventions L5-sharing

'100% sharing' refers to a scenario in which 100% of the people are willing to share. In the reference scenario for L5-sharing it is assumed that 100% of the people younger than 18 year are willing to share. For others this percentage is assumed to be between 5% - 75% depending on age, household income and car ownership. In 'Reduced time factor', it is assumed that the extra travel time factor for automated shared taxis and vans is reduced with 50% enabled by a larger vehicle fleet. In 'no automated taxi', these vehicles are just like private cars not allowed except in rural areas. 'Mix sharing' combines all these interventions and reduces the travel times by train, bus/tram/metro with 20%. The last 2 scenarios have the largest impact. They reduced the number of vehicle kilometres with respectively 88% and 79%.

Based on the results described above it can be concluded that a strong mix of interventions is needed to keep vehicle kilometres at the same level as in the reference scenario. This is especially the case in (very) highly urbanised areas. In other areas, the interventions can be more modest." (Snelder, et al., 2019).

The challenge is to manage the transition in such a way that collective services and ride share systems are offered in the cities and to make optimal use of the new opportunities offered by automated driving and shared taxis outside urban areas. After all, public transport in sparsely populated areas requires a

large degree of public investment. By deploying collective services and rideshare systems, mobility can be offered at socially acceptable costs. Only by means of long-term management with knowledge of technological developments and social impacts in various transition paths can automated driving be developed and implemented in such a way as to maximise the benefits for society and minimise any adverse effects for society. Desired scenarios can be accelerated by spatial interventions (e.g. adapting parking locations), stimulating sharing concepts, price incentives and infrastructure modifications (Arcadis ; TNO, 2018).

Lessons learned for EU

This case study explored the mobility impacts of connected and automated driving and shared mobility. The main lessons learned is that if automated vehicles and sharing are accepted, it is likely that there will be considerable changes in mobility patterns and traffic performance, with both positive and problematic effects. The study focussed on an entire region including different geographical locations -from highly urbanised to rural locations. The results are relevant for local, national and European authorities as it shows that public authorities need to prepare for the deployment of automated driving and explore the policy interventions that can support the introduction such that positive effects are achieved, and negative effects are avoided or mitigated.

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ANNEX E. CASE STUDY III: NATIONAL MAAS STRATEGY OF FINLAND

Description of the case

Finland is often considered one of the frontrunners in the field of Mobility-as-a-Service (MaaS) in Europe. The Finnish government was one of the earliest to formulate a vision on MaaS and set up larger scale policy changes to accommodate mobility services and a funding strategy for MaaS pilot projects. The approach is a combination of changes in regulation, new policies, investments, funding for pilot projects, setting up Public Private Partnerships (PPPs) and integrating MaaS in the larger Transport Sector Program. The main stakeholders are the Finish Ministry of Transport and Communications (LVM), the Finnish Transport Agency (FTA) and new private companies offer mobility and MaaS services (with MaaS Global - offering MaaS subscriptions and an integrated MaaS services via their own platform - being the most well-known). The national government aims for an accessible, sustainable and efficient transportation system and developing a well-connected multimodal transport system.

The scale of the case study is on the national level and the focus is on the national MaaS strategy of the Finnish National government. The goal or starting point of the national strategy was to put an appropriate regulatory framework in place to make new mobility services possible and encourage business innovations built through large scale public 'experiments' (Pangbourne, et al., 2020). This ambition and the legislative actions that followed it have established an enabling landscape for MaaS in Finland. The role of the public sector is seen to enable the change and provide favourable operating conditions, by facilitating business efficiency, whereas the responsibility for both innovation and service development lies with the private sector. Finland's governance model around MaaS is thus characterised by large-scale regulation change and government investment in kick-starting private companies through investments and PPPs with the goal to build a modern, efficient and sustainable mobility system for urban as well as rural Finland.

Detailed description of the case

The national government is striving for multiple goals in their MaaS strategy and sets the focus on a well-connected multimodal transport system. Generating positive societal impacts is the main goals, including emission reductions in the mobility sector, improving accessibility for people and improving the service level for users. Next to that, the MaaS strategy has the goal to facilitate the market and create new markets, jobs and services. In 2009, the Ministry of Transport and Communications (MTC or LVM in Finnish) decided that a major reform of transport market legislation was needed if the public goals for the Finnish transport sector were to be met. In the same year they published Finland's first national strategy for ITS which proposed that an increased use of ITS could encourage greater use of environmentally sustainable, economical and safe modes of transport, while pointing out that this development required a modern, customer-oriented transport policy. Subsequently, major legislative modifications have resulted in a unified Act, known as the 'Transport Code'. The new transport code was meant to lead to better and more agile services, data utilisation and deregulation of the market and improved market access.

The Ministry of Transport and Communications (LVM) of Finland is responsible for the legislation covering the Transport Code. Starting point was the initiative of the Minister for Transport and Communications in 2014 to set up a 'club for new transport policy' inviting different stakeholders and discussing the needed reform of transport policy, future mobility systems and ideas around MaaS. Initial funding was provided in early 2015 by the MTC and the Finnish Funding Agency for Innovation (Tekes, now called Business Finland) launched a joint programme for the development of MaaS.

Another public actor, Export Finland, also launched a growth programme for MaaS aimed at supporting Finnish MaaS-related ventures to attract international investors and develop global business opportunities. MaaS Global is the best-known example of a Finnish start-up company promoting the MaaS concept.

The role of the public sector is seen to enable the change and provide favourable operating conditions, by facilitating business efficiency, whereas the responsibility for both innovation and service development lies with the private sector. Public transport operators have been less involved in the development of MaaS in Finland. The organisation of public transport in Finland is arguably an institutional barrier to MaaS since the responsibility for public transport (including subsidies) rests at either the state or municipal level. Single tickets are not subsidised, and each municipality has the responsibility for subsidising its 'own' residents' public transport passes. The public transit sector has had little involvement in either the preparation of the Transport Code or the creation of the national MaaS vision (SMARTA, 2019).

The main steps needed in the development of MaaS in Finland in the next years therefore also seem to be evolving around facilitating the integration of services of different parties and increasing the willingness to cooperate between stakeholders. Two important factors in reaching this seem to be the development of common goals and trust (especially between public and private actors).

Barriers and enablers for the deployment of the various applications

Barriers

The old transport regulation acted as a barrier to the development of new mobility services. It was outdated, mode based and there were large entry barriers for new players. Examples of obstacles that were removed are the difficult to get a permit (e.g. on taxi market) and possibilities for interoperability.

An important barrier for the successful development of MaaS is also the missing experience of cooperating across modes and across public and private actors and missing trust between them. Private transport providers feel threatened by the new service providers and are stuck in their legacy systems. More interaction is needed to overcome these attitudes slowing down the development and building a common vision. Also, technical barriers still exist, for example in integrating (booking) systems. The authorities need to discuss the common vision, but also data exchange and standardisation with the different stakeholders.

Another important barrier for the scaling up of MaaS is also still the insecurity about the business case of MaaS for the different stakeholders involved. Correlated to this and another important factor for the scaling up of MaaS is the slow change in people's behaviour and need for strong incentives and well managed information and marketing campaigns.

Enablers

The combination of Transport and Communications in one ministry has enabled the Finnish government to make structural links between transport and ICT and has been an enabler for the early involvement of the Finnish government in the development of MaaS. The continued collaboration and facilitation of network building has also been enabling the market development. The large reform of the transport legislation has been the largest enabler for the development of MaaS services in Finland. Without the change in legislation, new players and services were strained from market entry. An important detail in the legislation reform is that it is not MaaS or mode specific but sees the mobility system as a whole.

Impacts

Now MaaS is still in its early stages in Finland. Early adopters in the largest cities use the MaaS platform. However, individual new mobility services (e.g. scooter- bike and car sharing or packages by bus providers) grow successfully and new players enter the markets for mobility services. The openness towards these services grows.

On the long term, the impacts are expected to be positive on the efficiency, sustainability and accessibility of the mobility system and generating a positive economic impact. MaaS is expected to not only offer solutions for urban areas but also for sub-urban and rural areas (with different foci). MaaS is seen as an alternative to the use of single occupancy vehicles.

Policies and policy recommendations

Multiple instruments have been used to stimulate MaaS in Finland

The largest impact has been generated through ***changes in regulation***. In 2017, the Finnish Transport Code (Liikennekaari) brought major changes to facilitate a modern, customer-oriented transport policy. The development of the Finnish Transport Code has been ICT-led and closely coupled to MaaS developments. The key objectives of the Code are to 'promote the creation of new service models, ease market entrance, dismantle national regulation that limits competition and reduce the level of public guidance'. The underpinning idea of the Code is to take advantage of digitalisation and enable both the development of better and more agile transport services, and their integration into MaaS offerings. It aims to deregulate transport markets (e.g. with a new passenger transport license under which any type of vehicle will be allowed to be used as a taxi, and limits on the number of taxi licenses as well as price regulations for taxis are removed). The code focuses on the use of open and interoperable data interfaces. The Code obliges incumbents as well as new entrants to the transport market to provide their operational data as well as their single tickets for third party resale and use.

It made changes in taxi license quotas and forced all transport service providers to open data and single tickets APIs. However, the exact technical solutions for opening their data and ticketing are not standardised in the law.

Another instrument that has been used is ***funding and investment*** in MaaS-related activities. Business Finland and the Finnish Ministry of Transport and Communications (LVM) had several funding programs for supporting MaaS developments.

Facilitation of networking and supporting the communication between actors has been another important tool of the Finnish government to encourage the development of MaaS.

Lessons learned for EU

MaaS is a chance to increase the efficiency of the mobility system if public transit is seen as its backbone and market entry of new players offering new mobility services is facilitated. Finland is a forerunner in the digitisation of the mobility system. How well a MaaS system develops depends on the variety and number of options that are offered, the openness of users and the level of responsibility the public actors take. With active steering new actors can be facilitated to grow out to become world players (e.g. as happened with MaaS Global). The Finnish approach differs from most other European countries in the way government sees their role and responsibility in developing the MaaS market. In Finland, the government mainly created positive frame conditions (by changing the transport legislation) and facilitating networking of market players and financial investments. They let the market fill in the type of services and technical details of standardisation and collaboration.

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ANNEX F. CASE STUDY IV: CHANGING COMPETITIVENESS OF ROAD, RAIL AND INLAND WATERWAYS FOR FREIGHT TRANSPORT

Description of the case

This case study explores the changing competitiveness of road, rail and inland waterways for freight transport at the EU level. Currently, transport policy for freight transport is often aimed at achieving a modal shift from road to rail and inland navigation (also known as inland shipping or barge) in order to reduce the pressure on road infrastructure and contribute to policy goals such as accessibility, safety and sustainability [1]. In this case study combinations of development in freight transport are analysed such as: connected automated driving, electric driving, use of digital platforms and driving at night. The sector trends are investigated in amongst others the Flex-Rail project [2] and translated into the long-term impacts on road, rail and inland shipping. The case study shows that these developments take place faster in road transport than in rail and inland navigation. As a result, the competitive position (e.g. costs, flexibility, sustainability, etc.) of road transport is expected to strongly improve in the near future compared to rail and inland navigation [3] [4]. Without policy measures, this could lead to a reversed modal shift from rail and inland navigation back to road transportation. This case study explains the relevance of the interactions between developments, explores various policy directions and discusses how to deal with uncertain developments of emerging technologies.

Detailed description of the case

As explained, transport policy focusses a lot on a 'classic' modal shift (from road to rail and barge) to reduce congestion and to make freight transport more sustainable. We see this both at European level with for instance the Paris climate agreement (UN, 2015) and at national level with for instance the climate agreement of the Dutch government (Klimaatberaad, 2019). Besides, other factors such as competitive position of the logistics industry and robustness of the transport network are important. For the relative short term there is focus on the 'classic' modal shift, for the longer term more focus in put on synchromodal transport[48] (Synchromodaliteit.nl, 2020) self-organising logistics (Pan, et al., 2016) and the physical internet (ALICE, ongoing). For all these concepts and developments, it is important that several alternatives (among which transport modes) are available in the multimodal transport network that can be used in an optimal way to organise freight transport and logistics as efficient and sustainable as possible. Although there is much focus on the 'classic' modal shift for many years, from several analyses of the potential (TNO, 2011) and evaluations of the progress (EPP Group, 2015) it appears to be very hard to realise this.

Currently and for the short term, strong technological developments are expected: digitisation, automation and energy transition. In what order these developments will really break through, in what combination and when in time is still uncertain and hard to predict. Because of this, the impact on the modal shift is also uncertain. To gain more insight in the possible impact, transition paths will be developed. As an example, a transition path that combines automated driving, electric driving, use of digital platforms and driving by night is briefly elaborated.

For road freight transport, automated transport is already developed and tested for several years. For the first levels of automation this concerns truck platooning (TNO, 2015) and for higher levels of

[48] Synchromodal transport refers to the provision of efficient, reliable, flexible, and sustainable services through the coordination and cooperation of stakeholders and the synchronization of operations within one or more supply chains driven by ICT and intelligent transportation system (ITS) technologies.

automation this concerns fully automated transport (Reuters, 2019). Once trucks will drive fully automated at highways and trailers can be handled fully automated by electric dollies at ports and yards, the transport costs of road freight transport are expected to be reduced by about 50% (McKinsey Center for Future Mobility, 2018). Also, for rail and barge transport, developments are ongoing to automate these modes of transport. However, it is expected that the pace of this development will be much lower for rail and barge compared to road (TNO, 2018). Besides, the cost reduction for rail and barge will be much lower than for road transport. This means that the competitive position of road will improve a lot in this situation compared to rail and barge.

In the field of sustainability, developments are ongoing to reduce emissions of trucks or even to develop zero-emission trucks. Electric vehicles are being developed for short distance transport for use in city logistics. For the longer term, also electric vehicles are being developed for long distance transport (AD, 2019) either with battery-electric or hydrogen vehicles. Independent on what technology will break through for road transport, it is clear that a strong development of heavy road freight transport towards zero emission will take place. As a result, road transport is expected to become as sustainable as rail and barge transport.

Another relevant trend concerns the development of digital platforms for match transport demand and transport supply in an automated way [17]. An advantage of the use of such platforms is that companies are no longer dependent on planners and that these platforms will be operational 24/7.

If these developments are combined, it turns out that road freight transport becomes a very attractive alternative that can be organised for a large part of it by night. Road freight transport is getting more efficient, no or less truck drivers are needed, trucks become quiet (electric), trailers will be handled automatically by smart electric dollies at ports and yards and at night a lot of capacity is available on the road network.

This means that if this transition path will develop, most of the advantages of rail and barge over road will disappear and it is likely that a reversed modal shift (from rail and barge to road) will take place. One of the reasons, the 'classic' modal shift is aimed at is that extra road freight transport will lead to extra congestion. However, in this transition path more transport will shift to road, but because this transport can be organised for a large part at night, this will not lead to more congestion. Contrary, it can even reduce the amount of congestion, both for freight transport and for passenger transport. On the rail network also, more capacity becomes available for passenger transport.

Barriers and enablers for the deployment of the various applications

Barriers

Barriers for the elaborated transition pathway are:

- Modification of legislation to allow automated transport is not going fast enough. Legislation has to be modified to make automated transport possible, this is the case for road, rail and barge transport, all with different legislation.
- Limited acceptance of the public concerning automated transport might hinder and/or slow down the speed of the development of automated transport.
- Zero-emission road freight transport on the long distance still has to be developed in a feasible way.
- The use of digital platforms has to be accepted and trusted by companies and their employees.

- A shift of road freight transport from the day to the night has to be accepted by regions, municipalities and people living in the neighbourhood of heavily used roads and areas.

Enablers

Enablers for the elaborated transition pathway are:

- Digital platforms and data spaces for data sharing in a controlled and trusted way to create the required visibility in the logistics chain for connected and automated transport and self-organising logistics.
- Big data to process the large amount of data and to transform data into information, amongst other via digital platforms.
- AI in logistics for data driven autonomous decision making in the logistic chain.
- Investigation of alternatives for zero-emission road freight transport. Analysis of possible alternatives, most effective and feasible market segments and pros and cons of these alternatives.
- Development of pilots and living labs on digitisation, automation and energy transition in all modes of transport to analyse how these concepts/technologies work in the best possible way, to show the value, to deal with barriers, to make use of the enablers and to determine how these concepts can be implemented and scaled on a rather short term.

Impacts

As explained before, the impact of the combination of technological developments is uncertain, as well in seize of impact, order of the developments, as in moment in time when it really breaks through. In the elaborated example, the impact of the transition path of the technological developments is a reversed modal shift instead of a 'classic' modal shift that is currently aimed for. It is the question whether this is a wanted or unwanted situation. In the full elaboration of the transition path, it seems to be a wanted situation since it has a positive impact on all relevant indicators (amongst others efficiency and sustainability). However, this only occurs if automated transport, digitisation with digital platforms, strong reduction of emissions and driving by night really occur. If for instance, all these developments take place, but reduction of emissions is not going very fast, the impact might be a reversed modal shift with more emissions. This is an unwanted situation. Therefore, one of the main conclusions from this case is that much more insight is needed in the impact of combinations of different technological developments in possible transition paths to determine what situations are wanted or unwanted and how to avoid or stimulate for these possible future situations.

Policies and policy recommendations

Current policies are aiming at a 'classic' modal shift while the elaborated transition path shows that a combination of technological developments might lead to a reversed modal shift. Crucial questions are: when will be the turning point from 'classic' modal shift to reversed modal shift, what triggers can be used as a warning signal this development is about to take place and how should governments deal with this possible future situation? The speed of these kind of developments is uncertain, but there are examples it can go very fast. Therefore, it is very important that governments are prepared. Relevant questions are: is a reversed modal shift with substantial volumes of road freight transport by night a wanted or an unwanted situation, can the government influence these developments and what kind of (policy) measures should be taken?

In the result of the transition path leads to a wanted situation, it has to be decided when to stop with large investments in and stimulating the use of the other modes of transport (rail and barge). Besides, this transition path can be stimulated by applying reduced road charges for driving at night. If the result of the transition path leads to an unwanted situation it has to be investigated whether the development of automation in rail and barge can be stimulated to keep up with the pace of innovation in road freight transport. Besides, it has to be decided what measures can be taken to avoid and/or slow down this development in road freight transport.

Lessons learned for EU

In order to determine how local, national and European authorities should be prepared for the (un)expected impact of combinations of technological developments more insight is required in the possible impact by elaborating several transition paths. Governments and authorities should deal with the uncertainty by investigating possible futures and analysing how wanted and unwanted situations can be stimulated or avoided. Scenario studies and transition path analysis can support dealing with the uncertainty and making no-regret and future proof investments in road, rail and inland waterway infrastructure for freight transport. This way, governments can determine what future they want instead of waiting what kind of future will show up.

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Zware trucks op waterstof gaan in Los Angeles de weg op

This study provides an overview of the impact of Smart Mobility and their underlying emerging technologies on transport, the transport infrastructure and society. The main challenges for the deployment of Smart Mobility applications are identified and (policy) actions are defined that could be taken to overcome these challenges.

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